Article

Optimization of Activated Carbon Preparation Process Using Eggplant Stems with Response Surface Methodology

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Abstract: This research investigates the key factors affecting the production of activated carbon from eggplant stems, aiming to optimize the process and enhance the value of agricultural by-products. Eggplant stems were utilized as the raw material, with potassium carbonate serving as the activating agent. The study examined variables including the amount of activator (A), carbonization temperature (B), and activation temperature (C). Through single-factor experiments, the preparation process was optimized using a combination of response surface methodology and the entropy weight method. A comprehensive evaluation score (Y) was derived from the activated carbon yield, iodine adsorption capacity, and methylene blue adsorption capacity. A quadratic regression model was established: $Y = 0.660 + 0.064A - 0.013B + 0.024C + 0.041AB + 0.0003506AC + 0.053BC - 0.092A^2 - 0.013B^2 - 0.170C^2$ This research investigates the key factors affecting the production of activated carbon from eggplant stems, aiming to optimize the process and enhance the value of agricultural by-products. Eggplant stems were utilized as the raw material, with potassium carbonate serving as the activating agent. The study examined variables including the amount of activator (A), carbonization temperature (B), and activation temperature (C). Through single-factor experiments, the preparation process was optimized using a combination of response surface methodology and the entropy weight method. A comprehensive evaluation score (Y) was derived from the activated carbon yield, iodine adsorption capacity, and methylene blue adsorption capacity. A quadratic regression model was developed ($R^2 = 0.9602$), indicating a high degree of accuracy. The factors were ranked in order of influence as follows: activator amount > activation temperature > carbonization temperature. The activator amount was identified as having the most significant effect on the score ($P < 0.01$), with a notable interaction between carbonization and activation temperatures ($P < 0.05$). The optimized preparation conditions included an activator dosage of 2.22 g, a carbonization temperature of 323°C, and an activation temperature of 714°C. Under these conditions, the results showed a yield of 29.25%, an iodine adsorption capacity of 886.78 mg/g, a methylene blue adsorption capacity of 140.90 mg/g, and a composite score of 0.677, with a relative error of just 0.296%. The established model effectively predicts and evaluates the preparation of activated carbon from eggplant stems, demonstrating a stable and reliable process. Additionally, the methylene blue adsorption performance of the activated carbon meets the first-grade standards for water purification.

Keywords: Activated Carbon, Eggplant Stems , Response Surface Methodology (RSM).

1. Introduction

Eggplant stems, a globally cultivated crop, produce a substantial amount of agricultural by-products, particularly stems, which are often discarded or burned. These practices contribute to environmental challenges and result in underutilization of valuable resources. With their high lignin, hemicellulose, and cellulose content, eggplant stems offer significant potential as a raw material for producing activated carbon. Transforming these stems into high-value activated carbon not only mitigates environmental issues but also enhances the economic value of agricultural residues, fostering sustainable farming practices. Leveraging agricultural by-products for activated carbon production can extend the agricultural value chain, delivering both economic and ecological benefits (Guo et al., 2018; Liu et al., 2018).

In recent years, research has intensified around biomass-based activated carbon derived from agricultural residues. For instance, Ma and Chen (2009) explored the use of zinc chloride activation for biomass carbon preparation and optimized parameters through orthogonal testing. Similarly, Tian (2010) examined the chemical activation of biomass, focusing on factors like activator type, particle size, activation duration, and temperature, and their effects on adsorption performance. Wu et al. (2011) analyzed the impact of carbonization temperature and retention time on yield and adsorption properties using potassium carbonate activation. Sun et al. (2011) adopted steam gasification coupled with phosphoric acid modification to create mesoporous activated carbon from biomass. Liu et al. (2015) improved the adsorption properties of activated carbon by introducing functional groups (e.g., hydroxyl and carboxyl) through Fenton reagent treatment, enhancing its gas adsorption capacity. Zhou et al. (2015) investigated the effects of zinc chloride concentration and activation conditions on adsorption properties under reduced pressure. Furthermore, Dong et al. (2017) compared phosphoric acid and alkaline activations, highlighting superior yield and adsorption performance with phosphoric acid activation.

Despite advancements, most studies focus on single-variable or orthogonal methods, neglecting the interactions between critical factors in the optimization process. Additionally, few studies have applied response surface methodology (RSM) to optimize the preparation of activated carbon from eggplant stems. This study addresses this gap by employing RSM integrated with the entropy weight method to optimize the preparation conditions. Key parameters, including activator dosage, carbonization temperature, and activation temperature, were examined to maximize yield and adsorption performance. This approach not only improves the utilization of eggplant by-products but also provides a theoretical framework for sustainable resource use.

