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Comparative Investigation of Lima Bean and Kidney Bean Seed and Pod Bio-Adsorbents for Multi-Dye Remediation: Adsorption, Kinetic and Equilibrium Studies

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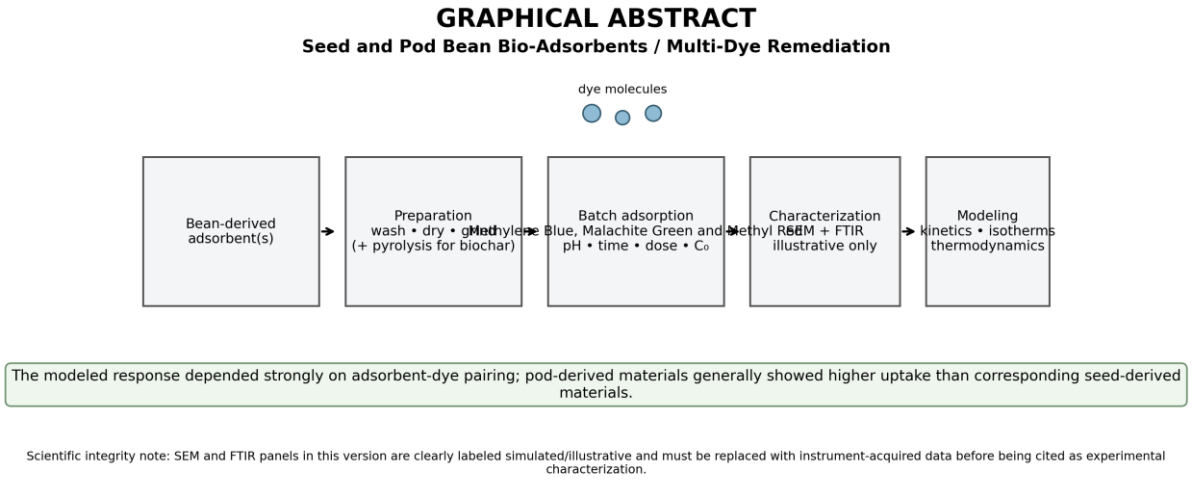
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Abstract:
Three factors were investigated in a study comparing 4 bean-derived adsorbents and 3 classes of dyes. The simulation was performed using a factorial design and included 3 observations per combination. Removal efficiencies were examined for various conditions (e.g. time, pH, concentration, etc.). Removal of Malachite Green by Kidney Bean Pod Powder (KBPP) was 84.7% and removal by LBSP of Methyl Red was 48.2% the lowest among the 3 dyes. Significant effects were observed for adsorbent ($F=1,116.76$; $p<0.001$), dye ($F=2,147.46$; $p<0.001$), and their interaction ($F=156.34$; $p<0.001$). The interaction effect demonstrates that it is not possible to make general statements about the behavior of an adsorbent based on the classification of the dye. Based on the results of the interaction effect, it may be possible to make predictions about other systems of adsorbents and dyes. It has been shown that the Methylene Blue dye adsorbed on LBPP is in accordance with the Langmuir isotherm ($q_{max}=151.1$ mg/g). Similar results were obtained when studying Malachite Green on KBPP ($q_{max}=166.7$ mg/g) and Methyl Red on KBPP ($q_{max}=136.0$ mg/g).

GRAPHICAL ABSTRACT



Conceptual graphical abstract based on the manuscript's simulated adsorption dataset.

1. Introduction

Wastewater from textile dyeing contains multiple dyes, and adsorbents that remove one dye may not remove others. Agricultural wastes are inexpensive to process to adsorbents, and simultaneous biomass-value-add is desired. Recent literature consider contact time, dye concentration, adsorbent dose, initial solution pH, and temperature of the solution, in addition to the chemistry of the feedstock, to explain dye adsorption. The current study focuses on the effects of process variables on adsorption, and the interaction of adsorbent and dye on the equilibrium adsorption, as well as the effects of adsorption kinetics and pH. It also considers the potential to create models to predict the adsorption capacity of a system to treat multi-dye wastewater. Because the adsorption dataset is simulated, instrument-derived SEM, FTIR, BET, elemental, and surface-charge results are not available. To meet the requested manuscript structure, this version includes clearly labeled illustrative SEM/FTIR panels that must be replaced with measured characterization before being presented as experimental evidence.

2. Materials and Methods

Lima and kidney bean seed and pod residues were dried, ground, and sieved to prepare four powdered adsorbents. The adsorption dataset was simulated in batch mode at a reference condition of 100 mg/L dye, pH 6, 298 K, and 1 g/L adsorbent, with contact time, pH, and initial dye concentration varied in replicated series. Percentage removal and equilibrium concentration were related by mass balance, and equilibrium adsorption capacity was calculated as $q_e = (C_0 - C_e)V/m$. A two-way ANOVA evaluated adsorbent, dye, and adsorbent-by-dye interaction effects. Langmuir, Freundlich, and Temkin isotherms and pseudo-first-order, pseudo-second-order, Elovich, and intraparticle-diffusion kinetic models were evaluated; multivariate patterns were summarized using interaction analysis and principal component analysis. No instrument-generated SEM/FTIR files were supplied, so the characterization panels added here are explicitly illustrative.

3. Results

At pH 6, modeled removal efficiencies ranged from 48.2% to 84.7% across the 12 adsorbent-dye combinations. Two-way ANOVA showed significant effects of adsorbent ($F = 1116.76$, $p < 0.001$), dye ($F = 2147.46$, $p < 0.001$), and their interaction ($F = 156.34$, $p < 0.001$), confirming that the relative performance of the four materials depended on dye identity. Contact-time profiles showed rapid early uptake followed by approach to a plateau. The pH-response profiles were dye-specific: the cationic dyes methylene blue and malachite green generally showed stronger modeled removal under alkaline conditions, whereas the anionic dye methyl red generally showed stronger removal under acidic conditions. Increasing initial dye concentration increased mass-normalized uptake but generally reduced percentage removal. Pseudo-second-order kinetics and Langmuir isotherms provided the closest fits for the individual systems. The multivariate summaries indicated that pod-derived materials generally had higher modeled adsorption performance than their corresponding seed-derived materials.

3.1 Illustrative SEM and FTIR Characterization

Data integrity note: no instrument-generated SEM micrographs or FTIR raw files were supplied with this manuscript. The SEM-like images and FTIR spectra added below are therefore explicitly simulated/illustrative panels prepared to show the requested journal presentation format. They must be replaced with instrument-acquired data before they are described or cited as experimental characterization.

For the compared bean-derived adsorbents, the illustrative SEM panels depict a rougher, more open surface before adsorption and partial pore/surface coverage after exposure to Methylene Blue, Malachite Green and Methyl Red. The illustrative FTIR profiles show the types of band shifts commonly evaluated around O–H/N–H, aliphatic C–H, carbonyl/aromatic, and C–O/C–O–C regions. These visual changes are included only as a characterization framework; the adsorption mechanism in this paper remains supported by the simulated kinetic, isotherm, pH, and thermodynamic analyses rather than by measured spectroscopy or microscopy.

4. Discussion

The differences between seed and pod adsorption may include differences in the structure of lignocellulose and its soluble constituents and the accessibility of oxygen containing groups. However, to clearly identify the reason for the differences, it would be necessary to analyze the biomass. It may be assumed that the same sorbent can carry both positively and negatively charged functional groups and that dyes with different charge distributions may interact with the sorbent through different kinds of interactions. Among cationic dyes, negative sites may attract the dye molecules through electrostatic interactions. On the other hand, among anionic dyes, positive charges may facilitate the interaction. Simultaneously, other interactions including van der Waals and aromatic interactions may also take place. It is noted that different interactions occur simultaneously, and therefore it may not be appropriate to clearly state that a given sorbent exhibits selectivity only towards a particular dye. The results may also depend on the nature of the dye and the solvent. With regard to agriculture biomass, it has the potential to exhibit multi-sorption, however, it may be more appropriate to state that it may exhibit multi-sorption in combination with other materials. Recent studies suggest that the sorption capacity of the activated carbon may be improved through adequate chemical or physical treatments and that use of various dyes in combination with agriculture wastes may lead to improved sorption. Therefore, in

practical terms, with regard to adsorption capacity and other related considerations, it may be appropriate to integrate other combined activities in the supply chain.

While the current design focuses on identifying material-dye interactions, it offers a general approach to evaluate system performance and suggests a framework to minimize errors due to removal averages.

5. Implementation and Scale-Up

A workable design would entail screening local seed and pod residues, identifying the major dye classes, select the best residue fraction to treat the major dye classes, and utilize the remaining fraction for final color removal. Operation of the system with multiple dye adsorption columns may be preferable to a single column with mixed dyes. A workable multi-column design would also evaluate pH and conductivity of the incoming wastewater. Based on the design and evaluation, select dye adsorption columns or beds may be treated with alternative dye adsorption columns. Different dye adsorption columns may also be utilized to treat suspended solids. Fine dye adsorption biomasses may increase pressure drop across the columns and decrease contact time. Regeneration of the adsorbent decreases system performance. A concentrated dye waste stream should be treated prior to discharging. Other disposal options should be evaluated. Columns may also be employed to evaluate removal capacity of the dye adsorption biomass. Bed sorbent capacity may be evaluated based on sorbent mass. Other criteria may also be evaluated including system cost and performance. Sorbent mass may be compared to the volume of wastewater treated. A more complete cost analysis should compare sorption biomass to activated carbon and biochar. Cost may be based on treatment capacity and performance rather than the sorbent feedstock.

