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Optimization of Remazol Brilliant Blue R dye removal by novel biosorbent *P. eryngii* immobilized on Amberlite XAD-4 using response surface methodology

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ABSTRACT

This study investigates preparation of biosorbent *Pleurotus eryngii* immobilized on Amberlite XAD-4 and the optimal conditions for removal of Remazol Brilliant Blue R (RBBR) reactive dye from synthetic aqueous solutions. The process was optimized using the response surface methodology (RSM) developed by the application of the quadratic model associated with the central composite design. For this purpose, RSM was employed to determine the effects of operational parameters on this material as effective and available adsorbent. The investigated variables were dye initial concentration (10–60 mg L^{-1}), solution pH (2–9), adsorbent dosage (0.1–0.5 g), and temperature (20–45˚C). The significant factors on each experimental design response were identified from the analysis of variance (ANOVA). The RSM indicated that optimum conditions of initial dye concentration, pH, adsorbent dosage, and temperature for maximum RBBR removal (98%) were achieved as 36.3 mg L^{-1}, 2.0, 0.304 g, and 38.7˚C, respectively. The results showed that this biosorbent was an appropriate adsorbent for the removal of RBBR from aqueous solutions.

Keywords: Amberlite XAD-4; *Pleurotus eryngii*; RSM; Remazol Brilliant Blue R

1. Introduction

The textile industry is a large sector and is considered the greatest creator of liquid effluents in the form of pollutants. According to the reported study, about one thousand tons of the textile dyes per year are discharged in the form of industrial effluent. Discharged wastewater from these industries usually contains different types of un-reactive dyes [1]. Reactive dyes are used extensively for dyeing cellulosic fiber due to their suitable characteristics of bright color, water-fastness, simple application techniques, and low energy consumption [2]. In addition, these dyes are known for their low degree of fixation on the textile surface and thus the generated industrial wastewaters are highly colored in nature [3]. In spite of toxic reactive dyes,

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these dye molecules are biologically inactive, but it separated the azo (–N=N–) groups and aromatic amines. Most of these complexes are also toxic and even carcinogenic. At the same time, they affect the human health by direct contact or through the environment [4,5]. Therefore, it is undoubtedly important to treat the dye wastewater prior to its discharge into a water body [6]. Various processes such as anaerobic/aerobic biological treatments [7], coagulation/flocculation [8], membrane filtration [9], oxidation [10], photocatalysis [11], and sonolysis [12] have been used for treatment of wastewater containing reactive dyes. However, these processes have disadvantages and limitations, such as high cost, generation of secondary pollutants, and poor removal efficiency [13]. Among these, adsorption has been found to be superior to other techniques for water re-use in terms of initial cost, flexibility, and simplicity of design, ease of operation and insensitivity to toxic pollutants. Adsorption also does not result in the formation of harmful substances [14]. Activated carbon, peat, chitin, silica, fly ash, clay, and others were used as sorbents, but the dye sorption capacity of these sorbents is not effective. Therefore, to enhance the dye sorption performance, new sorbents are still under investigation [1]. Amberlite XAD resins have received a considerable attention as basic matrices for designing new chelating resins. These resins possess enormous advantages over the others; for example, structure of these resins provides excellent chemical, physical, and thermal stability under various experimental conditions [15]. These advantages include a high degree of selectivity by controlling the pH, versatility, durability, and enhanced hydrophilicity. The biomass immobilized within a suitable matrix is meant to overcome these problems by offering ideal size, mechanical strength, rigidity, and porous characteristics to the biological material [16]. Various technologies have demonstrated the capacity of microorganisms, particularly white rot fungi (WRF), to decolorize and remove a wide variety of structurally diverse pollutants including synthetic dyes. The WRF have an advantage over bacteria owing to their capability to degrade insoluble pollutants by producing extracellular ligninolytic enzymes such as laccase, lignin peroxidases, and manganese-dependent peroxidase [17,18]. Response surface methodology (RSM) is an effective tool to study the interactions between two or more independent parameters. A standard RSM design called a central composite design (CCD) is suitable for fitting a quadratic surface and it helps to optimize the effective parameters with a minimum number of experiments as well as to analyze the interaction between the parameters [19,20].

The aim of the present work was to conduct RBBR adsorption onto immobilized fungi on Amberlite XAD-4 and to investigate the combined effect of various process parameters like initial concentration, solution pH, adsorbent amount, and temperature on RBBR removal using CCD in RSM.

2. Materials and methods

2.1. Materials

RBBR and Amberlite XAD-4 were purchased from Sigma and the chemical form of RBBR was illustrated in Fig. 1. The different solutions of RBBR were prepared by dissolving the sufficient amount of RBBR in distilled water. Diluted NaOH and H_2SO_4 solutions were used to adjust the pH values [9,19].