2. Materials and methods

Eggplant stems were sourced from Samarra city, Iraq. After drying, the stems were crushed and passed through 40–60 mesh sieves to ensure uniform particle size, then stored for subsequent experiments. Potassium carbonate served as the activator, alongside other chemicals such as concentrated hydrochloric acid, sodium thiosulfate, iodine, potassium iodide, and soluble starch. The primary instruments utilized included:

- BSA223S Analytical Balance
- UV-5200 UV-Visible Spectrophotometer
- BJ-150 Multifunctional Grinder
- SHB-III Circulating Water Vacuum Pump
- SX2-8-10 Box Resistance Furnace
- HY-5 Rotary Oscillator
- 101-2A Electric Thermostatic Drying Oven

2.1 Preparation of Activated Carbon

To prepare the activated carbon, 10 g of crushed eggplant stem powder was mixed with 100 mL of distilled water and the required amount of potassium carbonate activator. The mixture was thoroughly stirred and left to soak for 12 hours. Afterward, it was dried in an oven at 105°C. The dried mixture was placed in a crucible and subjected to carbonization and activation at high temperatures in a box furnace for a specified time. After activation, the product was washed with acid and water until neutral, then dried and ground into a fine powder. The activated carbon was analyzed for yield, iodine adsorption capacity, and methylene blue adsorption capacity.

2.2 Single-Factor Experiments

2.2.1 Effect of Activator Dosage

Five potassium carbonate dosages (0.5, 1.0, 1.5, 2.0, and 2.5 g) were tested with eggplant stem powder. The mixtures were soaked, dried, carbonized at 300°C for 1 hour, and activated at 700°C for 1.5 hours. The influence of activator dosage on yield and adsorption capacity was evaluated.

2.2.2 Effect of Carbonization Temperature

A mixture of 2.0 g potassium carbonate and eggplant stem powder was prepared, soaked, and dried. It was then carbonized at temperatures of 200, 250, 300, 350, and 400°C for 1 hour, followed by activation at 700°C for 1.5 hours. The impact of carbonization temperature on yield and adsorption properties was analyzed.

2.2.3 Effect of Activation Temperature

The mixture of 2.0 g potassium carbonate and eggplant stem powder was soaked, dried, carbonized at 300°C for 1 hour, and activated at 500, 600, 700, 800, and 900°C for 1.5 hours. The effect of activation temperature on adsorption performance was studied.

2.2.4 Effect of Activation Time

A mixture of 2.0 g potassium carbonate and eggplant stem powder was prepared and subjected to carbonization at 300°C for 1 hour. Activation was carried out at 700°C for durations of 0.5, 1.0, 1.5, 2.0, and 2.5 hours. The effect of activation time on yield and adsorption performance was assessed.

2.3 Entropy Weight Method for Weight Assignment

Step 1: Data Normalization

Given k indicators X1, X2, …Xk, where Xi = (X1,X2,…..,Xn), the normalized values Y1,Y2, ……,Yk are calculated using the formula:

$$Y_i = \frac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)}$$

Step 2: Calculate Information Entropy

Using the formula for information entropy, calculate the entropy for each indicator E1,E2, …,Ek

$$Ei = -\ln(n)-1\sum_{i=1}^{n} P_{ij} \ln(P_{ij})$$

Where

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}$$

Step 3: Determine Indicator Weights

The weight for each indicator Wi is determined using the formula:

$$W_i = \frac{1-E_i}{n-\sum E_i}, (i=1,2,…,m)$$

Step 4: Calculate Comprehensive Score

The comprehensive score Y is calculated as a weighted sum of the normalized indicators:

$$Y = W_1Y_1 + W_2Y_2 + W_3Y_3$$

2.4 Box-Behnken Central Composite Experimental Design

Building on the findings from single-factor experiments, three critical variables were identified as having a significant impact on the performance of activated carbon derived from eggplant stems: activator dosage (A), carbonization temperature (B), and activation temperature (C). To optimize the preparation process, a Box-Behnken central composite design was employed. This experimental design included three factors and three levels, allowing for the analysis of interactions between the variables and their combined effects. The selected factors and their corresponding levels are detailed in Table 1.

This approach ensures a systematic evaluation of the variables, enabling precise optimization of the production conditions for activated carbon from eggplant stems.

Table 1: Factors and Levels for Response Surface Experimental Design

Level	Activated dosage (g)(A)	Carbonization Temperature (°C) (B)	Activation Temperature (°C) (C)
-1	1.5	250	600
0	2	300	700
1	2.5	350	800

3. Measurement Indicators and Methods

3.1 Calculation of Activated Carbon Yield (Y_1)

The yield of activated carbon was calculated using the following formula:

$$Y1 \; (\%) = m/m0 \times 100$$

Where:

- m: mass of activated carbon after activation (g).

- m_0: mass of raw material before activation (g).

3.2 Measurement of Iodine Adsorption Value (Y_2) and Methylene Blue Adsorption Value (Y_3)

The iodine adsorption value and methylene blue adsorption value of the activated carbon were measured using a UV-Vis spectrophotometer. Iodine adsorption was evaluated at a wavelength of 254 nm, while methylene blue adsorption was assessed at 664 nm, following the standard test method for iodine adsorption of wood-based activated carbon. This ensured consistent and reliable assessment of the adsorption properties.

