

Supplementary materials for:

Activated Biochar from Pineapple Crown Biomass: A High-Efficiency Adsorbent for Organic Dye Removal

Table S1. Results of the pseudo-first-order kinetic model for the adsorption of biochar and activated biochar

The pseudo-first-order equation is expressed as [1]:

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (\text{Eq. S.7.})$$

Where k_1 (1/min) is the first order adsorption kinetic constant and q_e and q_t are amounts of dye adsorbed (mg/g) on adsorbent at equilibrium and at time t , respectively.

Material	Dye	q_e (mg/g) (experimental)	Pseudo-first-order		
			k_1 (min ⁻¹)	q_e (mg/g) (calculated)	R^2
Biochar	MB	3.4829 ± 0.0431	12.87	0.06	0.1977
	RhB	1.0866 ± 0.0200	3.75	0.01	0.0399
	GM	8.8295 ± 0.1126	5.66	0.02	0.1200
Activated biochar	MB	10 ± 0.0632	1.44	0.34	0.2346
	RhB	10 ± 0.5072	3.88	0.17	0.9865
	GM	10 ± 0.1212	2.37	0.30	0.4543

Table S2. Comparison of recent studies on pollutant removal by various biomass–derived biochar.

Biomass	Pyrolysis conditions (Temperature)	Activation type	Pollutant	Dye concentration	Biochar dosages	Max. Removal efficiency		Contact time	Ref.
						Before Activation	After activation		
Moringa leaves	450 °C	Chemical	MB	10 ppm	1 g/L	33.1%	88.0%	40 min	[2]
			RhB	10 ppm	1 g/L	12.6%	71.5%	40 min	
			MG	10 ppm	1 g/L	88.1%	93.0%	40 min	
Pineapple waste biomass	105 °C	Chemical	MB	1000 ppm	2 g/L	≈52%	≈54%	12 h	[3]
Water lily through	110 °C	Physical and chemical	MG	100 ppm	1 g/L	–	100%	75 min	[4]
Jack fruit peel (Activated)	550 °C	Chemical	RBB	25 ppm	1 g/L	–	90 %	420 min	[5]
Algae biochar	400 °C	–	DNA	–	50 g/L	6.9	–	50 min	[6]
Sediment biochar	400 °C	–	DNA	–	50 g/L	66.47	–	50 min	
Peanut shell	900 °C	–	RBB	25 ppm	8.3 g/L	100%	–	30 min	[7]

The comparison of recent studies on water pollutant removal, as presented in Table S1, reveals significant insights into how fabrication variables and operational conditions influence the performance of biochar as an adsorbent for dyes. This analysis underscores the importance of factors such as the biomass source, pyrolysis conditions, and activation type, all of which play a crucial role in the adsorption capacity of biochar.

Firstly, the results show that the biomass source, such as moringa leaves and pineapple waste, has a notable impact on the surface structure and porosity of the biochar, directly influencing its removal efficiency. The high efficiency observed in moringa biochar (88.0% for MB and 93.0% for MG after chemical activation) at 450°C suggests that higher pyrolysis temperatures promote the creation of additional adsorption sites, thereby enhancing its pollutant capture capacity. In contrast, the biochar derived from pineapple waste at 105°C exhibited significantly lower removal (~54% for MB), confirming that suboptimal pyrolysis restricts the development of an effective active surface.

Chemical activation emerges as a key process for optimizing adsorption. In several studies, this technique significantly improved removal capabilities, particularly in biomasses such as moringa and jackfruit peel. In these cases, activation greatly increased contaminant removal, attributable to the introduction of additional functional groups and the development of more accessible porosity. However, inactivated biochars, such as those derived from algae

and sediments, showed limited ability to remove complex pollutants, highlighting the necessity of activation treatments to enhance biochar's effectiveness in environmental applications.

Another critical factor is the relationship between the biochar dosage and the initial dye concentration. Although increasing the biochar dosage may improve removal efficiency, high contaminant concentrations, such as 1000 ppm of MB, resulted in lower removal effectiveness, as seen in the pineapple waste-derived biochar (~54% removal). This emphasizes the importance of balancing biochar dosages with pollutant load to achieve maximum efficiency.

Finally, the contact times required to achieve high adsorption performance varied considerably depending on the biochar structure and the type of contaminant. While activated moringa biochar achieved efficient removal in 40 minutes, jackfruit peel biochar required over seven hours. This disparity highlights the influence of porosity and the accessibility of adsorption sites, factors that must be considered when designing water treatment systems.