2.2. Preparation of fungal biomass

Indigenous white rot fungus *Pleurotus eryngii* as biosorbent was collected from the province of Tunceli-Pulumur in Turkey. The fungal sample was washed twice with distilled water to remove contaminants and then dried at room temperature. The dried fungal biomass was ground in a porcelain mortar to obtain a fine powder. It was then dried at 80˚C in an oven for 24 h to achieve complete death of the dried cells. For viability testing, the cells were inoculated to Sabouraud Dextrose Agar (SDA) medium at 27˚C for 24 h. The absence of mycelian *P. eryngii* indicated positive results, which reflects the complete death of the fungus. The dead cells stored at −5˚C in a deep freeze until further use.

2.3. *Preparation and immobilization of* P. eryngii *on Amberlite XAD-4*

The cell wall of the fungi is a thick, rigid structure composed of complex layers of polysaccharides, proteins, lipids, and polyphosphates. The most common constituent of the wall is chitin, consisting of N-acetylglucosamine residues. Amberlite XAD-4 is a polymeric resin, supplied as white unsoluble beads. It is a

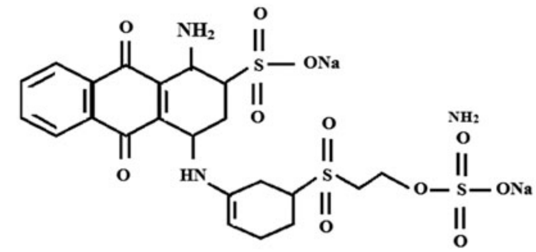

Fig. 1. The chemical form of RBBR.

nonionic crosslinked polymer which drives its adsorptive properties from its patented macroreticular structure (containing both a continuous polymer phase and continuous pore phase), high surface area, and the aromatic nature of its surface. This structure gives Amberlite XAD-4 polymeric adsorbent excellent physical, chemical, and thermal stability. Because of these reasons, fungi both physically and chemically interact with polymeric resin surface. This might be explained by the mechanism of fungi binding to XAD-4 which involves surface adsorption to functional groups.

The immobilization of *P. eryngii* on the substrate was performed as follows: 200 mg of fungus powder was mixed with 2 g of preprocessed Amberlite XAD-4. The mixture was wetted with 2 mL of ultra pure water two times to improve the immobilization efficiency and mixed thoroughly. The mixture was heated in an oven at 50℃ for 24 h for drying. Then, the product was ground to get original size (less than 240 meshes) and used as an adsorbent for RBBR removal [16,21].

2.4. Adsorption experiments

Batch adsorption experiments were carried out in 50 mL erlenmeyer flasks. The flasks included the variable concentrations of adsorbent and synthetic dye solutions according to RSM design that was taken in orbital shaking incubator. The flasks were then subjected to agitation at 250 rpm. All experiments were carried out under conditions summarized in Table 1. Samples were filtered by centrifugation prior to analysis. Analyses of RBBR in the supernatant solutions were determined by UV spectrophotometer (Shimadzu, Japan) at 595 nm wavelength. The removal rate of RBBR was calculated using following equation;

$$\%\ \text{Removal} = \frac{C_\text{i} - C_\text{o}}{C_\text{i}} \times 100 \tag{1}$$

where C_i is the initial (before biosorption) RBBR concentration (mg L^{-1}) and C_o is the final (after biosorption) RBBR concentration in solution (mg L^{-1}).

2.5. Experimental design and statistical analysis

2.5.1. Response surface methodology

RSM is a collection of mathematical and statistical techniques for empirical model building. It is useful for modeling and analysis of problems [22]. Once the ranges and interval of the significant factors were decided, RSM was used to determine the optimum magnitude of the factors respected to the RBBR removal.

A CCD with four factors at five levels was conducted in this study. The total number of experiments was $30 = 2k + 2^k + 6$, where k is the number of factors. Fourteen experiments were augmented with six replications at the center points to evaluate the pure error. Table 1 shows the levels of the significant factors tested in CCD and Table 2 shows experimental design and results of CCD. The first four columns of Table 2 show run number and experimental conditions of the runs. Optimization of the process was evaluated by analyzing the response which was RBBR removal. In the optimization process, the response can be related to selected factors in quadratic models. A quadratic model is supposed to be as follows:

$$Y = \beta_0 + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{3} \beta_{ii} X_i^2 + \sum_{i<1}^{3} \sum_{j=1}^{3} \beta_{ij} X_i X_j \tag{2}$$

where Y is the response, β_0 is the constant coefficient, X_i (i = 1–3) are variables, β_i are the linear, and β_{ii} are the quadratic, and β_{ij} (i and j = 1–3) are the second-order interaction coefficients. Data were processed using the Design-Expert 6.0 program (trial version) and an analysis of variance (ANOVA) test was calculated to obtain the interaction between the process