3.3 Statistical Analysis

The results of the single-factor experiments were analyzed for statistical significance using the least significant difference (LSD) method. Data processing, analysis, and

visualization were conducted with SPSS 2020 and Design-Expert V8.0.6 software, ensuring accuracy and precision in interpreting the experimental findings.

4. Results and Analysis

4.1 Single-Factor Experimental Results

4.1.1 Effect of Activator Dosage on the Properties of Activated Carbon

The influence of varying potassium carbonate dosages on the yield and adsorption performance of activated carbon derived from eggplant stems is presented in Figures 1 and 2. Figure 1 shows that as the activator dosage increased, the yield of activated carbon exhibited a steady rise. Figure 2 highlights the behavior of adsorption properties, where both the iodine adsorption value and methylene blue adsorption value initially improved with increasing activator dosage. However, at higher levels of activator addition, a decline in adsorption performance was observed.

This suggests that while an appropriate amount of activator enhances both yield and adsorption capacity, excessive activator levels may lead to over-etching or pore collapse, reducing the performance of the activated carbon.
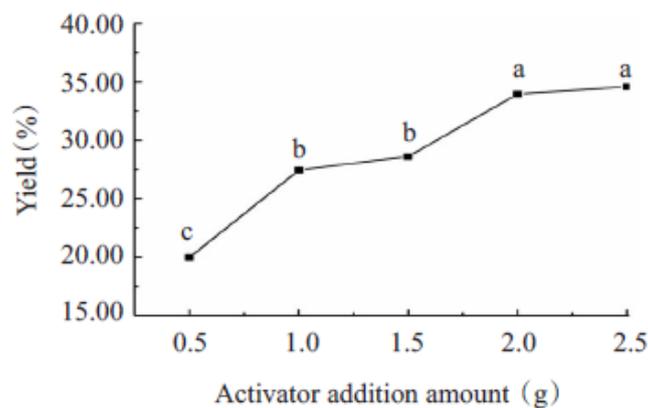

Fig.1 Effects of different activator addition amounts on the yield of eggplant stems based activated carbon

Different lowercase letters on the broken line indicate significant differences (P<0.05). The same applies to Figures 3, 5, and 7.
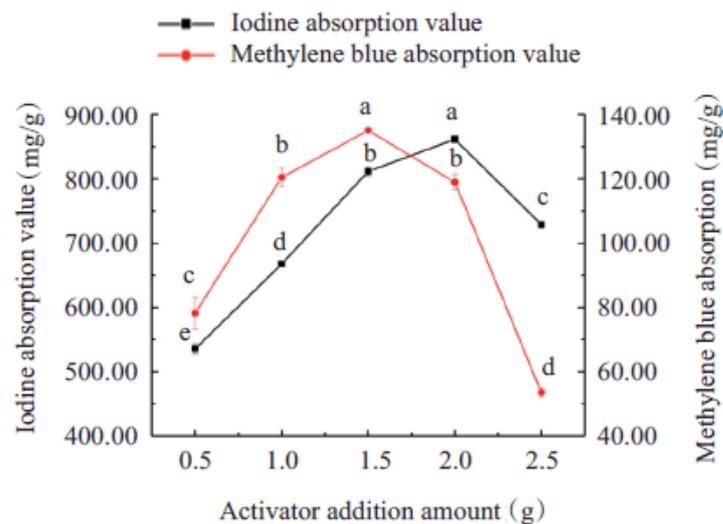

Fig. 2 Effect of Different Activator Addition Amounts on the Adsorption Performance of Eggplant Stem-Based Activated Carbon

Different lowercase letters on the same line indicate significant differences (P<0.05). The same applies to Figures 4, 6, and 8.

When the activator addition amount increased from 0.5 g to 2.0 g, the yield significantly increased from 19.97% to 33.97% (P<0.05, the same applies below), and after 2.0 g, the yield remained relatively stable. As shown in Figure 2, the iodine adsorption value and methylene blue adsorption value of eggplant stem-based activated carbon first increased and then decreased with the increase in activator addition amount. When the activator addition amount was 1.5 g and 2.0 g, the methylene blue adsorption value and iodine adsorption value reached their maximum values of 135.08 mg/g and 861.61 mg/g, respectively. However, when the activator addition amount increased to 2.5 g, the methylene blue adsorption value and iodine adsorption value significantly decreased by 61.87% and 15.43%, respectively, compared to their maximum values. At this point, intense activation reactions occurred, causing the pores formed in the activated carbon to expand continuously until they collapsed, resulting in a decline in adsorption performance (Zuo Songlin, 2017). Considering the cost and performance of the activated carbon, an activator addition amount of 2.0 g was chosen for subsequent experiments.