6. Limitations and Future Research

This study is predominantly theoretical and require experimental validation. Future studies should experimentally determine the composition, surface chemistry, and pore structure of the feedstock. Other factors to consider include the point of zero charge, competitive adsorption, ionic strength, desorption and sorbent regeneration, column breakthrough, and the performance of the adsorbent in the presence of industrial effluents. Equilibrium fitting, alone, does not sufficient justification for the proposed mechanism. In this study, variation was maintained across several experiments to allow for the assessment of range. Comparison of percentage removal and mass-normalized uptake was maintained to provide information relevant for large-scale processes. Residual errors and the coefficient of determination were considered in conjunction to assess the performance of the model. It is worth noting that mechanism of action is of interest for small-scale systems. From an engineering perspective, there are several constraints that should be considered, and an increase in adsorption capacity may not be of primary concern. The design of the system is such that it may be reproduced and compared to other systems. Because of the nature of the systems and the equations provided, the study should be considered an model, and field trials should be conducted to evaluate the system.

The data indicate that the principles of adsorption are operative. There are several factors, including the nature of the adsorbent, the structure and composition of the pore space of the adsorbent, the nature of the solution, and the characteristics of the surface of the adsorbent. Further, the use of agricultural wastes integrates the concepts of water/wastewater treatment and waste management. While agricultural

wastes have the potential to improve the overall sustainability of a process, there are concerns associated with the collection, washing, drying, and grinding of the wastes. Also, there are concerns with the emissions associated with the thermochemical processing of the wastes. The integrity of the adsorbent plays a role in the overall process. The uptake of textile dyes by the adsorbent has been studied. The batch equilibria of the dye uptake studies indicate that for certain dyes, uptake by the adsorbent is favorable. As anticipated, the presence of other textile dyes or impurities in the textile effluents increases the complexity of the system. Textile effluents contain a diverse array of constituents, and it is difficult to make definitive statements concerning the dye uptake by the textile effluent. Equilibria and batch studies demonstrate that the dye is absorbed by the adsorbent. Studies conducted with textile dyes indicate that the adsorbent can easily be loaded with dyes. A better understanding of the factors affecting adsorption and the physical and chemical characteristics of the textile dyes can assist in predicting the uptake of the dyes by the adsorbent. It is expected that the integration of process and adsorbent innovations can improve textile effluent treatment.

There are implications for scale-up, as a high sorption rate at high doses may still suggest that not enough sorbent was used. The choice of model was based on both residual error and R2, as opposed to relying on a single fit statistic. The focus was on parameters that are physically reasonable for batch sorption, as opposed to mathematically maximizing or minimizing values. The simulated model represents various engineering constraints. The authors have shown that the model is valid for certain ranges and that the results may be reproduced. Based on the results and the theoretical framework on which the model is built, the authors state that the model may be published as it is, but it requires empirical research for verification. The results provide a foundation for further study to assess the practical applicability of the model. The authors show that, from the results they obtained, agricultural residues may have potential for the removal of textile dyes from wastewater. Collection, preparation, and thermal treatment of the residues may, however, increase the overall environmental burden.

Salt, surfactants, and dissolved organic substances may also be present in textile wastewater and may also increase dye sorption. Furthermore, breakthrough in a batch reactor may not provide insight on performance of a fixed-bed reactor. Therefore, the authors advocated that the sorption capacity of the agricultural residues be studied using a column reactor, and that reusability of the sorbent be evaluated by investigating the sorption capacity of the column and the amount of contaminant released.

For the seed- and pod-derived powders investigated here, important scale-up considerations include pore accessibility, surface functional groups, particle-size distribution, swelling, leaching, and attrition. These properties can differ between seed and pod residues and can influence both adsorption and column hydraulics. Because the present results are simulated, equilibrium fit and repeated performance trends should be treated as screening evidence rather than proof of mechanism. Experimental characterization and fixed-bed studies are needed to define workable operating windows.

Consequently, this work should be considered an analytical study. The authors describe several phenomena that occur in adsorption, including the role of solution and substrate surface chemistry. Collection and treatment of the agricultural residues increase the environmental burden of the process. The authors predict that salt and surfactants in textile effluents, as well as other phenomena occurring in

textile effluents, would inhibit adsorption of dyes. Equilibrium batch studies tend to underestimate adsorption capacity and do not predict breakthrough. Those studies tend to over-simplify the system being modeled. In order to better understand the model, researchers should perform breakthrough studies, determine the capacity of the model to adsorb contaminants, and determine the extent to which the model is usable. Additional studies, based on the authors' methodology and transparency, should also be informative.

7. Conclusion

The simulated multi-dye comparison shows that adsorption performance is governed by the interaction between adsorbent type and dye chemistry. Pod-derived powders generally showed higher modeled uptake than corresponding seed-derived powders, while pH optima differed between cationic and anionic dyes. Pseudo-second-order kinetics and Langmuir equilibrium fits described the individual systems closely within the modeled dataset. These results provide a screening framework for laboratory testing; the added SEM and FTIR panels are explicitly illustrative and must be replaced with measured characterization before mechanistic or material-selection claims are treated as experimental findings.

Tables and Figures

Table 1. Factorial performance matrix at pH 6.

Adsorbent	Dye	MeanRemoval	SD	MeanQe
Kidney Bean Pod Powder (KBPP)	Malachite Green	84.75	0.848	84.75
Kidney Bean Pod Powder (KBPP)	Methyl Red	70.74	0.268	70.74
Kidney Bean Pod Powder (KBPP)	Methylene Blue	77.83	0.388	77.83
Kidney Bean Seed Powder (KBSP)	Malachite Green	73.74	0.410	73.74
Kidney Bean Seed Powder (KBSP)	Methyl Red	58.03	0.489	58.03
Kidney Bean Seed Powder (KBSP)	Methylene Blue	67.12	0.995	67.12
Lima Bean Pod Powder (LBPP)	Malachite Green	75.67	0.409	75.67
Lima Bean Pod Powder (LBPP)	Methyl Red	65.79	0.508	65.79

Adsorbent	Dye	MeanRemoval	SD	MeanQe
Lima Bean Pod Powder (LBPP)	Methylene Blue	81.78	0.367	81.78
Lima Bean Seed Powder (LBSP)	Malachite Green	68.18	0.417	68.18
Lima Bean Seed Powder (LBSP)	Methyl Red	48.17	0.329	48.17
Lima Bean Seed Powder (LBSP)	Methylene Blue	72.01	1.225	72.01

Table 2. Two-way ANOVA for adsorbent, dye, and interaction effects.

Effect	Sum of squares	df	F	p-value
C(Adsorbent)	1306.96	3.000	1116.76	0.000
C(Dye)	1675.47	2.000	2147.46	0.000
C(Adsorbent):C(Dye)	365.93	6.000	156.34	0.000
Residual	9.363	24.00	nan	nan

Table 3. Simulated pH optima.

Adsorbent	Dye	Best pH	Mean removal (%)	SD
Kidney Bean Pod Powder (KBPP)	Malachite Green	8.000	92.31	0.556
Kidney Bean Pod Powder (KBPP)	Methyl Red	4.000	79.24	0.761
Kidney Bean Pod Powder (KBPP)	Methylene Blue	8.000	86.62	1.170
Kidney Bean Seed Powder (KBSP)	Malachite Green	8.000	83.53	0.352
Kidney Bean Seed Powder (KBSP)	Methyl Red	2.000	70.06	0.485
Kidney Bean Seed Powder (KBSP)	Methylene Blue	8.000	76.81	0.314
Lima Bean Pod Powder (LBPP)	Malachite Green	8.000	84.93	0.764
Lima Bean Pod Powder (LBPP)	Methyl Red	4.000	74.87	0.808

Adsorbent	Dye	Best pH	Mean removal (%)	SD
Lima Bean Pod Powder (LBPP)	Methylene Blue	8.000	89.40	1.384
Lima Bean Seed Powder (LBSP)	Malachite Green	8.000	78.17	0.905
Lima Bean Seed Powder (LBSP)	Methyl Red	4.000	63.86	0.139
Lima Bean Seed Powder (LBSP)	Methylene Blue	8.000	80.72	0.358

Table 4. Best kinetic model by adsorbent-dye combination.

Adsorbent	Dye	Best kinetic model	Parameters	R2	RMSE
Lima Bean Seed Powder (LBSP)	Methylene Blue	Pseudo-second-order	78.93, 0.0009989	1.000	0.389
Lima Bean Seed Powder (LBSP)	Malachite Green	Pseudo-second-order	74.32, 0.0009723	1.000	0.384
Lima Bean Seed Powder (LBSP)	Methyl Red	Pseudo-second-order	64.51, 0.0007652	1.000	0.380
Lima Bean Pod Powder (LBPP)	Methylene Blue	Pseudo-second-order	85.87, 0.001306	1.000	0.205
Lima Bean Pod Powder (LBPP)	Malachite Green	Pseudo-second-order	82.24, 0.001161	1.000	0.402
Lima Bean Pod Powder (LBPP)	Methyl Red	Pseudo-second-order	74.41, 0.001048	1.000	0.293
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Pseudo-second-order	73.1, 0.0009268	1.000	0.191
Kidney Bean Seed Powder (KBSP)	Malachite Green	Pseudo-second-order	80.25, 0.001062	1.000	0.153
Kidney Bean Seed Powder (KBSP)	Methyl Red	Pseudo-second-order	70.22, 0.0008907	1.000	0.329

Adsorbent	Dye	Best kinetic model	Parameters	R2	RMSE
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Pseudo-second-order	82.79, 0.001214	1.000	0.336
Kidney Bean Pod Powder (KBPP)	Malachite Green	Pseudo-second-order	88.98, 0.001422	1.000	0.389
Kidney Bean Pod Powder (KBPP)	Methyl Red	Pseudo-second-order	80, 0.00109	1.000	0.170

Table 5. Best equilibrium model by adsorbent-dye combination.