Table 1
Coded and actual values of independent factors

Variables	Symbols	Coding				
		−2	−1	0	1	+2
Initial concentration (mg L^{-1})	x_1	10	22.5	35	47.5	60
pH	x_2	2	3.75	5.5	7.25	9
Temperature (℃)	x_3	20	26.25	32.5	38.75	45
Amount of adsorbent (g)	x_4	0.1	0.2	0.3	0.4	0.5

Table 2
Parameters, their intervals in the runs conducted in CCD and corresponding results

Run	x_1 (mg L^{-1})	x_2	x_3 (°C)	x_4 (g)	RBBR removal (%)
1	35.0	9.00	32.50	0.3	96
2	35.0	5.50	45.00	0.3	98
3	22.5	7.25	38.75	0.4	96
4	47.5	3.75	26.25	0.2	80
5	35.0	5.50	32.50	0.3	95
6	35.0	5.50	32.50	0.3	95
7	22.5	3.75	38.75	0.2	95
8	35.0	5.50	32.50	0.5	98
9	47.5	3.75	38.75	0.2	91
10	35.0	5.50	32.50	0.1	65
11	35.0	5.50	20.00	0.3	93
12	35.0	5.50	32.50	0.3	95
13	35.0	5.50	32.50	0.3	95
14	47.5	7.25	26.25	0.2	79
15	22.5	7.25	26.25	0.2	85
16	47.5	7.25	38.75	0.2	92
17	22.5	7.25	38.75	0.2	93
18	47.5	7.25	26.25	0.4	96
19	35.0	2.00	32.50	0.3	98
20	35.0	5.50	32.50	0.3	95
21	10.0	5.50	32.50	0.3	98
22	22.5	3.75	26.25	0.2	95
23	22.5	3.75	38.75	0.4	86
24	35.0	5.50	32.50	0.3	95
25	47.5	3.75	26.25	0.4	96
26	60.0	5.50	32.50	0.3	97
27	47.5	7.25	38.75	0.4	97
28	22.5	3.75	26.25	0.4	97
29	22.5	7.25	26.25	0.4	97
30	47.5	3.75	38.75	0.4	90

variables and the response. The quality of fit of the polynomial model was expressed by the coefficient of determination R^2, and its statistical significance was checked by the F-test.

2.5.2. Analyses of maximum points

The second-order model obtained from CCD studies, Eq. (3), is adequate for the optimal points. A general mathematical expression, Eq. (4), was used to locate the stationary points [20,22]. We used the following second-order model in matrix notation,

$$y = \beta_0 + x^1 b + x^1 B x_s \tag{3}$$

where,

$$x_s(\text{Stationary points}) = \begin{bmatrix} X_1 \\ X_2 \\ X_k \end{bmatrix}, \quad b = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_k \end{bmatrix}, \quad \text{and}$$

$$B = \begin{bmatrix} \beta_1 & \frac{\beta_{12}}{2} & \frac{\beta_{1k}}{2} \\ & \frac{\beta_{22}}{2} & \frac{\beta_{2k}}{2} \\ \text{sym} & & \beta_{kk} \end{bmatrix}$$

where b is a $(k \times 1)$ vector of the first-order regression coefficient and B is a $(k \times k)$ symmetric matrix whose main diagonal elements are the pure quadratic coefficients (β_{ii}) and whose off-diagonal elements are one half of the mixed quadratic coefficients (β_{ij}, $i \neq 1$). The stationary points (x_s) are the solution of Eq. (4).

$$x_s = -\frac{1}{2} B^{-1} b \tag{4}$$

3. Result and discussions

3.1. FTIR studies

The FTIR spectra revealed that various functional groups detected on the surface of RBBR before and after adsorption in Fig. 2(a) and (b). There are some shifted, disappeared peaks and new peaks were also detected in the RBBR dye adsorption on adsorbent. As seen in Fig. 2(a) and (b), four significant bands at 3,371, 2,900, 2,360, and 1,632 nm which indicated the bonds, –OH groups, NH stretching, –C=C–, and SO group revealed. These four significant bands in the spectrum indicate the possible involvement of the respective functional group on the surface of the adsorbent in RBBR dye adsorption process. In this figure, the band at 3,371 cm^{-1} can be attributed to the presence of O–H and N–H groups for RBBR. The peaks observed at 2,900 cm^{-1} can be assigned to stretching vibrations of the C–H alkyl groups for RBBR. The peak around 1,632 cm^{-1} is due to the C=C aromatic or may be asymmetric and symmetric stretching C=O vibration for RBBR. The observed runoff http://tureng.com/search/run off and intensity changes of the FTIR bands were rather weak, which can be indication of the dominance of ion exchange over the precipitation/coprecipitation occurring during RBBR sorption on our biosorbent. Hence, this result suggests that the RBBR dye adsorbed biosorbent *P. eryngii* immobilized on Amberlite XAD-4 might induce bulk phase changes.