4.1.2 Effect of Carbonization Temperature on the Performance of Eggplant Stem-Based Activated Carbon

As shown in Figures 3 and 4, with the increase in carbonization temperature, the yield and adsorption performance of eggplant stem-based activated carbon initially increased and then decreased. When the carbonization temperature rose to 300°C, the yield and iodine adsorption value of the activated carbon reached their maximum values of 30.65% and 810.79 mg/g, respectively. When the carbonization temperature increased from 300°C to 350°C, the methylene blue adsorption value of the activated carbon reached its maximum value of 162.44 mg/g, while the yield and iodine adsorption value gradually decreased. In summary, a carbonization temperature of 300°C is recommended.
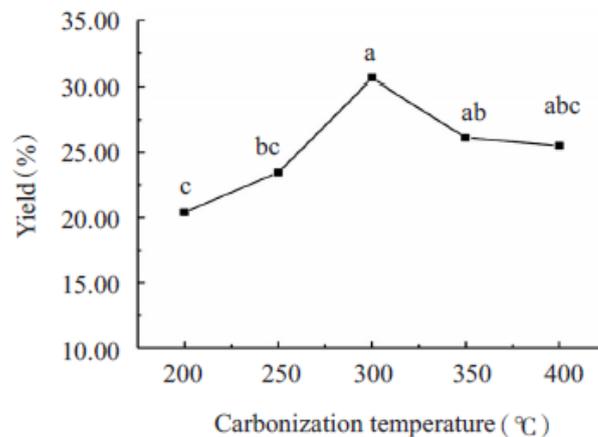

Fig.3 Effects of Different Carbonization Temperatures on the Yield of Eggplant Stem-Based Activated Carbon
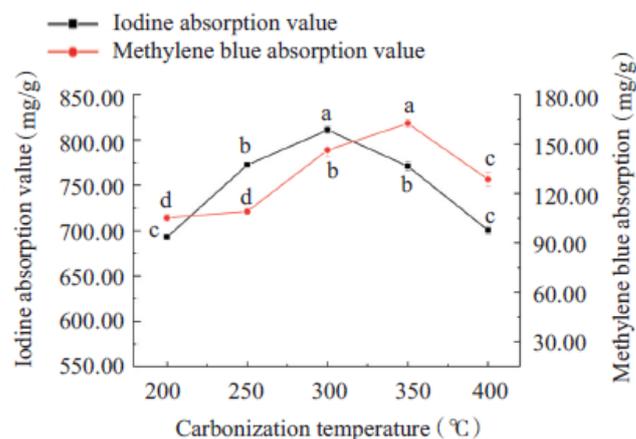
Fig.4 Effects of different carbonization temperatures on the adsorption performance of eggplant stems based activated carbon

4.1.3 Effect of Activation Temperature

Activation temperature is one of the key factors influencing the yield and adsorption properties of activated carbon. As shown in Figure 5, the yield of activated carbon derived from eggplant stems decreases gradually as the activation temperature increases. Specifically, when the activation temperature rises from 500°C to 700°C, the yield drops from 39.60% to 33.00%, showing a relatively slow decline. However, as the temperature reaches 900°C, the yield decreases sharply to 17.45%.

Figure 6 illustrates that the adsorption performance of activated carbon follows a trend of first increasing and then decreasing with rising activation temperatures. When the temperature increases from 500°C to 700°C, the methylene blue adsorption capacity of the activated carbon significantly rises from 15.66 mg/g to its peak value of 154.69 mg/g. Similarly, at 800°C, the iodine adsorption capacity reaches its maximum value of 956.33 mg/g. However, further increases in activation temperature lead to a rapid decline in adsorption performance, likely due to the excessive temperature causing carbon framework degradation and pore collapse (Cheng Qing et al., 2019). Based on these observations, 700°C is identified as the optimal activation temperature.
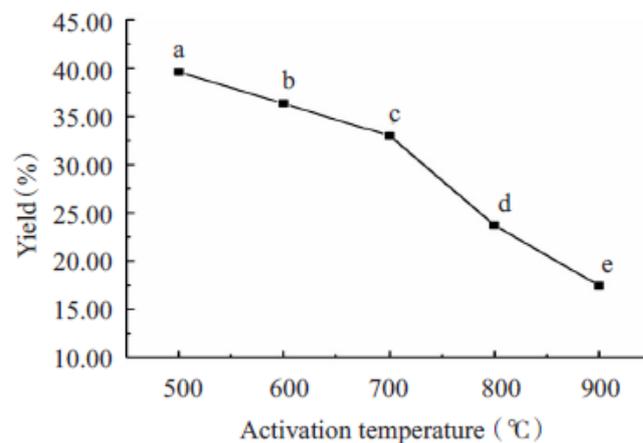

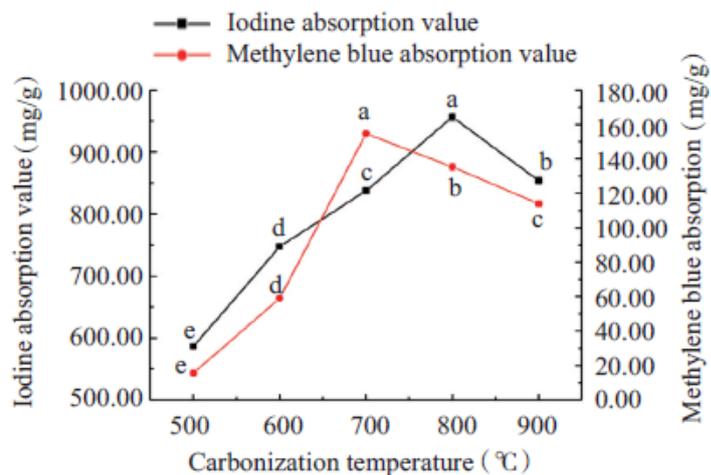Fig.5 Effects of different activation temperatures on the yield of eggplant stems based activated carbon