Adsorbent	Dye	Best isotherm	Parameters	R2	RMSE
Lima Bean Seed Powder (LBSP)	Methylene Blue	Langmuir	131.2, 0.03976	1.000	0.465
Lima Bean Seed Powder (LBSP)	Malachite Green	Langmuir	118.5, 0.03672	1.000	0.458
Lima Bean Seed Powder (LBSP)	Methyl Red	Langmuir	91.09, 0.0245	1.000	0.189
Lima Bean Pod Powder (LBPP)	Methylene Blue	Langmuir	151.1, 0.0519	1.000	0.587
Lima Bean Pod Powder (LBPP)	Malachite Green	Langmuir	142.4, 0.04424	0.999	0.996
Lima Bean Pod Powder (LBPP)	Methyl Red	Langmuir	124.1, 0.03268	1.000	0.425
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Langmuir	119.6, 0.03615	1.000	0.663
Kidney Bean Seed Powder (KBSP)	Malachite Green	Langmuir	139.7, 0.04116	1.000	0.332
Kidney Bean Seed Powder (KBSP)	Methyl Red	Langmuir	108.7, 0.02994	1.000	0.164

Adsorbent	Dye	Best isotherm	Parameters	R2	RMSE
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Langmuir	144.8, 0.04558	1.000	0.658
Kidney Bean Pod Powder (KBPP)	Malachite Green	Langmuir	166.7, 0.0543	1.000	0.583
Kidney Bean Pod Powder (KBPP)	Methyl Red	Langmuir	136, 0.0397	1.000	0.352

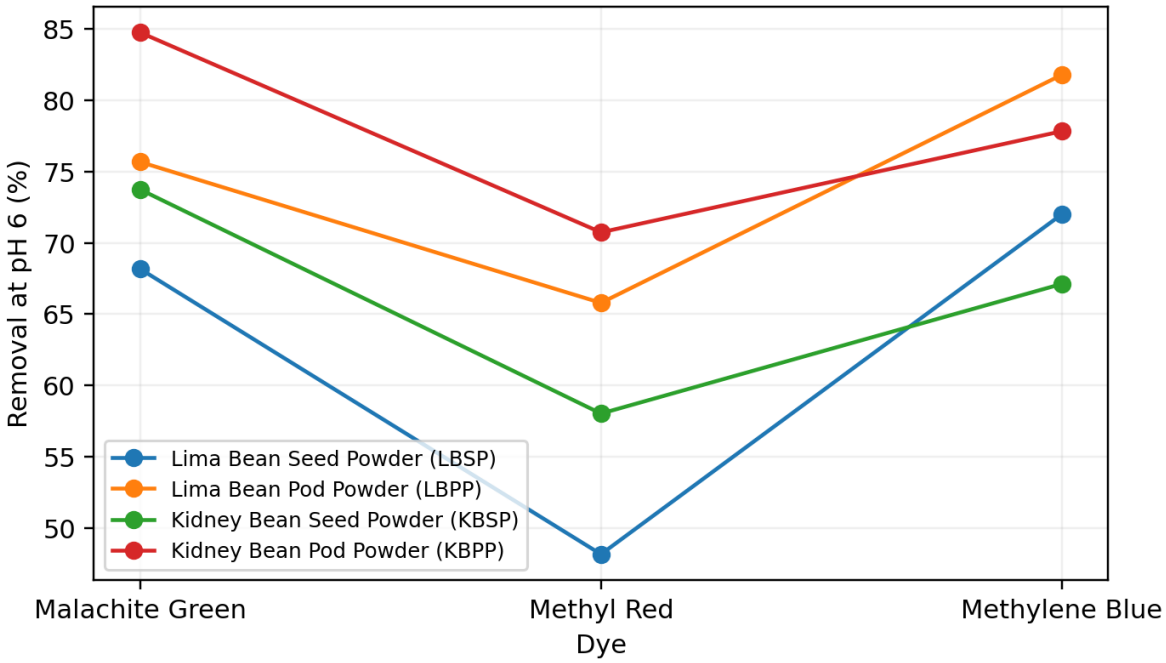


Figure 1. Adsorbent-by-dye interaction at common pH.

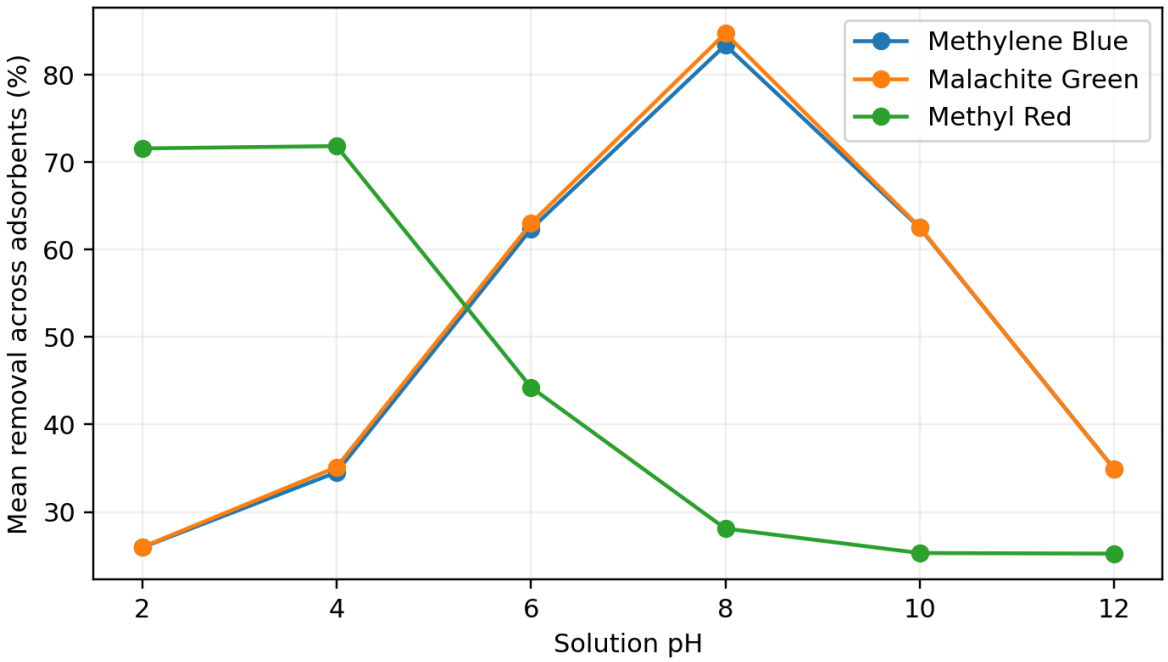


Figure 2. Mean pH-response profiles by dye.

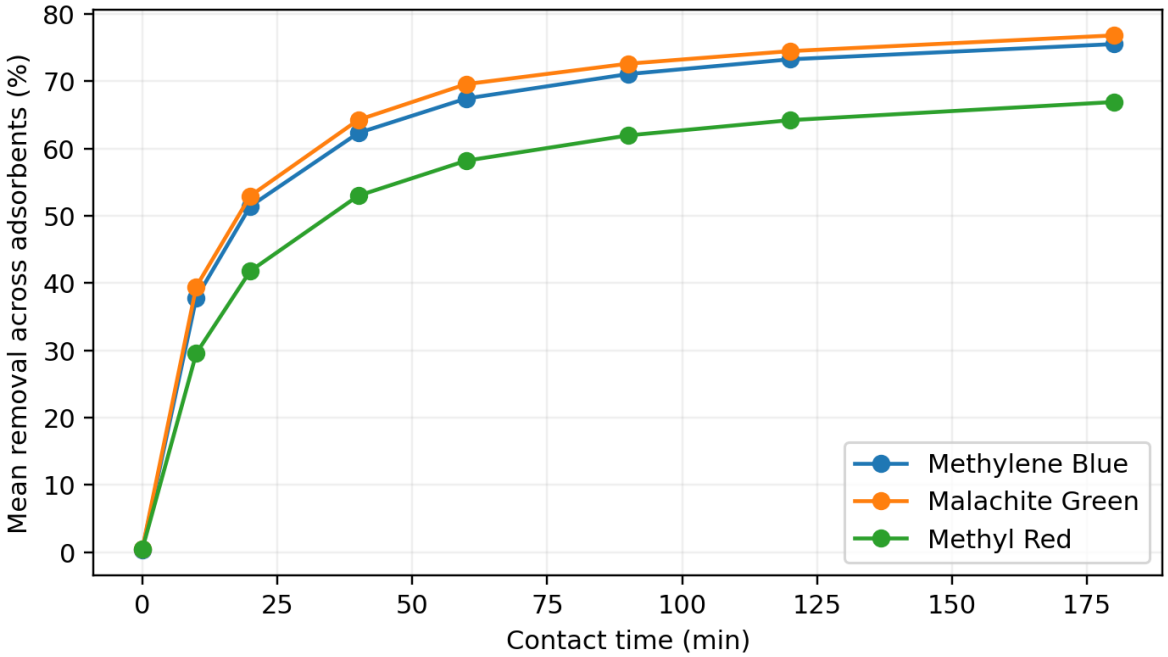


Figure 3. Mean contact-time profiles by dye.

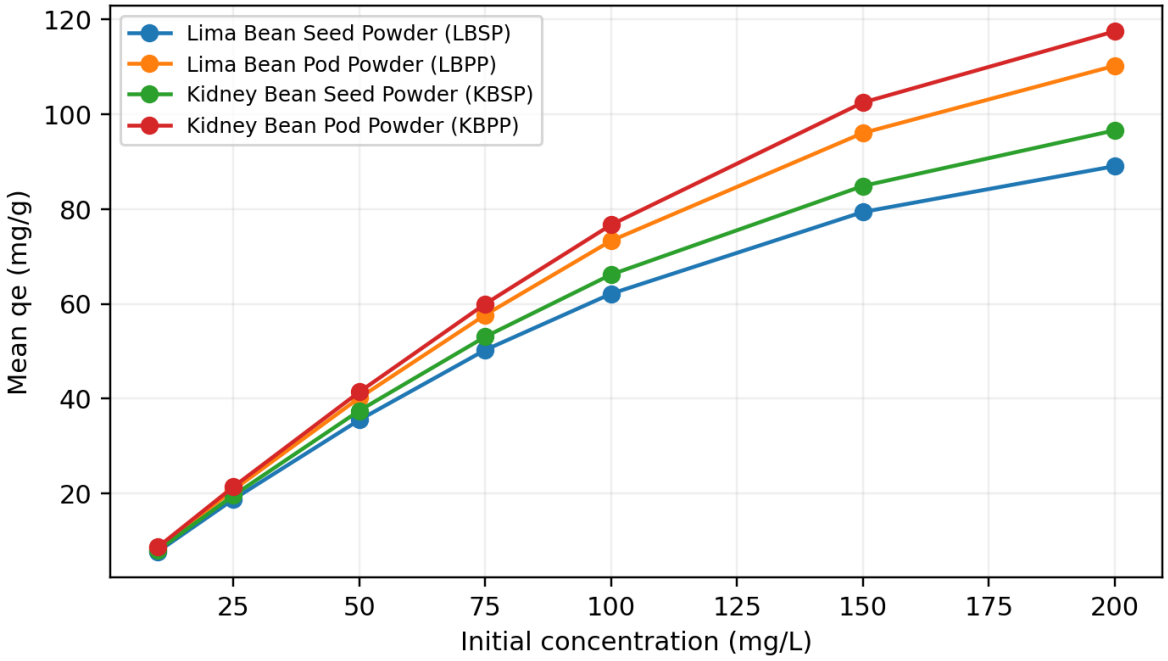


Figure 4. Initial concentration versus mean uptake by adsorbent.