3.2. Analysis variance (ANOVA)

It is quite difficult to optimize the removal of dyes with some adsorbents modeling for economic cost and less time needed cases. Therefore, using of RSM eliminated these problems and RSM was applied to build up an empirical model related to the RBBR removal by analyzing the significant factors. Table 1 indicates the level of the selected factors designed for CCD while Table 2 shows experimental conditions for batch shaking-flask runs and the results (responses) in terms of RBBR removal. According to RSM, the medium conditions were randomly designed and corresponding

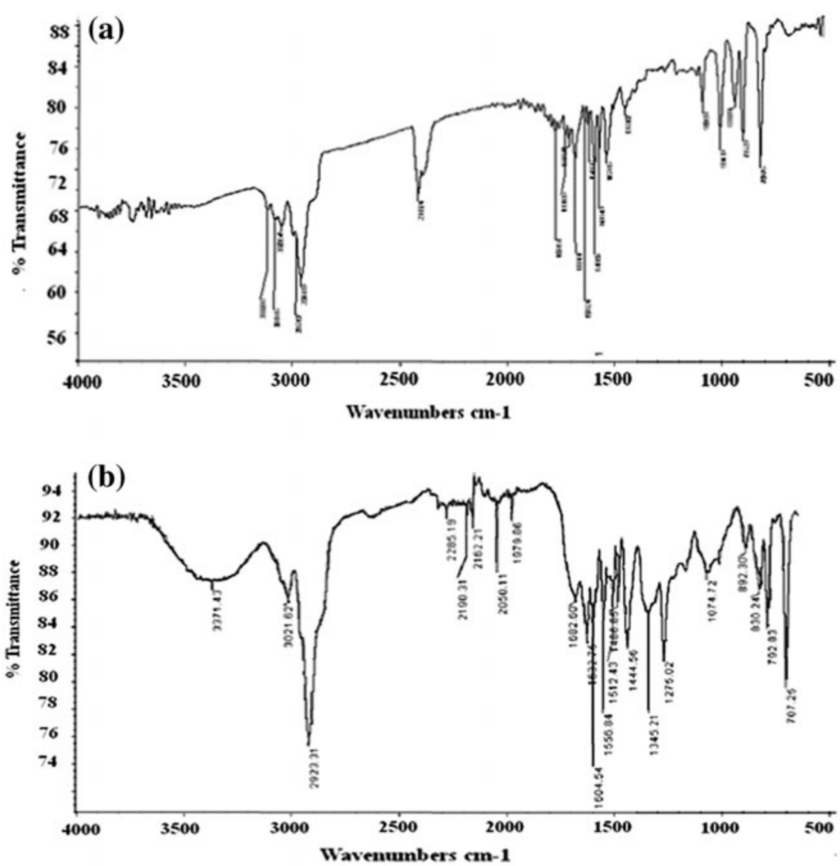

Fig. 2. FT-IR spectra of Amberlite XAD-4 and *P. eryngii* mixture. (a) After Amberlite XAD-4 and *P. eryngii* mixture adsorption; (b) before Amberlite XAD-4 and *P. eryngii* mixture adsorption.

responses were recorded as shown in Table 2. The observed results were given in Table 3. By applying multiple regression analysis on the experimental data, the following second-order polynomial equation was established to explain RBBR removal in terms of the medium conditions, which are initial concentration, pH, medium temperature and adsorbent amount Eq. (5).

$$\begin{aligned}\text{RBBR Removal}\,\% = {} & 95-1.041670\,x_1+0.041667\,x_2\\ & +1.041667\,x_3+4.625\,x_4\,0.5625\,x_1x_2\\ & +1.4375\,x_1x_3+1.8125\,x_1x_4\\ & +1.6875\,x_2x_3\\ & +1.8125\,x_2x_4-3.0625\,x_3x_4\\ & +0.40625\,x_1^2\\ & +0.28125\,x_2^2-0.09375\,x_3^2-3.593750\,x_4^2\end{aligned} \quad (5)$$

In this equation; x_1, x_2, x_3 and x_4 are the initial concentration (mg L^{-1}), pH, medium temperature (℃), and adsorbent amount (g), respectively.