Fig.6 Effects of different activation temperatures on the adsorption performance of eggplant stems based activated carbon

4.1.4 Effect of Activation Time

As seen in Figure 7, the yield of activated carbon decreases gradually with the extension of activation time. Between 0.5 and 1.5 hours, the yield declines slowly from 35.80% to 32.03%. However, during the interval from 1.5 to 2.0 hours, the yield drops rapidly to 22.06%, stabilizing thereafter.

Figure 8 shows that the methylene blue adsorption capacity of the activated carbon increases rapidly at first and then decreases gradually as activation time extends. At 2.0 hours, the methylene blue adsorption value reaches its peak of 173.49 mg/g. Additionally, the iodine adsorption capacity continues to increase with longer activation times, likely due to the progressive deepening of activation and the formation of more micropores and mesopores. This development enhances the pore structure of the activated carbon, thereby improving its adsorption performance. To ensure both a high yield and excellent adsorption properties, an activation time of 1.5 hours is considered optimal.
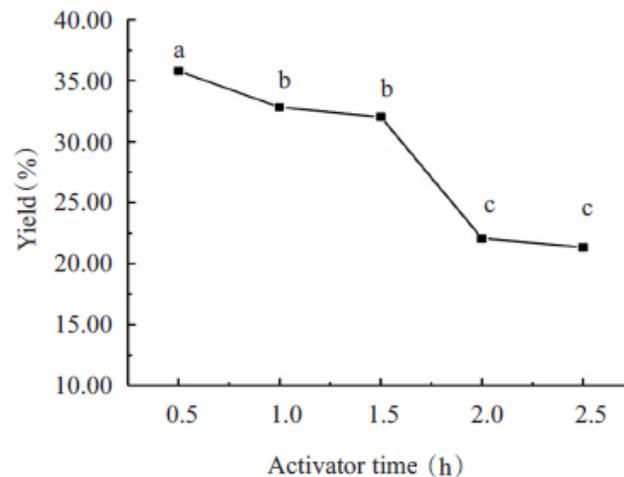

Fig.7 Effects of different activation times on the yield of eggplant stemsbased activated carbon
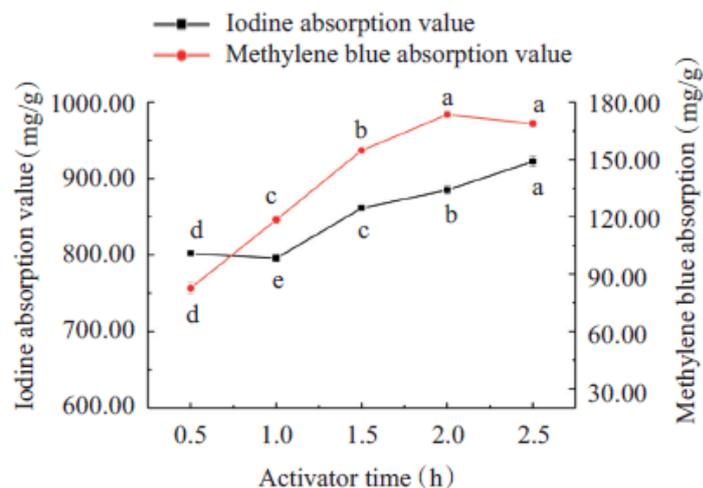
Fig.8 Effects of different activation times on the adsorption performance of eggplant stems based activated carbon

4.2.1 Response Surface Experimental Design and Results

Using Design-Expert V8.0.6, regression analysis was conducted on the experimental results. Based on the factors and levels selected in Table 1, the entropy weight method was applied to calculate the weight values of each indicator. The weights for activated carbon yield, iodine adsorption capacity, and methylene blue adsorption capacity were determined to be 0.424, 0.308, and 0.268, respectively. The comprehensive scoring formula is as follows:

Comprehensive Score=0.424Y₁+0.308Y₂+0.268Y₃

 Where:

Y_1: Normalized value of activated carbon yield,

Y_2: Normalized value of iodine adsorption capacity,

Y_3: Normalized value of methylene blue adsorption capacity.

The experimental design and results, as generated by Design-Expert V8.0.6, are presented in Table 2.

