Supplementary material of manuscript titled "**Coagulation-flocculation/pyrolysis integrated system for dye-laden wastewater treatment: A techno-economic and sustainable approach**"

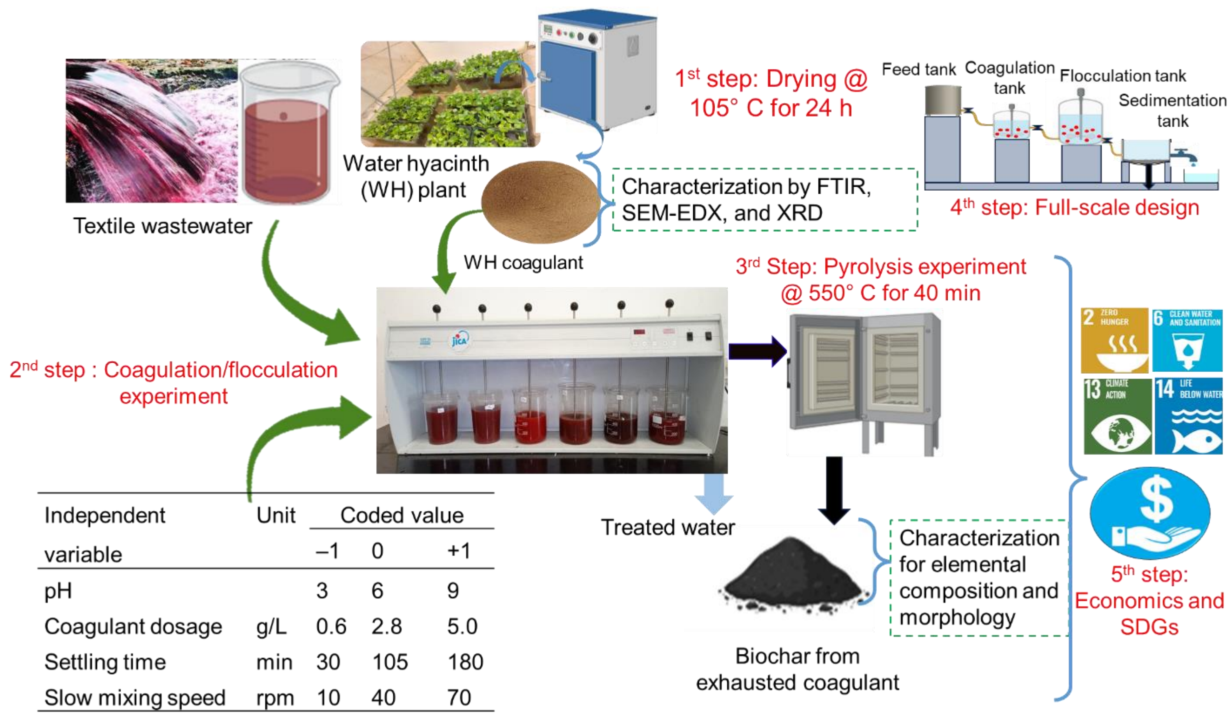


Fig. S1. Schematic diagram of CF/pyrolysis system for textile wastewater treatment followed by techno-economic estimation