The analysis of variance test was conducted with experimentally observed data to test the significance of the second-order polynomial equation Eq. (5) and the test results were presented in Table 3. The model *F*-value of 6.73 implies that the model is significant. The fit of the model was checked by the coefficient of determination R^2, which was calculated to be 0.86, indicating that 86% of the variability in the response could be explained by the model. It indicates a good agreement between experimental and predicted values and implies that the mathematical model is reliable for RBBR removal. The value 0.0004 of "Prob > *F*", which is less than 0.05 indicates that the model terms are significant. According to the results of the statistical design and by application of Eqs. (3) and (4), the optimum values of tested factors (initial concentration, pH, temperature, and adsorbent amount) were evaluated as 36.3 mg L^{-1}, 2, 38.7℃, and 0.304 g, respectively. Under the optimized conditions, maximum RBBR removal was predicted to be approximately 98%.

3.3. Effects of the factors and their interactions on RBBR removal

The effects of parameters on the response are valuable for regression analysis because the positive sign increases the response, while the negative sign decreases the response [23]. The interactions between adsorbent amount and temperature, adsorbent amount and pH, adsorbent amount and initial concentration have positive effects while interaction between pH and initial concentration has negative effects. The results of the experiments were expounded by Pareto analysis since it gave more significant information. The following equation was used for calculation of percentage of factors on removal dyes [24,25].

$$Pi = \frac{b_i^2}{\sum b_i^2} \times 100 \quad (i \neq 0) \quad (6)$$

Pareto graphic analysis was shown in Fig. 3. Among variables, quadratic effect of initial concentration of

Table 3
Regression analyses for RBBR removal obtained through CCD

Source	Sum of squares	DF	Mean square	*F* value	Prob > *F*	
Model	1,296.95	14	92.639	6.737	0.0004	Significant
x_1	26.04	1	26.041	1.893	0.1890	
x_2	0.041	1	0.041	0.0030	0.956	
x_3	26.041	1	26.041	1.893	0.189	
x_4	513.37	1	513.375	37.336	<0.0001	
x_1x_2	5.062	1	5.062	0.368	0.553	
x_1x_3	33.062	1	33.062	2.404	0.141	
x_1x_4	52.562	1	52.562	3.822	0.069	
x_2x_3	45.562	1	45.562	3.313	0.088	
x_2x_4	52.562	1	52.562	3.82	0.069	
x_3x_4	150.062	1	150.062	10.91	0.004	
x_{12}	4.526	1	4.526	0.329	0.574	
x_{22}	2.169	1	2.169	0.157	0.696	
x_{32}	0.241	1	0.241	0.017	0.896	
x_{42}	354.241	1	354.241	25.762	0.0001	

Note: R^2 = 0.86.

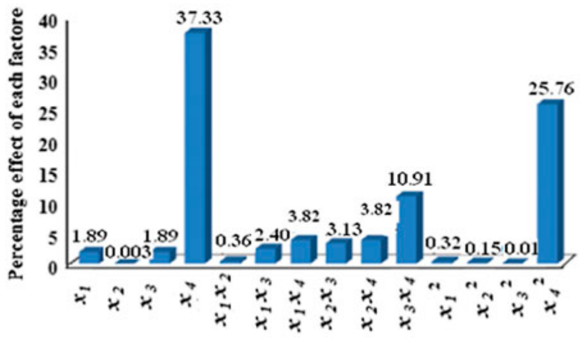

Fig. 3. Pareto graphic analysis.

dye (1.89%), pH (0.003%), temperature (1.89%), and adsorbent amount (37.33%) were found effective parameters on dye removal by *P. eryngii*.

3.4. Response surface plots

The effect of each parameter on RBBR removal and interaction between the four variables were illustrated in Figs. 4–7. Depending on the quadratic model, 3D response surface and 2D response surface plots were arranged. To study the impact of the adsorbent amount and temperature on the RBBR removal efficiency, some experiments with valuables that are