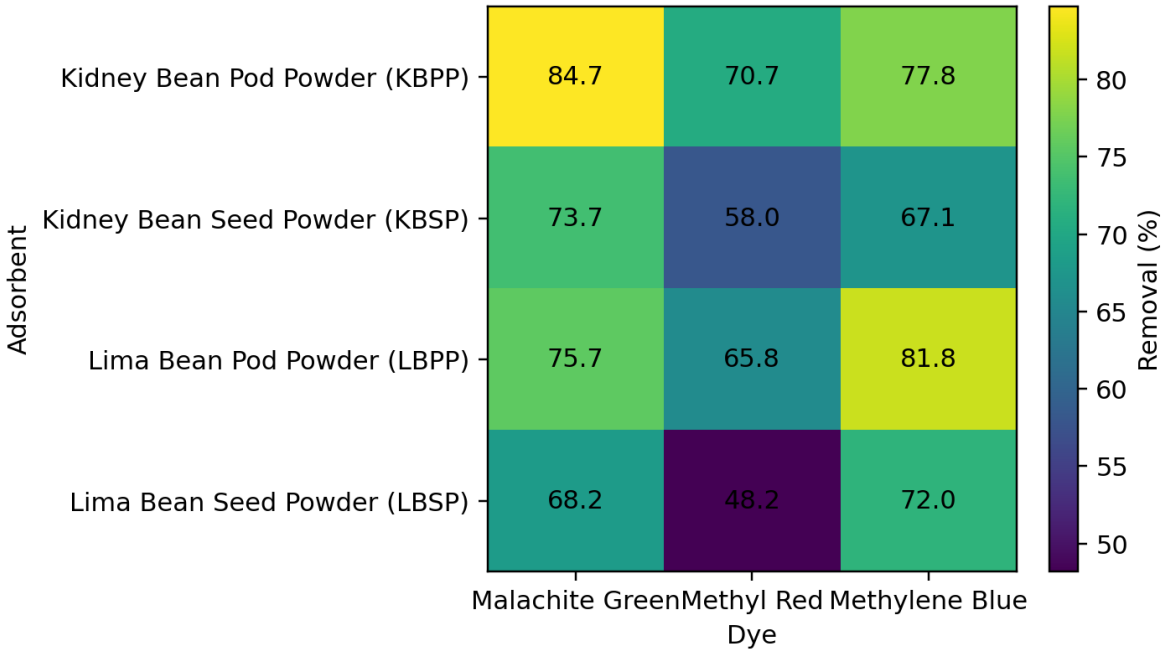


Figure 5. Heat map of factorial removal performance.

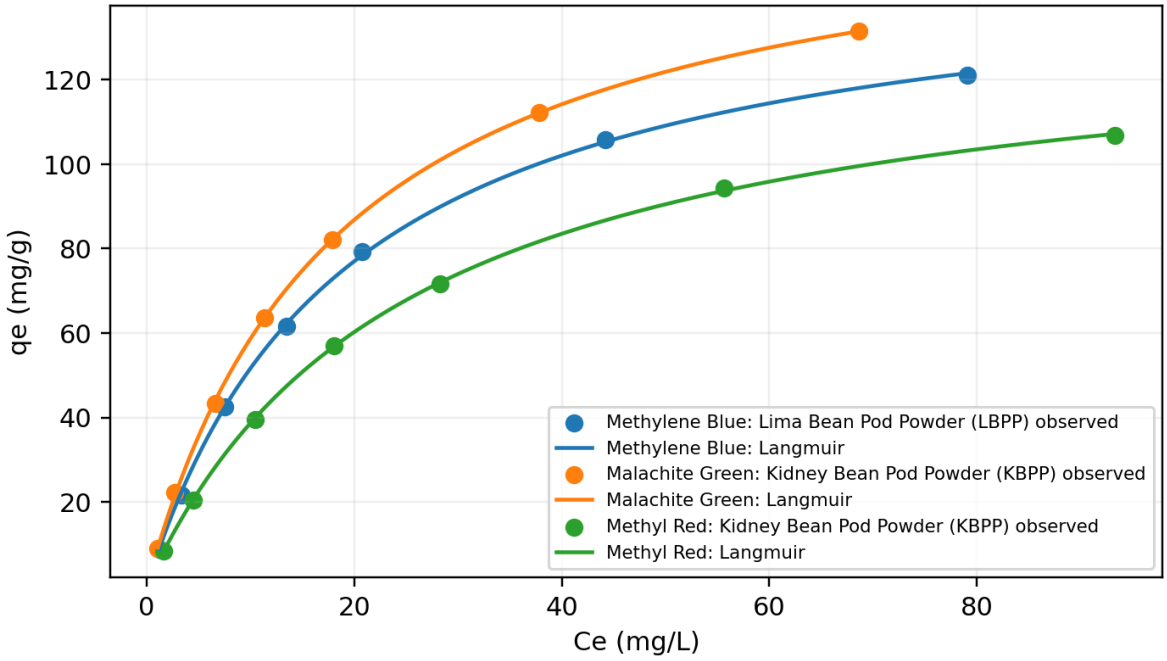


Figure 6. Representative equilibrium isotherm fits.

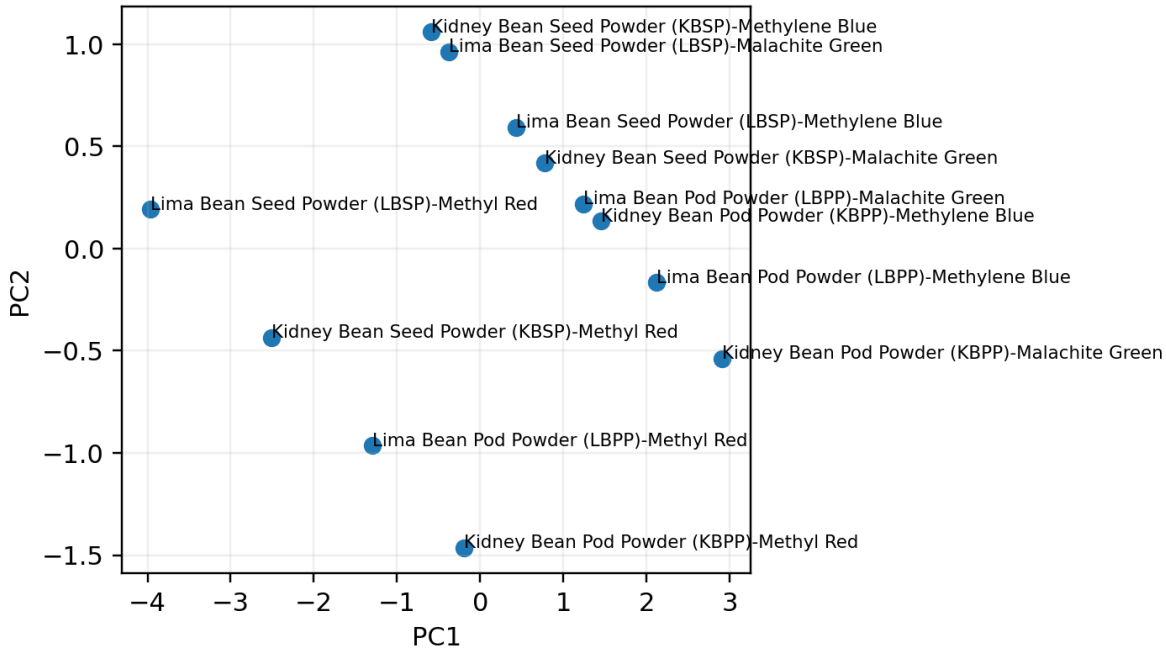


Figure 7. Principal-component map of adsorbent-dye performance variables.