4.2.2 Model Development and Variance Analysis Results

Using Design-Expert V8.0.6, a quadratic polynomial regression model was developed based on the comprehensive scores in Table 2. The regression equation is as follows:

$$Y = 0.660 + 0.064A - 0.013B + 0.024C + 0.041AB + 0.0003506AC + 0.053BC - 0.092A^2 - 0.013B^2 - 0.170C^2$$

From Table 3, the following key results were obtained:

- The model's F-value is 18.77, and the probability P = 0.0004 (< 0.01), indicating the regression model is highly significant.
- The coefficient of determination R^2= 96.02% (> 90.00%), demonstrating a strong linear relationship and high predictive accuracy for the comprehensive score of eggplant stem-based activated carbon.
- The first-order term A and the second-order terms A^2 and C^2 have highly significant effects on the comprehensive score (P<0.01).
- The interaction term BC has a significant influence.

The ranking of the influence of the three factors on the overall score is as follows: the amount of activating agent added > activation temperature > carbonization temperature. The lack-of-fit value for the model is not significant (P > 0.05), indicating that the model fits well and accurately reflects the experimental results.

Table 2: Box-Behnken experiment design and results

No.	Factor A	Factor B	Factor C	Activated carbon yield (%)	Activated carbon iodine absorption value (mg/g)	Activated carbon methylene blue absorption value (mg/g)	Composite score
1	-1	-1	0	27.02	831.51	128.4	0.518
2	1	-1	0	30.09	858.84	118.89	0.617
3	-1	1	0	23.87	855.8	102.77	0.415
4	1	1	0	31.91	885.89	106.62	0.677
5	-1	0	-1	36.36	732.34	36.53	0.531
6	1	0	-1	28.53	885.89	37.45	0.424
7	-1	0	1	22.23	958.93	111.11	0.424
8	1	0	1	21.88	832.1	53.52	0.403
9	0	-1	-1	20.37	958.93	158.53	0.551
10	0	1	-1	19.33	907.76	145.95	0.68
11	0	-1	1	20.49	907.76	145.95	0.554
12	0	1	1	26.56	889.56	144.18	0.642
13	0	0	0	27.12	895.12	141.36	0.641
14	0	0	0	28.01	895.12	141.36	0.68

15	0	0	0	26.42	895.12	144.18	0.654
16	0	0	0	27.43	889.56	141.36	0.642
17	0	0	0	28.81	895.12	148.28	0.692

Table 3 Analysis of variance for the established regression model and significance test of regression coefficient

Source	Sum of squares	df	Mean square	F	P	Significance
A	0.032	1.0	0.032	23.83	0.0018	**
B	0.001451	1.0	0.001451	1.07	0.3352	
C	0.004585	1.0	0.004585	3.38	0.1084	
AB	0.006618	1.0	0.006618	4.88	0.0628	
AC	4.917e-07	1.0	3.635e-07	nan	0.9853	
BC	0.011	1.0	0.011	8.34	0.0234	*
A²	0.036	1.0	0.036	26.42	0.0013	**
B²	0.0007446	1.0	0.0007446	0.56	0.4826	
C²	0.13	1.0	0.13	92.98	<0.0001	**
Model	0.23	9.0	0.025	18.77	0.0004	**
Residual	0.009485	7.0	0.001355	nan	None	
Lack of fit	0.007387	3.0	0.002462	4.69	0.0847	
Pure error	0.002098	4.0	0.0005245	nan	None	
Cor error	0.24	16.0	nan	nan	None	
R²	0.9602	nan	nan	nan	None	

*indicated significant difference（P<0.05），** indicated extremely significant difference（P<0.01）

4.2.3 Interaction Effects of Model Factors and Analysis Results

Using Design-Expert V8.0.6, the interaction effects of various factors on the comprehensive score of eggplant stem-based activated carbon were analyzed. The response surface and contour plots are shown in Figures 9–11.

The response surface plots provide a three-dimensional view of the relationship between response values and experimental factors, visually illustrating the interaction effects between factors.

The shape of the contour lines indicates the strength of these interactions: elliptical contours represent significant interactions, while circular contours suggest weaker interactions (Niu Zhirui et al., 2014; Li Li et al., 2015).

Figure 9: The impact of activator dosage on the comprehensive score is greater than that of the carbonization temperature. As the activator dosage increases, the comprehensive score rises initially and then plateaus.

Figure 10: The comprehensive score follows a trend of first increasing and then decreasing with the combined effects of increasing activator dosage and activation temperature. The highest score in the experiment was achieved when the activator dosage was 2.0 g and the activation temperature was 700°C.

Figure 11: The activation temperature has a more significant effect on the comprehensive score than the carbonization temperature. The steep slope of the response surface and the elliptical shape of the contour lines indicate a significant interaction between carbonization temperature and activation temperature, consistent with the variance analysis results in Table 3.

Based on the analysis and optimization of experimental data, the predicted optimal preparation conditions are as follows:

- Activator dosage: 2.22 g
- Carbonization temperature: 322.60°C
- Activation temperature: 713.93°C

Under these conditions, the predicted maximum comprehensive score for eggplant stem-based activated carbon is 0.675.

