

Optimization and Modeling of Reactive Black 5 Dye Removal Using ZnO-Loaded *Pupalia lappacea* Adsorbent

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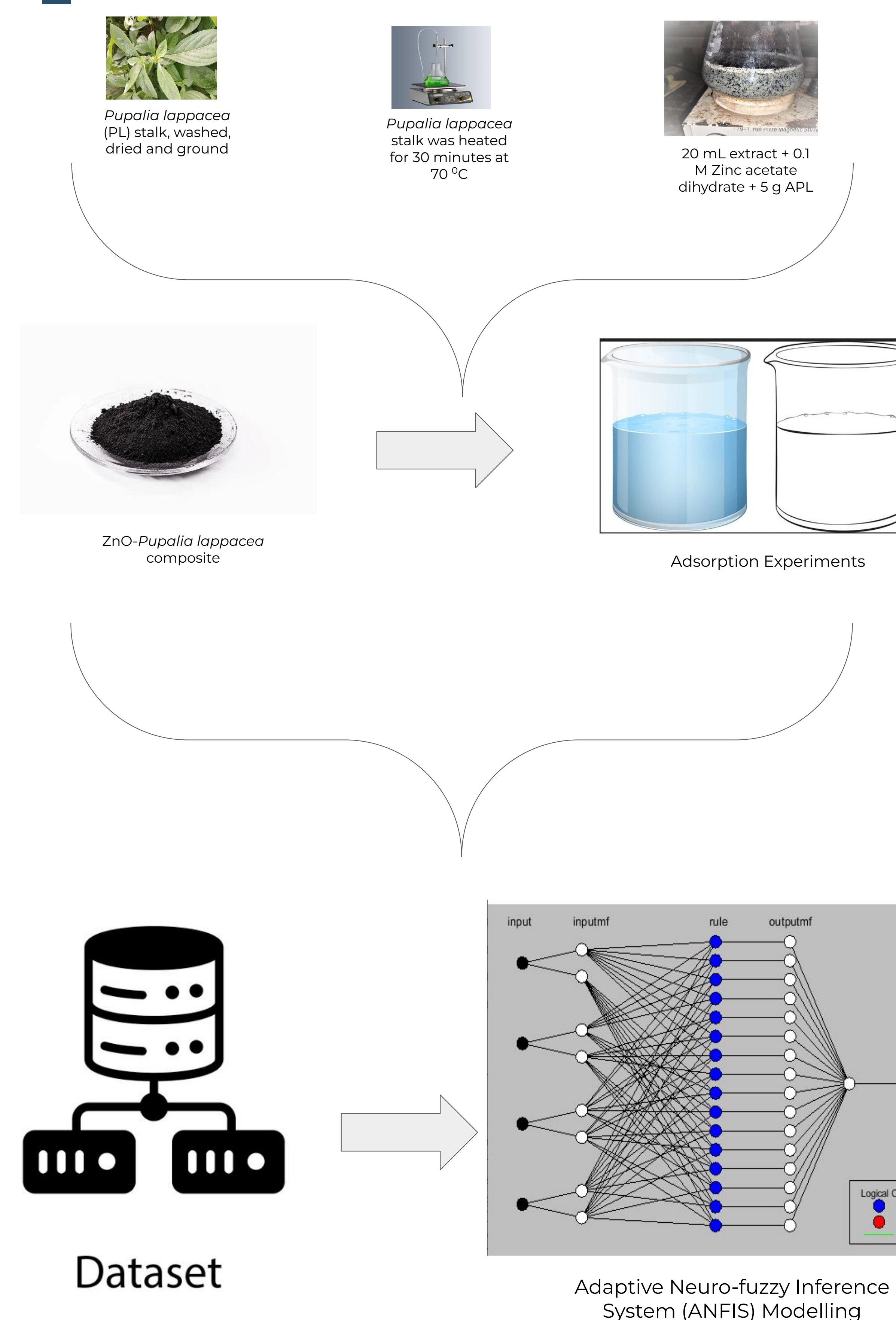
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Introduction

The presence of reactive dyes such as Reactive Black 5 (RB5) have been reported in various environmental mediums such as water, sediments and in fishes. Due to their chemical structure, which comprises of aromatic amines, they also can undergo cleavage to produce toxic by-products (Kamati et al. 2024).

Different methods have been employed for RB5 removal from wastewater and varying degrees of success have been noted with each method. In this study, ZnO-nanoparticles incorporated acid-modified *Pupalia lappacea* adsorbent composite (Z-APL) was prepared from *Pupalia lappacea* stalks. Additionally, RSM and ANFIS modelling techniques were also used to investigate the adsorption process.

Methodology



Results

Table 1: ANOVA parameters for the modified cubic model of RB5 removal onto Z-APL

Source	Degree of freedom	Sum of squares	Mean square	F value	P value
Model	6	1964.32	327.39	170.15	< 0.0001
A-pH	1	52.50	52.50	27.29	< 0.0001
B-Conc.	1	380.21	380.21	197.61	< 0.0001
C-Time	1	73.26	73.26	38.07	< 0.0001
D-Dosage	1	972.94	972.94	505.66	< 0.0001
D ²	1	169.70	169.70	88.20	< 0.0001
A ³	1	12.51	12.51	6.50	0.0207
Residual	17	32.71	1.92		
R ²	0.984				
Adjusted R ²	0.978				
Predicted R ²	0.942				

Table 2: ANFIS model parameters and related prediction errors

Adsorbent/Adsorbate	Membership function	Number Membership functions	Training error (RMSE)	Testing Error (RMSE)
Z-APL/RB5	Gbellmf	3	0.33335	14.7122
	Trimf	3	0.000184	0.52102
	Trapmf	3	0.6478	68.8109
	Gaussmf	3	0.18789	4.066
	Pimf	3	0.60978	114.3184
	Dsigmf	3	0.37488	71.0414