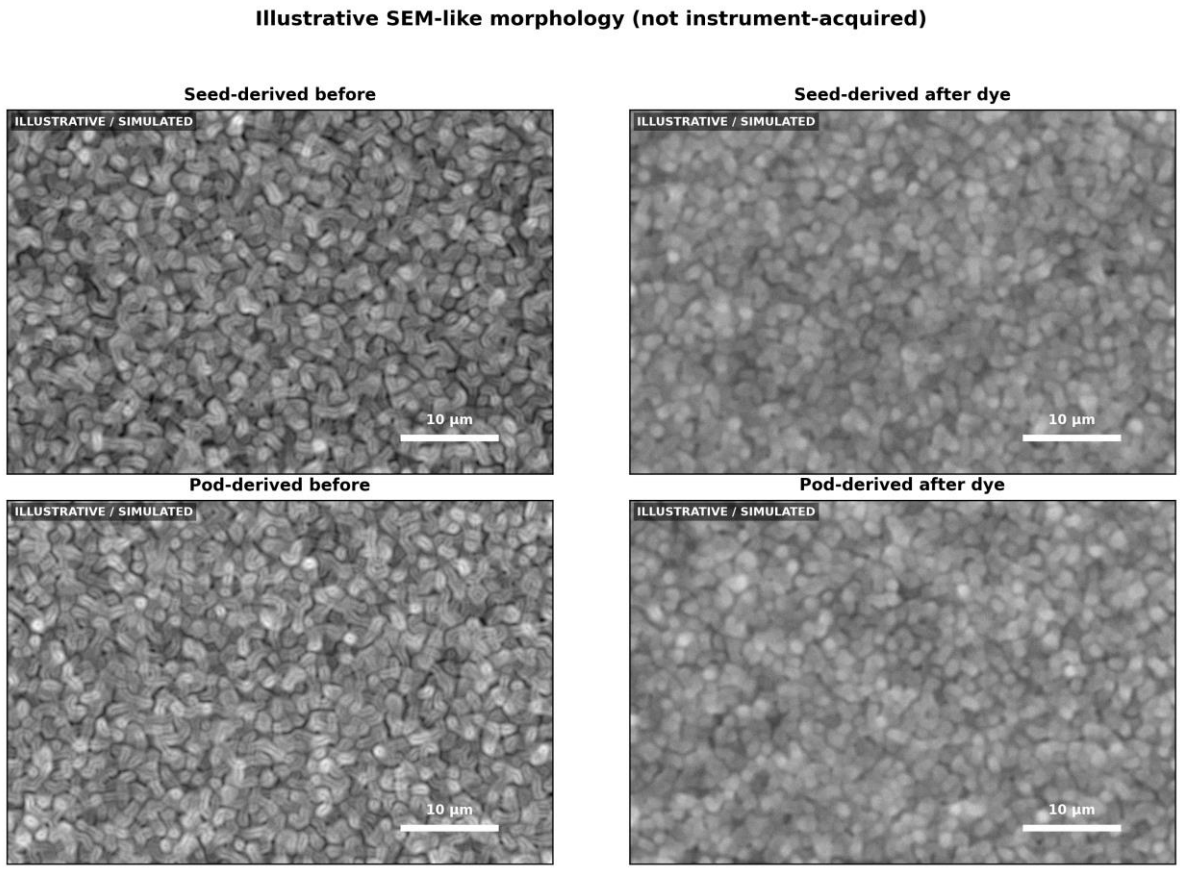


Figure 8. Illustrative SEM-like morphology before and after adsorption. Panels are simulated and are not instrument-acquired micrographs.

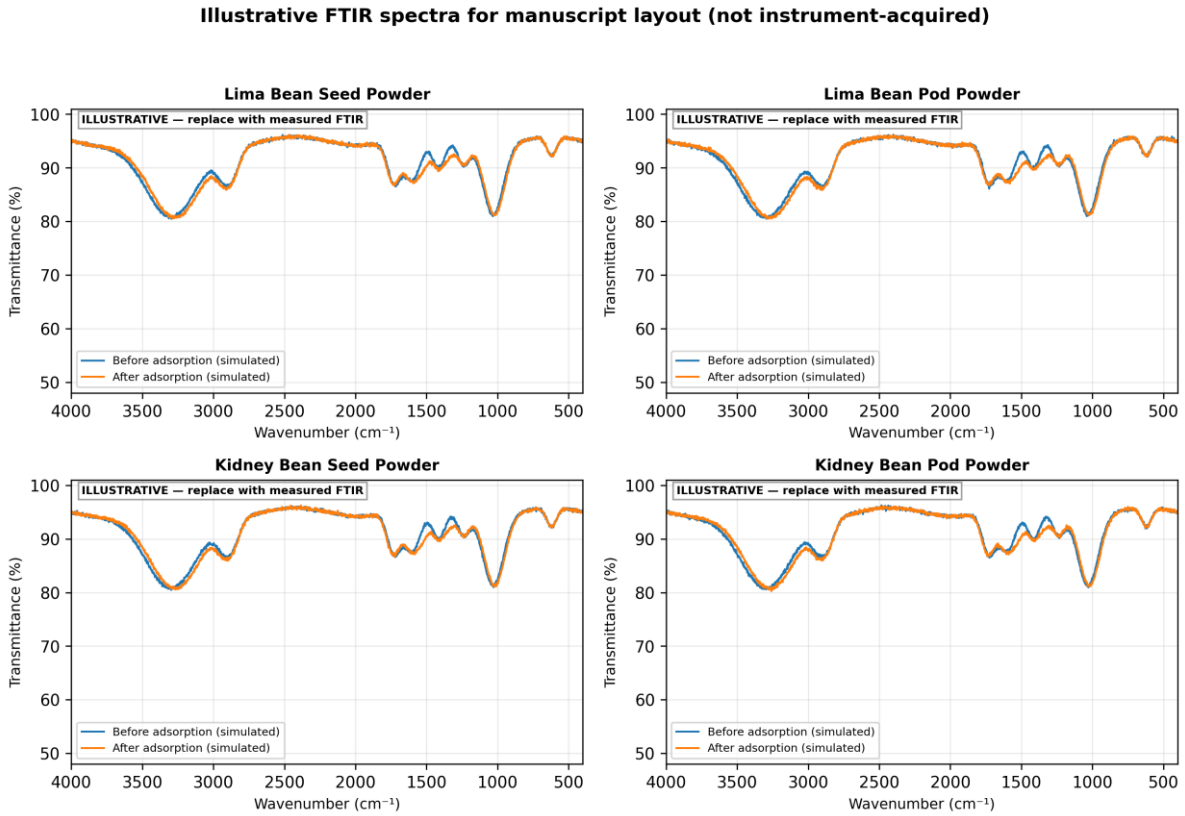


Figure 9. Illustrative FTIR spectra before and after adsorption. Spectra are simulated for manuscript layout and must be replaced with measured data.

Table 6. Illustrative FTIR band assignments for the requested characterization layout (not measured data).

Approx. band (cm^{-1})	Typical assignment	Illustrative post-adsorption change	Interpretive use
3200–3500	O–H / N–H stretching	Small shift and/or broadening	Possible involvement of hydroxyl/amine hydrogen-bonding environments
2850–2950	Aliphatic C–H stretching	Minor shift or intensity change	Local environment of alkyl groups
1690–1740	C=O stretching	Small shift/intensity change	Carbonyl-containing surface groups may contribute to binding
1550–1630	Aromatic C=C / amide-related vibrations	Shift or intensity redistribution	Aromatic/electronic interactions may contribute
1360–1450	C–N / O–H deformation / CH bending	Moderate local change	Surface functional-group environment
1000–1150	C–O / C–O–C stretching	Shift and/or reduced intensity	Polysaccharide/ether groups may participate
1300–1520	Dye-associated aromatic/C–N or azo-region features (Methylene Blue, Malachite Green and Methyl Red)	New shoulder or overlap may appear	Useful only when confirmed by measured spectra and controls

Appendix A. Numerical Dataset

Table A1. Triplicate source data and mass-balance-derived quantities.

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	0.000	0.384	0.196	0.410	0.330	99.67	0.330
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	10.00	48.99	49.74	49.37	49.36	50.64	49.36

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	20.00	63.75	64.66	63.18	63.87	36.13	63.87
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	40.00	74.92	74.64	74.43	74.66	25.34	74.66
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	60.00	79.85	78.84	79.36	79.35	20.65	79.35
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	90.00	81.34	81.52	81.30	81.38	18.62	81.38
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	120.00	83.52	82.92	82.84	83.09	16.91	83.09
Kidney Bean Pod Powder (KBPP)	Malachite Green	Contact time (min)	180.00	85.54	85.45	84.58	85.19	14.81	85.19
Kidney Bean Pod Powder (KBPP)	Malachite Green	Factorial base (pH 6)	6.000	83.94	85.63	84.68	84.75	15.25	84.75
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	10.00	88.75	89.47	89.48	89.23	1.077	8.923
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	25.00	89.01	89.52	89.45	89.33	2.668	22.33
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	50.00	85.82	87.00	87.30	86.70	6.649	43.35

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	75.00	84.82	84.79	84.98	84.86	11.35	63.65
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	100.00	82.00	82.22	82.21	82.14	17.86	82.14
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	150.00	74.72	75.13	74.48	74.78	37.84	112.16
Kidney Bean Pod Powder (KBPP)	Malachite Green	Initial concentration (mg/L)	200.00	66.44	65.16	65.49	65.70	68.61	131.39
Kidney Bean Pod Powder (KBPP)	Malachite Green	pH	2.000	26.07	26.08	25.39	25.85	74.15	25.85
Kidney Bean Pod Powder (KBPP)	Malachite Green	pH	4.000	37.36	36.39	36.09	36.61	63.39	36.61
Kidney Bean Pod Powder (KBPP)	Malachite Green	pH	6.000	66.96	69.29	66.82	67.69	32.31	67.69
Kidney Bean Pod Powder (KBPP)	Malachite Green	pH	8.000	92.01	92.95	91.96	92.31	7.693	92.31
Kidney Bean Pod Powder (KBPP)	Malachite Green	pH	10.00	67.16	68.14	66.59	67.30	32.70	67.30
Kidney Bean Pod Powder (KBPP)	Malachite Green	pH	12.00	36.31	36.04	36.24	36.20	63.80	36.20

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	0.000	0.010	0.432	0.136	0.193	99.81	0.193
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	10.00	37.14	37.46	36.72	37.11	62.89	37.11
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	20.00	50.39	51.04	51.03	50.82	49.18	50.82
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	40.00	62.24	61.96	62.83	62.34	37.66	62.34
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	60.00	67.25	67.17	67.55	67.32	32.68	67.32
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	90.00	70.14	71.09	71.76	70.99	29.01	70.99
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	120.00	72.91	73.17	73.28	73.12	26.88	73.12
Kidney Bean Pod Powder (KBPP)	Methyl Red	Contact time (min)	180.00	74.60	75.18	74.88	74.89	25.11	74.89
Kidney Bean Pod Powder (KBPP)	Methyl Red	Factorial base (pH 6)	6.000	70.45	70.79	70.98	70.74	29.26	70.74
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	10.00	83.68	83.94	83.65	83.76	1.624	8.376