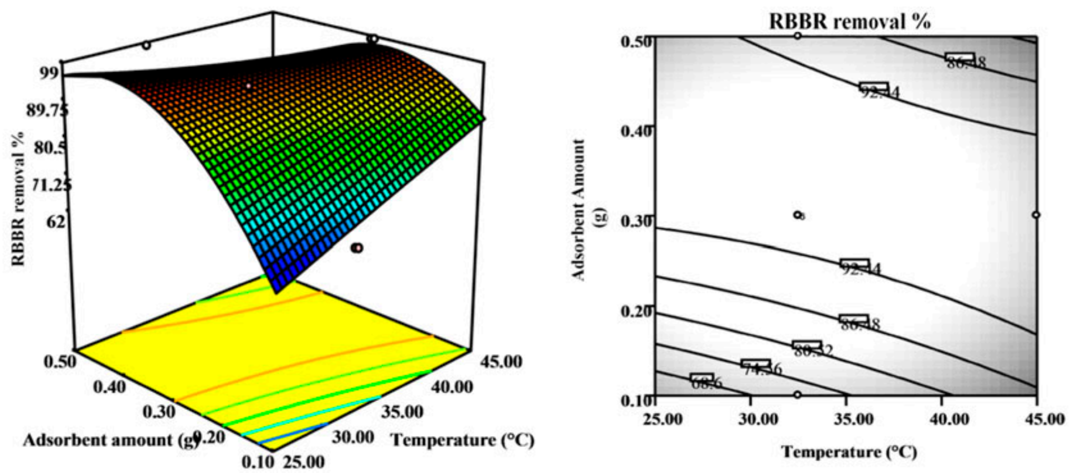

Fig. 4. Three-dimensional and two-dimensional response surface plots showing the effect of adsorbent amount and temperature on RBBR removal at fixed pH and initial concentration.

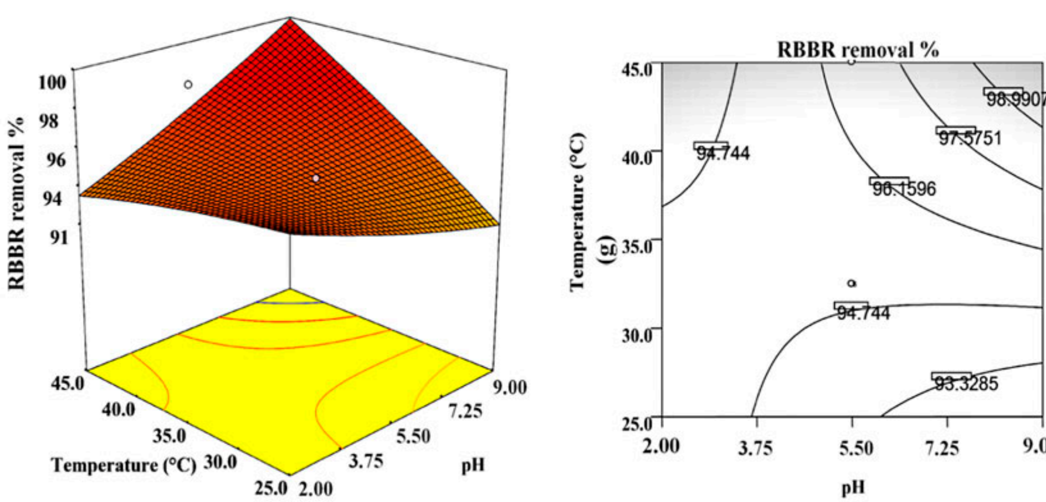

Fig. 5. Three-dimensional and two-dimensional response surface plots showing the effect of temperature and pH on RBBR removal at fixed adsorbent amount and initial concentration.

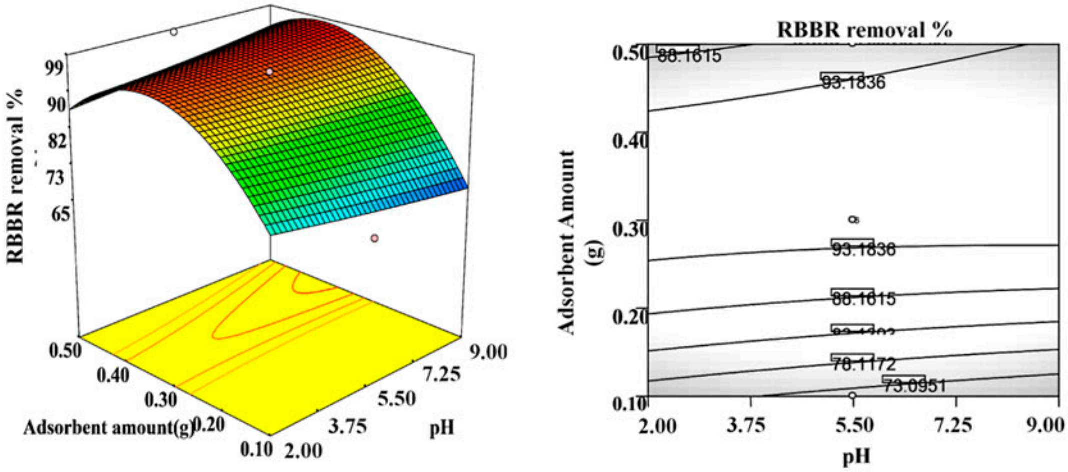

Fig. 6. Three-dimensional and two-dimensional response surface plots showing the effect of adsorbent amount and pH on RBBR removal at fixed temperature and initial concentration.