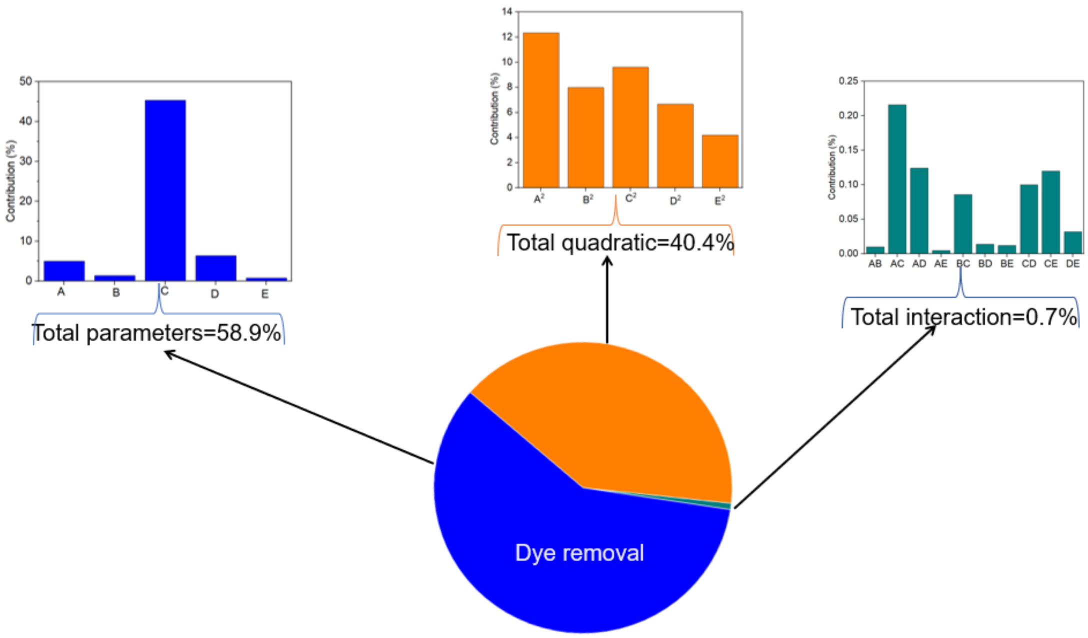


Fig. S2. Pareto analysis on statistical percentage contributions of different model components for dye removal, where A is initial pH (3–9), B is water hyacinth (WH) dosage (0.6–5.0 g/L), C is settling time (30–180 min), D is slow mixing speed (10–70 rpm), and E is temperature (15–25 °C)

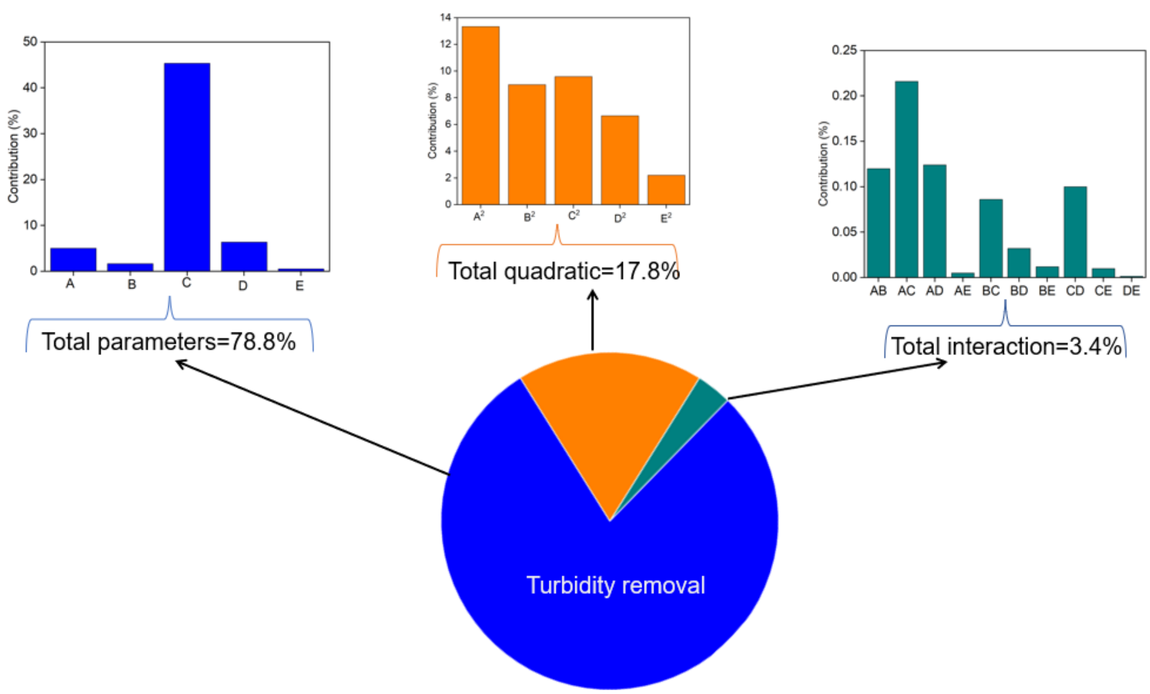


Fig. S3. Pareto analysis on statistical percentage contributions of different model components for turbidity removal, where A is initial pH (3–9), B is water hyacinth (WH) dosage (0.6–5.0 g/L), C is settling time (30–180 min), D is slow mixing speed (10–70 rpm), and E is temperature (15–25 °C)