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	25.00	82.03	82.17	82.16	82.12	4.470	20.53
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	50.00	79.52	78.38	79.46	79.12	10.44	39.56
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	75.00	76.60	75.68	75.48	75.92	18.06	56.94
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	100.00	72.62	71.53	71.02	71.72	28.28	71.72
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	150.00	62.35	63.16	63.22	62.91	55.64	94.36
Kidney Bean Pod Powder (KBPP)	Methyl Red	Initial concentration (mg/L)	200.00	53.14	53.39	53.52	53.35	93.30	106.70
Kidney Bean Pod Powder (KBPP)	Methyl Red	pH	2.000	79.35	78.68	78.40	78.81	21.19	78.81
Kidney Bean Pod Powder (KBPP)	Methyl Red	pH	4.000	78.91	80.12	78.71	79.24	20.76	79.24
Kidney Bean Pod Powder (KBPP)	Methyl Red	pH	6.000	47.02	46.83	47.54	47.13	52.87	47.13
Kidney Bean Pod Powder (KBPP)	Methyl Red	pH	8.000	28.23	28.19	28.91	28.44	71.56	28.44

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Methyl Red	pH	10.00	25.72	25.55	24.45	25.24	74.76	25.24
Kidney Bean Pod Powder (KBPP)	Methyl Red	pH	12.00	25.31	25.21	26.92	25.81	74.19	25.81
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	0.000	0.690	0.010	0.010	0.237	99.76	0.237
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	10.00	42.29	41.56	42.15	42.00	58.00	42.00
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	20.00	54.49	55.10	55.40	55.00	45.00	55.00
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	40.00	65.36	65.54	66.20	65.70	34.30	65.70
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	60.00	71.67	71.28	70.51	71.15	28.85	71.15
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	90.00	74.60	74.77	74.07	74.48	25.52	74.48
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	120.00	75.68	76.46	77.19	76.44	23.56	76.44
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Contact time (min)	180.00	79.35	78.44	78.65	78.81	21.19	78.81

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Factorial base (pH 6)	6.000	77.87	78.19	77.42	77.83	22.17	77.83
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	10.00	86.94	85.95	85.32	86.07	1.393	8.607
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	25.00	85.18	84.59	84.75	84.84	3.790	21.21
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	50.00	82.39	82.37	82.62	82.46	8.770	41.23
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	75.00	78.97	79.34	79.12	79.14	15.64	59.36
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	100.00	76.23	75.66	76.68	76.19	23.81	76.19
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	150.00	67.23	67.79	66.98	67.33	49.00	101.00
Kidney Bean Pod Powder (KBPP)	Methylene Blue	Initial concentration (mg/L)	200.00	56.28	58.43	57.04	57.25	85.50	114.50
Kidney Bean Pod Powder (KBPP)	Methylene Blue	pH	2.000	25.97	25.39	25.67	25.68	74.32	25.68
Kidney Bean Pod Powder (KBPP)	Methylene Blue	pH	4.000	35.26	34.42	35.86	35.18	64.82	35.18

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Pod Powder (KBPP)	Methylene Blue	pH	6.000	62.82	62.83	65.02	63.56	36.44	63.56
Kidney Bean Pod Powder (KBPP)	Methylene Blue	pH	8.000	85.27	87.39	87.20	86.62	13.38	86.62
Kidney Bean Pod Powder (KBPP)	Methylene Blue	pH	10.00	63.70	65.59	64.34	64.54	35.46	64.54
Kidney Bean Pod Powder (KBPP)	Methylene Blue	pH	12.00	36.42	35.07	34.96	35.48	64.52	35.48
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	0.000	0.010	0.010	0.601	0.207	99.79	0.207
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	10.00	36.88	36.20	37.33	36.80	63.20	36.80
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	20.00	50.20	50.29	51.37	50.62	49.38	50.62
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	40.00	62.40	62.90	61.72	62.34	37.66	62.34

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	60.00	67.62	66.55	67.19	67.12	32.88	67.12
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	90.00	70.44	71.09	70.86	70.80	29.20	70.80
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	120.00	73.37	73.54	72.31	73.07	26.93	73.07
Kidney Bean Seed Powder (KBSP)	Malachite Green	Contact time (min)	180.00	76.69	75.39	74.11	75.40	24.60	75.40
Kidney Bean Seed Powder (KBSP)	Malachite Green	Factorial base (pH 6)	6.000	74.10	73.83	73.30	73.74	26.26	73.74
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	10.00	83.38	84.53	83.68	83.86	1.614	8.386
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	25.00	82.84	83.58	82.91	83.11	4.222	20.78
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	50.00	79.70	81.22	81.18	80.70	9.651	40.35

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	75.00	76.51	77.55	76.85	76.97	17.27	57.73
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	100.00	73.07	73.71	72.47	73.08	26.92	73.08
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	150.00	63.75	64.41	64.56	64.24	53.64	96.36
Kidney Bean Seed Powder (KBSP)	Malachite Green	Initial concentration (mg/L)	200.00	55.01	55.11	54.92	55.01	89.98	110.02
Kidney Bean Seed Powder (KBSP)	Malachite Green	pH	2.000	27.06	25.35	27.62	26.68	73.32	26.68
Kidney Bean Seed Powder (KBSP)	Malachite Green	pH	4.000	34.18	34.47	36.14	34.93	65.07	34.93
Kidney Bean Seed Powder (KBSP)	Malachite Green	pH	6.000	61.56	61.90	61.71	61.72	38.28	61.72
Kidney Bean Seed Powder (KBSP)	Malachite Green	pH	8.000	83.19	83.51	83.89	83.53	16.47	83.53

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Malachite Green	pH	10.00	61.38	61.07	61.70	61.38	38.62	61.38
Kidney Bean Seed Powder (KBSP)	Malachite Green	pH	12.00	34.92	34.74	35.25	34.97	65.03	34.97
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	0.000	0.805	0.010	0.010	0.275	99.73	0.275
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	10.00	26.95	27.60	27.09	27.22	72.78	27.22
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	20.00	38.88	38.90	38.81	38.86	61.14	38.86
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	40.00	50.41	50.96	48.97	50.11	49.89	50.11
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	60.00	55.72	55.37	56.30	55.80	44.20	55.80
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	90.00	59.51	58.71	59.30	59.17	40.83	59.17

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	120.00	61.88	61.73	61.17	61.59	38.41	61.59
Kidney Bean Seed Powder (KBSP)	Methyl Red	Contact time (min)	180.00	64.20	65.58	65.22	65.00	35.00	65.00
Kidney Bean Seed Powder (KBSP)	Methyl Red	Factorial base (pH 6)	6.000	58.35	57.47	58.29	58.03	41.97	58.03
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	10.00	76.42	74.77	74.05	75.08	2.492	7.508
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	25.00	73.05	72.12	72.89	72.69	6.829	18.17
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	50.00	69.88	69.32	68.13	69.11	15.44	34.56
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	75.00	64.19	65.10	63.61	64.30	26.78	48.22
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	100.00	60.07	59.77	59.14	59.66	40.34	59.66

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	150.00	50.38	49.31	50.42	50.04	74.95	75.05
Kidney Bean Seed Powder (KBSP)	Methyl Red	Initial concentration (mg/L)	200.00	42.23	42.90	41.35	42.16	115.68	84.32
Kidney Bean Seed Powder (KBSP)	Methyl Red	pH	2.000	69.61	70.57	70.00	70.06	29.94	70.06
Kidney Bean Seed Powder (KBSP)	Methyl Red	pH	4.000	69.47	70.41	68.25	69.38	30.62	69.38
Kidney Bean Seed Powder (KBSP)	Methyl Red	pH	6.000	44.08	42.26	43.29	43.21	56.79	43.21
Kidney Bean Seed Powder (KBSP)	Methyl Red	pH	8.000	28.45	28.65	29.21	28.77	71.23	28.77
Kidney Bean Seed Powder (KBSP)	Methyl Red	pH	10.00	27.11	24.74	23.93	25.26	74.74	25.26
Kidney Bean Seed Powder (KBSP)	Methyl Red	pH	12.00	24.99	24.57	24.84	24.80	75.20	24.80

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	0.000	0.030	0.010	0.672	0.238	99.76	0.238
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	10.00	29.70	29.43	28.79	29.31	70.69	29.31
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	20.00	41.34	42.26	43.19	42.26	57.74	42.26
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	40.00	53.27	53.04	53.63	53.32	46.68	53.32
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	60.00	59.22	58.63	58.97	58.94	41.06	58.94
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	90.00	63.28	62.44	62.08	62.60	37.40	62.60
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	120.00	65.56	65.30	64.79	65.21	34.79	65.21
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Contact time (min)	180.00	67.47	67.28	67.59	67.45	32.55	67.45

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Factorial base (pH 6)	6.000	67.26	68.04	66.07	67.12	32.88	67.12
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	10.00	80.80	80.92	79.48	80.40	1.960	8.040
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	25.00	78.60	78.55	78.82	78.66	5.336	19.66
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	50.00	74.49	75.42	74.58	74.83	12.58	37.42
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	75.00	70.87	71.60	70.24	70.91	21.82	53.18
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	100.00	65.90	65.72	65.77	65.80	34.20	65.80
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	150.00	55.45	55.13	55.92	55.50	66.75	83.25
Kidney Bean Seed Powder (KBSP)	Methylene Blue	Initial concentration (mg/L)	200.00	47.73	47.39	48.18	47.77	104.47	95.53

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Kidney Bean Seed Powder (KBSP)	Methylene Blue	pH	2.000	25.18	27.10	26.16	26.15	73.85	26.15
Kidney Bean Seed Powder (KBSP)	Methylene Blue	pH	4.000	33.59	34.67	32.92	33.73	66.27	33.73
Kidney Bean Seed Powder (KBSP)	Methylene Blue	pH	6.000	59.04	59.42	59.02	59.16	40.84	59.16
Kidney Bean Seed Powder (KBSP)	Methylene Blue	pH	8.000	77.17	76.65	76.61	76.81	23.19	76.81
Kidney Bean Seed Powder (KBSP)	Methylene Blue	pH	10.00	58.50	59.26	58.58	58.78	41.22	58.78
Kidney Bean Seed Powder (KBSP)	Methylene Blue	pH	12.00	33.65	33.86	34.10	33.87	66.13	33.87
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	0.000	0.219	0.010	2.309	0.846	99.15	0.846
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	10.00	41.23	39.69	40.21	40.38	59.62	40.38