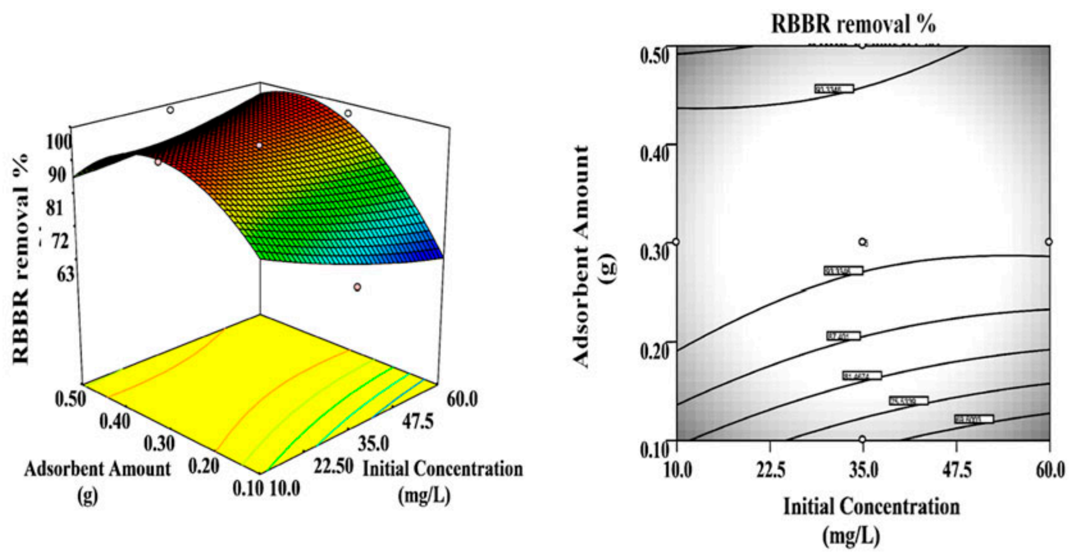

Fig. 7. Three-dimensional and two-dimensional response surface plots showing the effect of adsorbent amount and initial concentration on RBBR removal at fixed pH and temperature.

adsorbent amount (0.1–0.5 g) and temperature (25–45˚C) fixed pH (5.5) and initial concentration (32.5 mg L^{-1}) were designed in Fig. 4. In this figure, RBBR removal has strongly been affected by both factors. The increment in adsorbent amount up to 0.4 g significantly increased RBBR removal up to 98%. After this point, the response did not increase and it fixed after 0.4 g adsorbent amount. The effect of temperature was similar to the effect of adsorbent amount. Up to 39˚C, temperature also affected RBBR removal but higher values had negative effects on the response. The same trend was obtained in some similar studies also [26,27]. As seen in Fig. 5, the response wasn't slightly influenced by temperature and pH parameters. The increment or decrement of these parameters and interaction among them are not exactly effectively on response. The maximum temperature was maintained at 38.7˚C for the optimization process [28]. This can be explained by exothermicity and naturality of the adsorption process and the weakening of bonds between dye molecules and active sites of the adsorbent at high temperatures. The influence of solution temperature is diminished and rectified by higher pH [29].

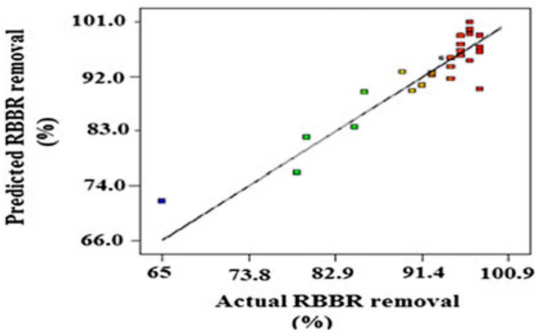

Fig. 8. Relation between predicted RBBR removal percentage and experimentally observed removal percentage.

Table 4
Parameters in the Langmuir and Freundlich adsorption isotherm models of RBBR removal

Langmuir			Freundlich		
q_m (mg g^{-1})	K_L (L mg^{-1})	R^2	K_F (mg g^{-1})	n^{-1}	R^2
1.92	0.028	0.94	1.04	0.98	0.99

The optimum pH was found to be 2.0. The optimum pH on dyes removal was reported in some works that to be in the range of 2.0 and 5.5 in acidic forms as similar to our studies [26,28,30]. Fig. 6 represents combined influence of adsorbent amount and pH on RBBR removal at the fixed temperature and initial concentration. As shown in Fig. 6, RBBR removal has strongly been affected by adsorbent amount up to 0.4 g but these effect was not exactly occurred in pH. As shown in Fig. 7, the response surface plots were developed as a function of adsorbent amount and initial concentration and while the temperature and pH were kept constant at 32.5˚C and 5.5, respectively. RBBR removal efficiency increases with increase in adsorbent amount, which can be attributed to the increased RBBR molecules-binding sites in the system. In other words, the percentage of dye removal efficiency decreased with increasing dye initial concentration. A similar trend was reported for the adsorption of dyes onto the different types of adsorbents such as coal, alg, activated carbon, and clay [27,29,31].