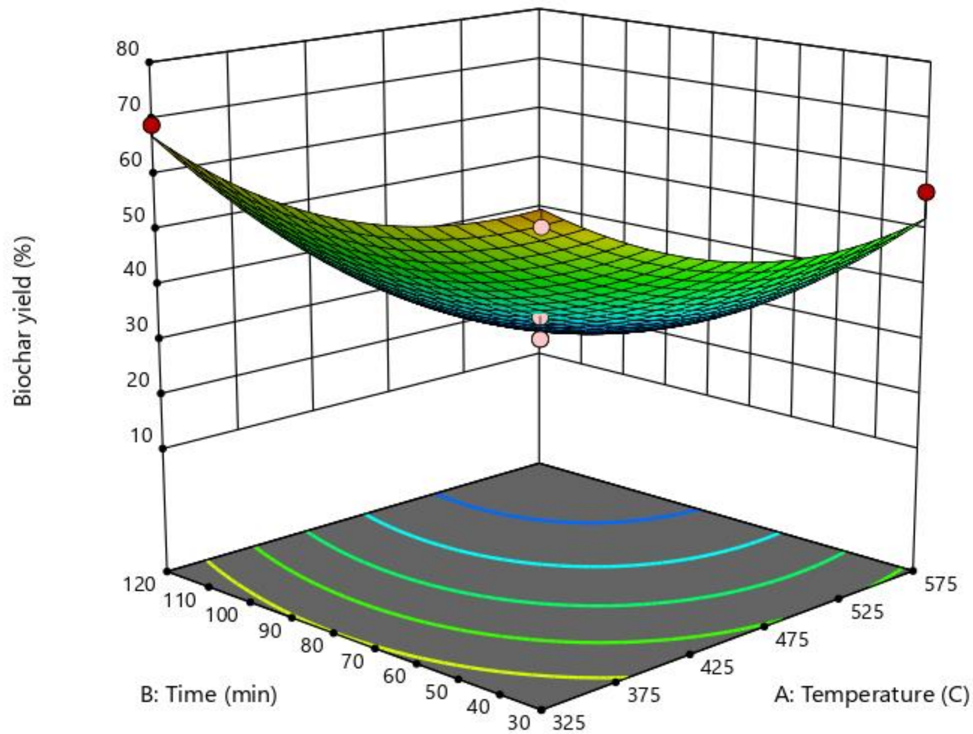
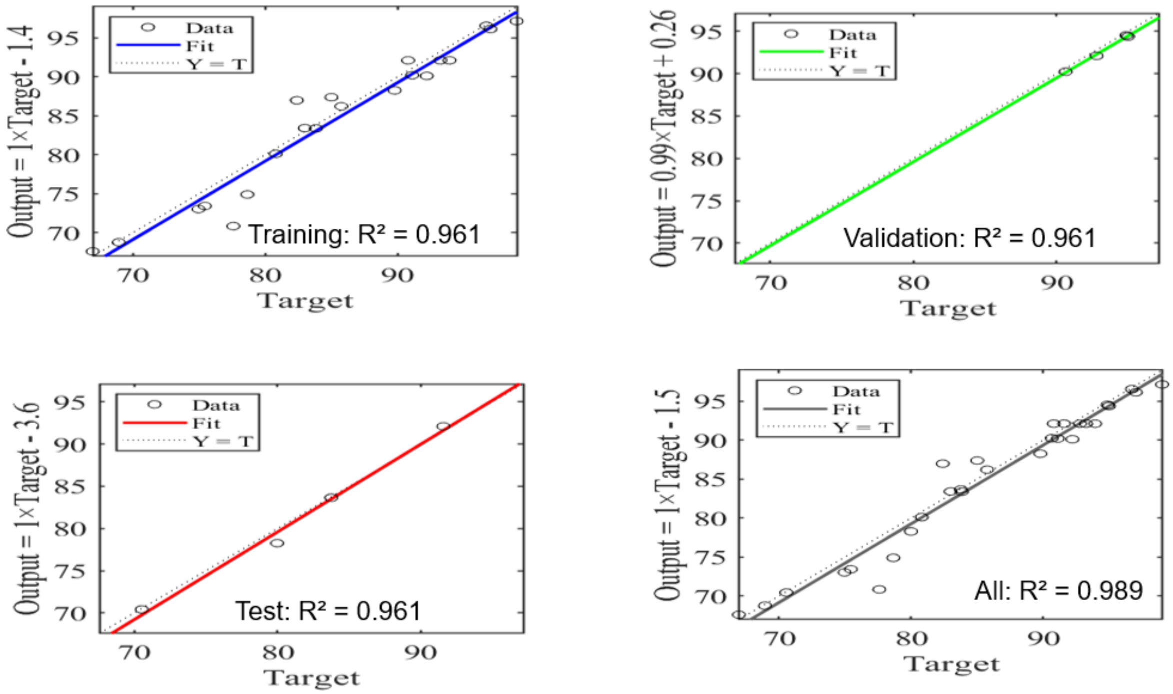


Fig. S4. 3D response surface plot for biochar production as a function interaction between heating time (min) and the pyrolysis temperature (°C).