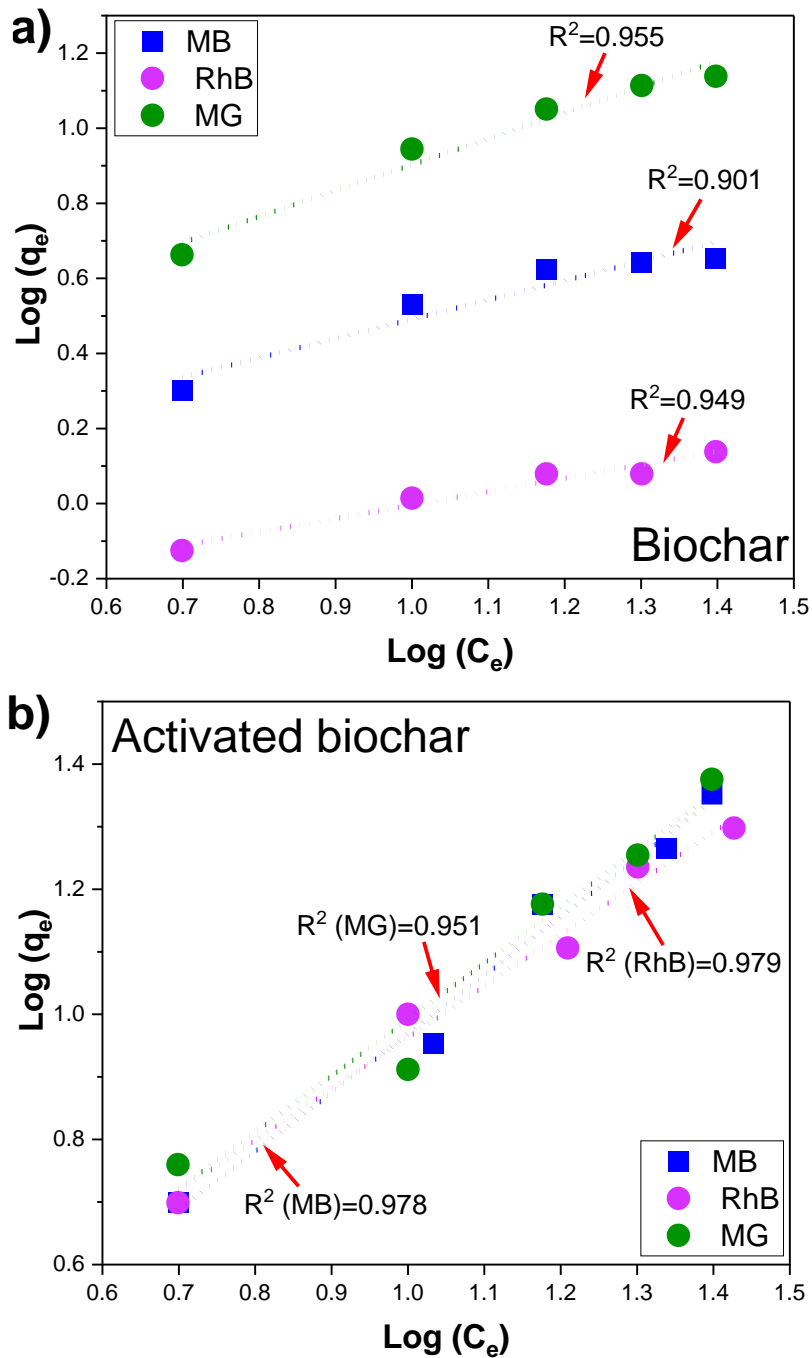
In summary, this analysis highlights the importance of optimizing biochar preparation conditions, particularly pyrolysis, and activation, to maximize its performance in water pollutant removal. These findings not only reinforce the applicability of biochar as an effective and sustainable solution for water decontamination but also pave the way for the continuous improvement of these technologies through precise adjustments to fabrication parameters.

Figure S1. Adsorption Freundlich isotherm of dyes by (a) biochar and (b) activated biochar

The linear form of the Freundlich adsorption isotherm, which assumes that adsorption takes place on heterogeneous surfaces, can be expressed as [8]:

$$\log (q_e) = \frac{1}{n} \log (C_e) + \log (K_F) \quad (\text{Eq. S. 8.})$$

The values of K_F and n were calculated from the intercept and slope of the plots of $\log (q_e)$ versus $\log (C_e)$



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