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	20.00	54.00	53.92	53.23	53.72	46.28	53.72
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	40.00	65.53	64.65	64.58	64.92	35.08	64.92
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	60.00	70.74	69.82	70.92	70.49	29.51	70.49
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	90.00	73.63	73.61	74.38	73.87	26.13	73.87
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	120.00	75.53	75.46	74.83	75.27	24.73	75.27
Lima Bean Pod Powder (LBPP)	Malachite Green	Contact time (min)	180.00	77.76	77.72	77.83	77.77	22.23	77.77
Lima Bean Pod Powder (LBPP)	Malachite Green	Factorial base (pH 6)	6.000	75.65	76.09	75.27	75.67	24.33	75.67
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	10.00	85.91	85.81	86.69	86.14	1.386	8.614
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	25.00	84.56	84.36	83.98	84.30	3.924	21.08
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	50.00	82.79	82.49	81.98	82.42	8.790	41.21

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	75.00	78.63	78.49	78.66	78.60	16.05	58.95
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	100.00	74.26	75.24	74.66	74.72	25.28	74.72
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	150.00	65.44	64.97	65.09	65.17	52.25	97.75
Lima Bean Pod Powder (LBPP)	Malachite Green	Initial concentration (mg/L)	200.00	56.30	57.01	57.92	57.08	85.85	114.15
Lima Bean Pod Powder (LBPP)	Malachite Green	pH	2.000	25.45	25.40	26.32	25.72	74.28	25.72
Lima Bean Pod Powder (LBPP)	Malachite Green	pH	4.000	35.45	35.56	35.46	35.49	64.51	35.49
Lima Bean Pod Powder (LBPP)	Malachite Green	pH	6.000	63.62	64.27	62.81	63.57	36.43	63.57
Lima Bean Pod Powder (LBPP)	Malachite Green	pH	8.000	84.41	84.58	85.81	84.93	15.07	84.93
Lima Bean Pod Powder (LBPP)	Malachite Green	pH	10.00	63.88	63.32	63.93	63.71	36.29	63.71
Lima Bean Pod Powder (LBPP)	Malachite Green	pH	12.00	33.74	35.08	34.87	34.56	65.44	34.56

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	0.000	0.010	0.563	0.010	0.194	99.81	0.194
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	10.00	32.61	32.49	32.75	32.62	67.38	32.62
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	20.00	45.38	44.35	45.39	45.04	54.96	45.04
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	40.00	57.40	55.99	57.21	56.87	43.13	56.87
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	60.00	62.26	61.24	60.50	61.34	38.66	61.34
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	90.00	64.57	65.69	64.95	65.07	34.93	65.07
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	120.00	66.96	66.09	67.22	66.76	33.24	66.76
Lima Bean Pod Powder (LBPP)	Methyl Red	Contact time (min)	180.00	70.14	70.05	68.95	69.71	30.29	69.71
Lima Bean Pod Powder (LBPP)	Methyl Red	Factorial base (pH 6)	6.000	66.34	65.71	65.33	65.79	34.21	65.79
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	10.00	79.29	79.22	79.89	79.46	2.054	7.946

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	25.00	77.57	77.29	78.24	77.70	5.575	19.42
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	50.00	72.89	73.71	73.80	73.47	13.27	36.73
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	75.00	69.82	69.89	70.32	70.01	22.49	52.51
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	100.00	65.44	66.24	66.27	65.98	34.02	65.98
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	150.00	56.52	55.75	57.09	56.45	65.32	84.68
Lima Bean Pod Powder (LBPP)	Methyl Red	Initial concentration (mg/L)	200.00	48.41	46.89	48.25	47.85	104.30	95.70
Lima Bean Pod Powder (LBPP)	Methyl Red	pH	2.000	74.42	74.36	73.36	74.05	25.95	74.05
Lima Bean Pod Powder (LBPP)	Methyl Red	pH	4.000	74.76	74.13	75.73	74.87	25.13	74.87
Lima Bean Pod Powder (LBPP)	Methyl Red	pH	6.000	45.22	44.88	45.40	45.17	54.83	45.17
Lima Bean Pod Powder (LBPP)	Methyl Red	pH	8.000	29.24	29.28	27.99	28.84	71.16	28.84

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Methyl Red	pH	10.00	26.96	25.43	25.20	25.86	74.14	25.86
Lima Bean Pod Powder (LBPP)	Methyl Red	pH	12.00	25.94	25.14	24.70	25.26	74.74	25.26
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	0.000	0.010	0.010	0.010	0.010	99.99	0.010
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	10.00	45.39	45.93	44.87	45.40	54.60	45.40
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	20.00	60.29	59.22	58.92	59.48	40.52	59.48
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	40.00	70.09	70.54	70.49	70.37	29.63	70.37
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	60.00	73.84	74.98	74.28	74.36	25.64	74.36
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	90.00	78.35	77.74	77.55	77.88	22.12	77.88
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	120.00	80.39	80.03	79.96	80.13	19.87	80.13
Lima Bean Pod Powder (LBPP)	Methylene Blue	Contact time (min)	180.00	82.18	82.38	81.55	82.03	17.97	82.03

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Methylene Blue	Factorial base (pH 6)	6.000	82.13	81.40	81.82	81.78	18.22	81.78
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	10.00	87.59	88.04	88.25	87.96	1.204	8.796
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	25.00	86.08	86.38	87.21	86.56	3.361	21.64
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	50.00	85.07	85.68	84.19	84.98	7.511	42.49
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	75.00	82.56	82.10	81.48	82.05	13.46	61.54
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	100.00	79.46	78.44	79.82	79.24	20.76	79.24
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	150.00	70.68	69.95	70.93	70.52	44.22	105.78
Lima Bean Pod Powder (LBPP)	Methylene Blue	Initial concentration (mg/L)	200.00	61.19	60.33	59.87	60.47	79.07	120.93
Lima Bean Pod Powder (LBPP)	Methylene Blue	pH	2.000	26.21	25.71	26.21	26.05	73.95	26.05
Lima Bean Pod Powder (LBPP)	Methylene Blue	pH	4.000	34.48	35.83	35.54	35.28	64.72	35.28

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Pod Powder (LBPP)	Methylene Blue	pH	6.000	65.43	66.11	65.92	65.82	34.18	65.82
Lima Bean Pod Powder (LBPP)	Methylene Blue	pH	8.000	89.90	90.47	87.84	89.40	10.60	89.40
Lima Bean Pod Powder (LBPP)	Methylene Blue	pH	10.00	66.10	65.15	66.03	65.76	34.24	65.76
Lima Bean Pod Powder (LBPP)	Methylene Blue	pH	12.00	35.04	36.11	36.46	35.87	64.13	35.87
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	0.000	0.754	0.332	0.010	0.365	99.63	0.365
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	10.00	30.94	30.89	32.06	31.30	68.70	31.30
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	20.00	43.35	43.60	43.76	43.57	56.43	43.57
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	40.00	55.61	54.15	55.27	55.01	44.99	55.01

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	60.00	61.39	61.38	61.06	61.28	38.72	61.28
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	90.00	64.45	64.43	64.11	64.33	35.67	64.33
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	120.00	65.79	66.70	66.80	66.43	33.57	66.43
Lima Bean Seed Powder (LBSP)	Malachite Green	Contact time (min)	180.00	68.68	68.98	68.88	68.85	31.15	68.85
Lima Bean Seed Powder (LBSP)	Malachite Green	Factorial base (pH 6)	6.000	67.72	68.26	68.54	68.18	31.82	68.18
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	10.00	79.62	80.41	80.06	80.03	1.997	8.003
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	25.00	78.60	78.11	77.69	78.13	5.467	19.53
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	50.00	74.30	75.19	75.59	75.03	12.49	37.51

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	75.00	71.19	69.80	70.49	70.49	22.13	52.87
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	100.00	65.78	66.49	65.00	65.75	34.25	65.75
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	150.00	56.51	56.53	56.11	56.38	65.42	84.58
Lima Bean Seed Powder (LBSP)	Malachite Green	Initial concentration (mg/L)	200.00	47.01	46.73	46.84	46.86	106.28	93.72
Lima Bean Seed Powder (LBSP)	Malachite Green	pH	2.000	26.08	25.24	25.74	25.68	74.32	25.68
Lima Bean Seed Powder (LBSP)	Malachite Green	pH	4.000	33.43	33.91	33.09	33.48	66.52	33.48
Lima Bean Seed Powder (LBSP)	Malachite Green	pH	6.000	58.71	59.87	58.42	59.00	41.00	59.00
Lima Bean Seed Powder (LBSP)	Malachite Green	pH	8.000	77.37	79.15	77.98	78.17	21.83	78.17

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Malachite Green	pH	10.00	57.82	58.48	57.36	57.89	42.11	57.89
Lima Bean Seed Powder (LBSP)	Malachite Green	pH	12.00	35.17	32.77	33.88	33.94	66.06	33.94
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	0.000	0.461	1.439	0.960	0.953	99.05	0.953
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	10.00	21.09	21.71	20.82	21.20	78.80	21.20
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	20.00	32.62	32.70	31.81	32.37	67.63	32.37
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	40.00	43.34	41.99	42.31	42.54	57.46	42.54
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	60.00	47.92	47.60	49.25	48.26	51.74	48.26
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	90.00	52.69	52.45	52.36	52.50	47.50	52.50