Fig. 8 displays the relation between predicted RBBR removal percentage using Eq. (4) and experimentally observed removal percentage. It proves that the predicted RBBR removal is well in agreement with the observed data. The correlation coefficient (R^2), 0.86, shows the suitability between predicted and observed RBBR removal percentage.

Many repetitions have been performed to check model durableness. It was observed that the differences between control experiments of model were not exceeded 5% in all runs. It was revealed that the model well represents the study.

3.5. Adsorption isotherms

Well-known adsorptions models were used to describe the system. Due to the shape of the isotherms, the sorption data were calculated according to Freundlich and Langmuir equations as given in below Eqs. (6) and (7) [32,33].

$$q_e = K_F C_e^{1/n} \tag{7}$$

$$\frac{1}{q_e} = \frac{1}{K_L C_e} + \frac{1}{Q_m} \tag{8}$$

where q_e is the amount of the dye per unit weight of *P. eryngii* immobilized on Amberlite XAD-4 (mg g^{-1}), C_e is the equilibrium concentration of the dye (mg L^{-1}), while K_F, K_L, and n are constants that give estimates of the adsorption capacity and intensity, respectively. K_L is a direct measure of the intensity of the adsorption process (L mg^{-1}), and q_m is a constant related to the surface area occupied by a monolayer of the dye,

Table 5
Comparison of the RBBR adsorption capacities of the various adsorbent

Adsorbent	Adsorbate	Adsorption capacity (mg g^{-1})	Refs.
Red mud	RBBR	27.80	[36]
Pirina was pretreated with HNO_3	RBBR	23.63	[37]
Orange peel	RBBR	11.62	[38]
Coir pith carbon	Congo Red	6.72	[39]
Fly ash	Rhodamine B	5.51	[40]
P. eryngii immobilized on Amberlite XAD-4	RBBR	1.92	This study
Fly ash	Acid Red 91	1.46	[41]

reflecting the adsorption capacity (mg g^{-1}). Based on the data of q_e from the fittings of the pseudo-second-order adsorption rate model, q_m, and K_L can be determined from its slope and intercept from a typical plot of $1/q_e$ vs. $1/C_e$. In Eq. (7), The slope n^{-1}, ranging between 0 and 1, is a measure for the adsorption intensity or surface heterogeneity. K_F is a constant for the system, related to the bonding energy. K_F can be defined as adsorption or distribution coefficient and represents the general capacity of the dye adsorbed on to fungi for a unit equilibrium concentration. The results of isotherms fitted using the data of adsorption capacity from the regression of Eq. (8). At the same time, the values of K_L and K_F define a measure of the adsorption capacity. As indicated in Table 4, the Freundlich models yield a somewhat better than Langmuir models on adsorption of dye on fungi as reflected with correlation coefficients (R^2) of 0.99 and 0.94, respectively [34,35]. Comparison of adsorption capacity observed in this work with other adsorption capacities in the literature is given in Table 5.

4. Conclusions

In this present study, RSM was applied to optimize the removal of RBBR by novel biosorbent *P. eryngii* immobilized on Amberlite XAD-4 system. CCD was used to obtain the optimum conditions of dye removal. The effect of independent variables such as initial concentration, pH of solution, adsorbent amount, and temperature on RBBR removal were analyzed. A mathematical model described to the RBBR removal with RSM. The optimum values for initial concentration, pH of solution, adsorbent amount, and temperature were found to be 36.3 mg L^{-1}, 2.0, 0.304 g, and 38.7°C, respectively. The maximum RBBR removal was achieved 98%, under the evaluated optimum conditions. To our knowledge, *P. eryngii* immobilized on Amberlite XAD-4 as a novel biosorbent system was used first time to optimize removal of dyes by RSM. It will be alternative to removal of textile wastewater from industrial areas.

Nomenclature

AA	—	amount of adsorbent
ANOVA	—	analysis of variance
β_0	—	constant coefficient of Eq. (1)
β_i	—	linear coefficient of Eq. (1)
β_{ii}	—	quadratic coefficient of Eq. (1)
β_{ij}	—	interaction coefficient of Eq. (1)
R^2	—	coefficient of determination

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