2.2.4 Validation of the Model

Considering practical operational constraints, the conditions were adjusted to:

- Activator dosage: 2.22 g
- Carbonization temperature: 323°C
- Activation temperature: 714°C

Verification experiments under these adjusted conditions yielded the following results:

- Activated carbon yield: 29.25%
- Iodine adsorption value: 886.78 mg/g
- Methylene blue adsorption value: 140.90 mg/g
- Comprehensive score: 0.677

The relative error was only 0.296%, indicating that the response surface results are reliable and accurate.
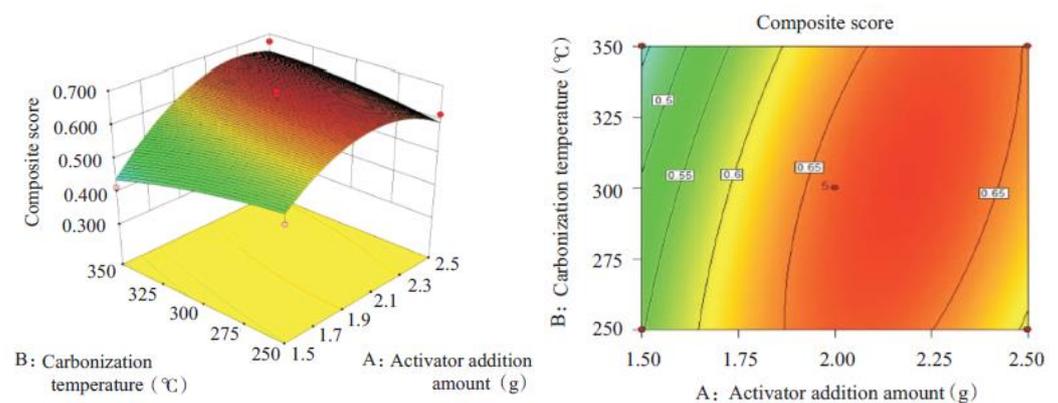

Fig.9 Response surface (left) and contour plot (right) of the interaction between activator addition amount and carbonization temperatures
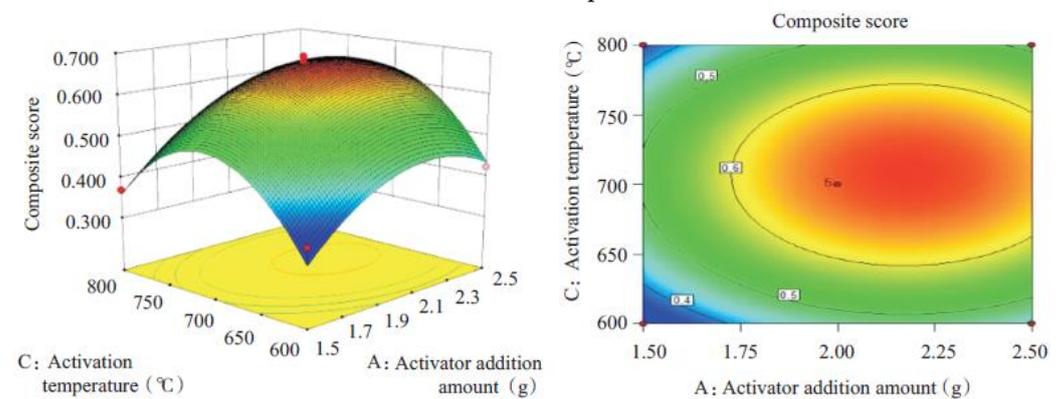

Fig.10 Response surface (left) and contour plot (right) of the interaction between activator addition amount and activation temperatures
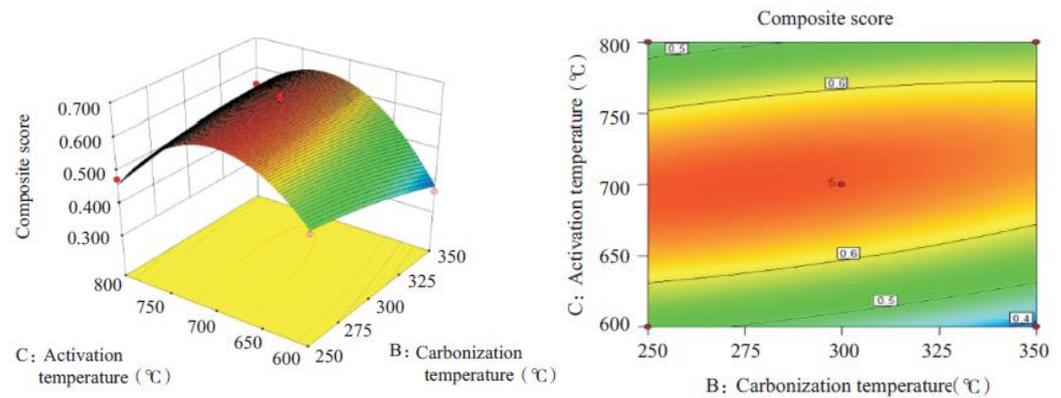
Fig.11 Response surface（left）and contour plot（right）of the interaction between carbonization temperatures and activation temperatures

5. Discussion

Activated carbon is a porous adsorption material produced by carbonizing and activating carbon-rich substances. Numerous studies have shown that the choice of activator, carbonization parameters, and activation conditions significantly influence the performance of activated carbon (Mao Yu et al., 2012; Li Jiaxing et al., 2013; Cheng Qing et al., 2019). The results of this study demonstrate that the amount of activator added has a significant impact on the yield and adsorption performance of activated carbon derived from eggplant stems. As the activator dosage increases, the yield of activated carbon increases, and an appropriate amount of activator enhances its adsorption capacity. This improvement can be attributed to the activator reacting with the raw material through cross-linking or polycondensation reactions, resulting in the release of volatile components, creating abundant pores, and retaining more carbon (Zuo Songlin, 2017).