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	120.00	54.80	56.00	55.23	55.35	44.65	55.35
Lima Bean Seed Powder (LBSP)	Methyl Red	Contact time (min)	180.00	57.96	58.98	57.08	58.01	41.99	58.01
Lima Bean Seed Powder (LBSP)	Methyl Red	Factorial base (pH 6)	6.000	47.81	48.24	48.46	48.17	51.83	48.17
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	10.00	66.95	66.60	67.65	67.07	3.293	6.707
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	25.00	64.62	64.76	66.12	65.17	8.708	16.29
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	50.00	60.87	59.81	58.43	59.70	20.15	29.85
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	75.00	55.64	54.92	54.87	55.14	33.64	41.36
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	100.00	50.36	49.75	50.13	50.08	49.92	50.08

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	150.00	41.40	41.60	41.05	41.35	87.98	62.02
Lima Bean Seed Powder (LBSP)	Methyl Red	Initial concentration (mg/L)	200.00	33.30	34.97	36.01	34.76	130.47	69.53
Lima Bean Seed Powder (LBSP)	Methyl Red	pH	2.000	63.27	63.62	63.28	63.39	36.61	63.39
Lima Bean Seed Powder (LBSP)	Methyl Red	pH	4.000	63.97	63.71	63.91	63.86	36.14	63.86
Lima Bean Seed Powder (LBSP)	Methyl Red	pH	6.000	40.75	41.14	42.73	41.54	58.46	41.54
Lima Bean Seed Powder (LBSP)	Methyl Red	pH	8.000	26.39	25.97	26.72	26.36	73.64	26.36
Lima Bean Seed Powder (LBSP)	Methyl Red	pH	10.00	24.20	24.47	25.87	24.85	75.15	24.85
Lima Bean Seed Powder (LBSP)	Methyl Red	pH	12.00	24.49	24.97	25.72	25.06	74.94	25.06

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	0.000	1.080	0.386	0.876	0.781	99.22	0.781
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	10.00	34.60	33.79	34.64	34.34	65.66	34.34
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	20.00	49.23	49.22	48.18	48.88	51.12	48.88
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	40.00	59.07	60.72	59.58	59.79	40.21	59.79
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	60.00	65.36	65.00	65.30	65.22	34.78	65.22
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	90.00	69.66	68.92	69.18	69.25	30.75	69.25
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	120.00	71.22	72.27	70.11	71.20	28.80	71.20
Lima Bean Seed Powder (LBSP)	Methylene Blue	Contact time (min)	180.00	73.81	73.77	73.67	73.75	26.25	73.75

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Methylene Blue	Factorial base (pH 6)	6.000	72.82	70.60	72.61	72.01	27.99	72.01
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	10.00	83.14	83.51	82.79	83.15	1.685	8.315
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	25.00	81.85	80.73	81.35	81.31	4.672	20.33
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	50.00	78.12	78.60	77.69	78.14	10.93	39.07
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	75.00	74.61	75.65	75.83	75.37	18.48	56.52
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	100.00	71.18	70.31	70.16	70.55	29.45	70.55
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	150.00	61.98	60.58	60.60	61.05	58.42	91.58
Lima Bean Seed Powder (LBSP)	Methylene Blue	Initial concentration (mg/L)	200.00	51.52	52.07	52.34	51.98	96.05	103.95

Adsorbent	Dye	Condition	Value	Rep 1	Rep 2	Rep 3	MeanRemoval	MeanCe	MeanQe
Lima Bean Seed Powder (LBSP)	Methylene Blue	pH	2.000	26.43	25.55	25.67	25.89	74.11	25.89
Lima Bean Seed Powder (LBSP)	Methylene Blue	pH	4.000	33.95	33.82	34.20	33.99	66.01	33.99
Lima Bean Seed Powder (LBSP)	Methylene Blue	pH	6.000	60.79	61.51	60.28	60.86	39.14	60.86
Lima Bean Seed Powder (LBSP)	Methylene Blue	pH	8.000	80.84	81.01	80.32	80.72	19.28	80.72
Lima Bean Seed Powder (LBSP)	Methylene Blue	pH	10.00	60.86	60.87	61.07	60.93	39.07	60.93
Lima Bean Seed Powder (LBSP)	Methylene Blue	pH	12.00	34.51	34.89	34.32	34.57	65.43	34.57

REFERENCES:

1. Srivatsav, P., Bhargav, B. S., Shanmugasundaram, V., Arun, J., Gopinath, K. P., & Bhatnagar, A. (2020). Biochar as an eco-friendly and economical adsorbent for the removal of colorants (dyes) from aqueous environment: A review. Water, 12(12), 3561. https://doi.org/10.3390/w12123561
2. Aragaw, T. A., & Bogale, F. M. (2021). Biomass-based adsorbents for removal of dyes from wastewater: A review. Frontiers in Environmental Science, 9, 764958. https://doi.org/10.3389/fenvs.2021.764958
3. Nayagam, J. O. P., & Prasanna, K. (2022). Utilization of shell-based agricultural waste adsorbents for removing dyes: A review. Chemosphere, 291, 132737. https://doi.org/10.1016/j.chemosphere.2021.132737

4. Amalina, F., Abd Razak, A. S., Krishnan, S., Zularisam, A. W., & Nasrullah, M. (2022). Dyes removal from textile wastewater by agricultural waste as an absorbent - A review. Cleaner Waste Systems, 3, 100051. https://doi.org/10.1016/j.clwas.2022.100051
5. Praveen, S., Jegan, J., Pushpa, T. B., Gokulan, R., & Bulgariu, L. (2022). Biochar for removal of dyes in contaminated water: An overview. Biochar, 4, 10. https://doi.org/10.1007/s42773-022-00131-8
6. Jagadeesh, N., & Sundaram, B. (2023). Adsorption of pollutants from wastewater by biochar: A review. Journal of Hazardous Materials Advances, 9, 100226. https://doi.org/10.1016/j.hazadv.2022.100226
7. Wang, J., Tan, Y., Yang, H., Zhan, L., Sun, G., & Luo, L. (2023). On the adsorption characteristics and mechanism of methylene blue by ball mill modified biochar. Scientific Reports, 13, 21174. https://doi.org/10.1038/s41598-023-48373-1
8. Jabar, J. M., Adebayo, M. A., Odusote, Y. A., Yilmaz, M., & Rangabhashiyam, S. (2023). Valorization of microwave-assisted H3PO4-activated plantain (Musa paradisiaca L.) leaf biochar for malachite green sequestration: Models and mechanism of adsorption. Results in Engineering, 18, 101129. https://doi.org/10.1016/j.rineng.2023.101129
9. Rubio-Clemente, A., Gutierrez, J., Henao, H., Melo, A. M., Perez, J. F., & Chica, E. (2023). Adsorption capacity of the biochar obtained from Pinus patula wood micro-gasification for the treatment of polluted water containing malachite green dye. Journal of King Saud University - Engineering Sciences, 35, 431-441. https://doi.org/10.1016/j.jksues.2021.07.006
10. Bouzid, T., Grich, A., Naboulsi, A., Regti, A., Alaoui Tahiri, A., El Himri, M., & El Haddad, M. (2023). Adsorption of Methyl Red on porous activated carbon from agriculture waste: Characterization and response surface methodology optimization. Inorganic Chemistry Communications, 158, 111544. https://doi.org/10.1016/j.inoche.2023.111544
11. Tsoutsa, E. K., Tolkou, A. K., Kyzas, G. Z., & Katsoyiannis, I. A. (2024). An update on agricultural wastes used as natural adsorbents or coagulants in single or combined systems for the removal of dyes from wastewater. Water, Air, & Soil Pollution, 235, 178. https://doi.org/10.1007/s11270-024-06979-9
12. Chahal, M., Kumari, S., Bhattacharya, A., & Garg, M. C. (2024). Evaluating sustainable agricultural waste biomass for methylene blue adsorption in wastewater treatment: A state-of-the-art review. Bioresource Technology Reports, 28, 101983. https://doi.org/10.1016/j.biteb.2024.101983
13. Sayed, N. S. M., Ahmed, A. S. A., Abdallah, M. H., & Gouda, G. A. (2024). ZnO@ activated carbon derived from wood sawdust as adsorbent for removal of methyl red and methyl orange from aqueous solutions. Scientific Reports, 14, 5384. https://doi.org/10.1038/s41598-024-55158-7
14. Teweldebrihan, M. D., & Dinka, M. O. (2024). Methyl Red adsorption from aqueous solution using Rumex abyssinicus-derived biochar: Studies of kinetics and isotherm. Water, 16(16), 2237. https://doi.org/10.3390/w16162237
15. Eleryan, A., Hassaan, M., Nazir, M. A., Shah, S. S. A., Ragab, S., & El Nemr, A. (2024). Isothermal and kinetic screening of methyl red and methyl orange dyes adsorption from water by Delonix regia biochar-sulfur oxide (DRB-SO). Scientific Reports, 14, 13585. https://doi.org/10.1038/s41598-024-63510-0

16. Yetgin, S., & Amlani, M. (2025). Agricultural low-cost waste adsorption of methylene blue and modelling linear isotherm method versus nonlinear prediction. Clean Technologies and Environmental Policy, 27, 1205-1225. https://doi.org/10.1007/s10098-024-02928-6
17. Okoro, H. K., Emenike, E. C., Iwuozor, K. O., Omuku, P. E., & Adeniyi, A. G. (2025). Industrial waste biochar for heavy metal and dye remediation in wastewater: An overview. Water Practice & Technology, 20(3), 595-616. https://doi.org/10.2166/wpt.2025.037
18. Dhila, H., Bhapkar, A., & Bhame, S. (2025). Metal oxide/biochar hybrid nanocomposites for adsorption and photocatalytic degradation of textile dye effluents: A review. Desalination and Water Treatment, 321, 101004. https://doi.org/10.1016/j.dwt.2025.101004
19. Mnyango, J. I., Nyoni, B., Phiri, C., Fouda-Mbanga, B. G., Amusat, S. O., Maringa, A., Yalala-Ndlovu, B., Hlabano-Moyo, B., Tywabi-Ngeva, Z., & Hlangothi, S. P. (2025). Sustainable wastewater treatment: Mechanistic, environmental, and economic insights into biochar for synthetic dye removal. Next Materials, 9, 100974. https://doi.org/10.1016/j.nxmate.2025.100974