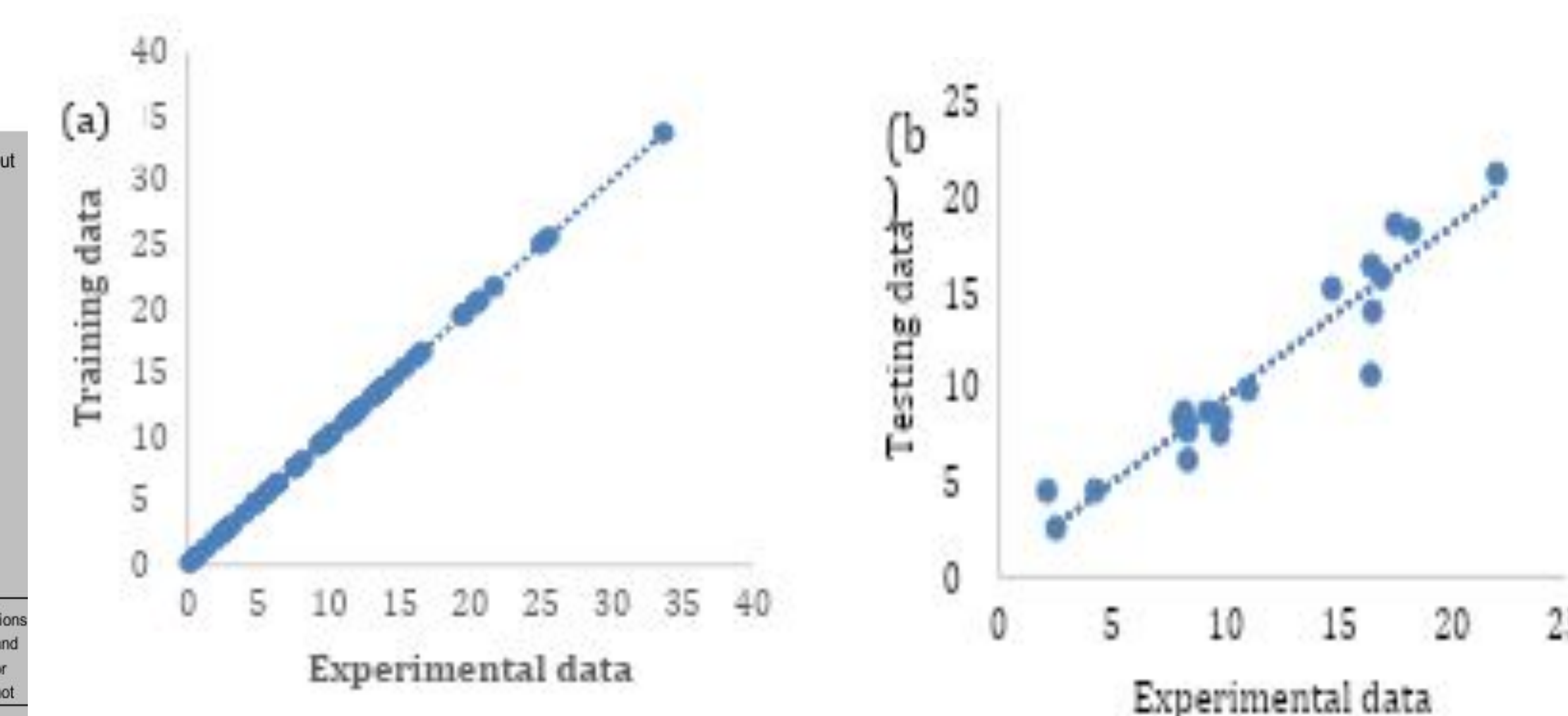


Figure 1: Plots comparing the experimental and predicted values of (a) training and (b) testing data for RB5 removal onto Z-APL

Discussion

Based on the R² and adjusted values, the modified cubic model was the best fit for modelling RB5 onto Z-APL (Table 1). The four factors of pH (A), initial dye concentration (B), contact time (C) and dosage (D) were all significant with P values far less than 0.05. Quadratic term D² and cubic term D³ were also significant terms with P values of <0.0001 and 0.0207 respectively (Table 1).

The six membership functions (Triangular and Generalized bell, Gaussian, Trapezoid, Pi etc.) employed were screened on the basis of their RMSE values (Table 6). Triangular membership function (Trimf) was employed for modelling RB5 Z-APL due to the low RMSE values of Training and Testing data (Table 2).

Figure 2 displays the cross plots of experimental and predicted values for RB5 removal onto Z-APL. Notably, the ANFIS model yielded R² value of 1 for RB5 removal onto Z-APL which is an indication of ANFIS predictive ability (Souza et al. 2018). In addition, the cross plot of testing data against the experimental data also gave high correlation coefficient for the selected membership function

Conclusion and Future Perspectives

Our study demonstrates the efficacy of green-synthesized ZnO/*Pupalia lappacea* adsorbent (Z-APL) for removing Reactive Black 5 from wastewater. The hybrid Response Surface Methodology (RSM) and Adaptive Neuro-Fuzzy Inference System (ANFIS) models effectively predicted adsorption behavior, with ANFIS showing exceptional accuracy (R² = 1).

This eco-friendly solution advances UN SDG 6: Clean Water and Sanitation. Future work will focus on scaling up Z-APL's application and exploring its potential for real-world wastewater treatment. This contributes to sustainable water management and a healthier environment. Z-APL shows promise for efficient water purification.