The carbonization process removes volatile components from the raw material through thermal decomposition, thereby increasing the carbon content and producing carbon-rich materials. Among the carbonization parameters, temperature is the most critical factor (Yu Jing, 2015). In this study, the yield and adsorption performance of activated carbon from eggplant stems exhibited a trend of first increasing and then decreasing with rising carbonization temperatures, consistent with findings by Li Jiaxing et al. (2013). Higher carbonization temperatures accelerate the evaporation of gases and liquids in the raw material, increase fixed carbon content, and create initial pores, allowing the activator to penetrate deeper and enhance the adsorption performance of the activated carbon.

Additionally, selecting suitable activation conditions is crucial for improving the yield and adsorption properties of activated carbon. The optimal activation temperature for this study was determined to be 700–800°C, with an activation time of 1.5–2.0 hours, which aligns with findings by Cheng Qing et al. (2019) on durian-shell-based activated carbon (optimal activation temperature: 800°C, activation time: 1.5 hours). Inadequate activation conditions, such as low temperatures or short times, result in limited pore formation and weak adsorption capacity. Conversely, excessively high temperatures or prolonged activation times cause over-etching, carbon framework collapse, and reduced yield and adsorption performance, as supported by Wei Xinlai et al. (2015).

Recent studies have applied the response surface methodology (RSM) to optimize the preparation of biomass-based activated carbon, such as corn cob (Jiang Li et al., 2012), rice husk (Chen Junying et al., 2015), and macadamia nutshell (Cheng Song et al., 2015) activated carbons. RSM offers high precision and ensures minimal deviation between experimental and theoretical values while providing insights into factor interactions (Li Li et al., 2015). However, there have been no previous studies on using RSM to optimize the preparation of eggplant-stem-based activated carbon.

In this study, the optimal preparation conditions for eggplant-stem-based activated carbon were determined using a combination of entropy weight and response surface methods. The conditions were:

- Activator dosage: 2.22 g

- Carbonization temperature: 323°C

- Activation temperature: 714°C

Under these conditions, the measured results were:

- Activated carbon yield: 29.25%

- Iodine adsorption value: 886.78 mg/g

- Methylene blue adsorption value: 140.90 mg/g

The methylene blue adsorption value meets the first-grade standard for activated carbon used in wood-based water purification, and the iodine adsorption value is close to the second-grade standard (900 mg/g). These results exceed the yield (19.7%) and iodine adsorption value (674.2 mg/g) reported by Chen Han (2013) for single-factor experiments on tea-seed-shell-based activated carbon. Compared to the activated carbon optimized using orthogonal tests by Gu Jie et al. (2015), this study achieved a lower yield (by 8.22%) but increased iodine adsorption by 61.78 mg/g while requiring lower activation temperatures (100–200°C less), thereby reducing energy consumption. These findings demonstrate that RSM is more effective than single-factor or orthogonal tests in optimizing the preparation of activated carbon from by-products of eggplant processing.

However, this study did not investigate the adsorption mechanisms of iodine and methylene blue molecules. Future research could involve experiments using simulated and actual wastewater to explore these mechanisms and provide more practical insights into the application of eggplant processing by-products for activated carbon production.

6. Conclusion

The validation process confirmed that prepared parameters functional through response surface methodology integration and entropy weight methods exhibit accurate and reliable performance which makes them suitable for industrial-scale production. The combined method uses response surface methodology and entropy weight methods to achieve precise variable optimization which guarantees consistent production efficiency. Industrial requirements can be satisfied through large-scale production of eggplant stem activated carbon which maintains original quality standards and operational efficiencies by utilizing this advanced optimization approach.

Research demonstrates that eggplant stems represent a superior biomass choice for activated carbon manufacturing while providing environmentally beneficial renewable alternatives to conventional raw materials. These materials demonstrate commercial value because of their easy accessibility and exceptional potential to produce activated carbon of high quality. The eggplant stem agricultural waste integration follows both sustainability standards and global waste valorization criteria to form circular economic products.

The results demonstrate eggplant-stems activated carbon's significant industrial prospects in three major fields: water cleaning and gas capture alongside energy storage applications. The study lays groundwork for future investigations that will extend activated carbon production from diverse agricultural wastes by focusing on operational enhancements and cost-reduction strategies and potential utilization areas.

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