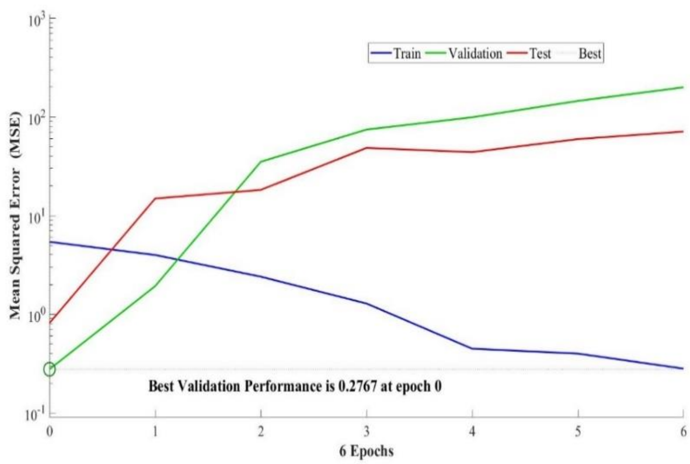


Fig. S5. Training plots for validation regression, performance, and test for dye ANN model

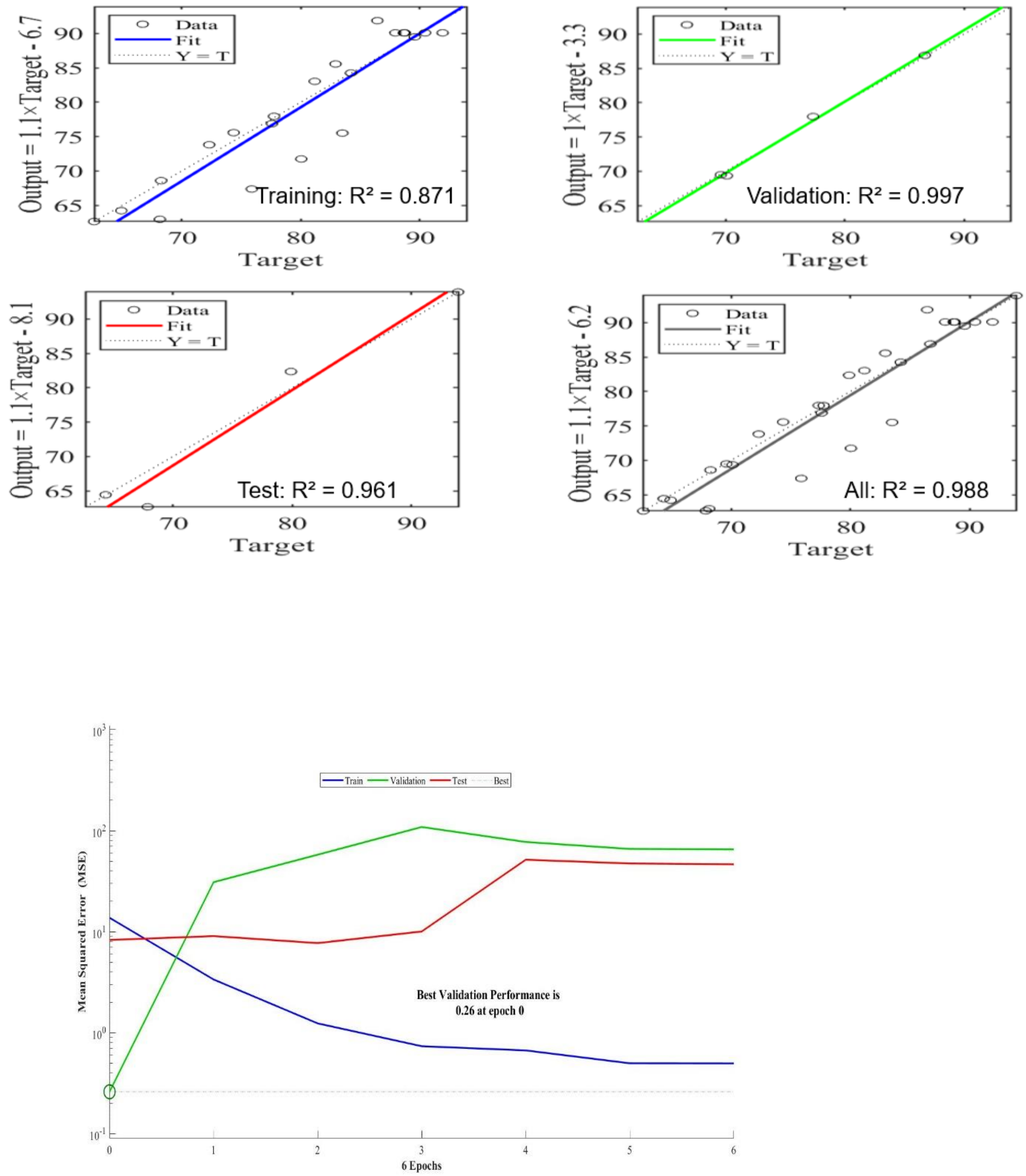


Fig. S6. Training plots, validation regression, and performance plots for turbidity ANN model

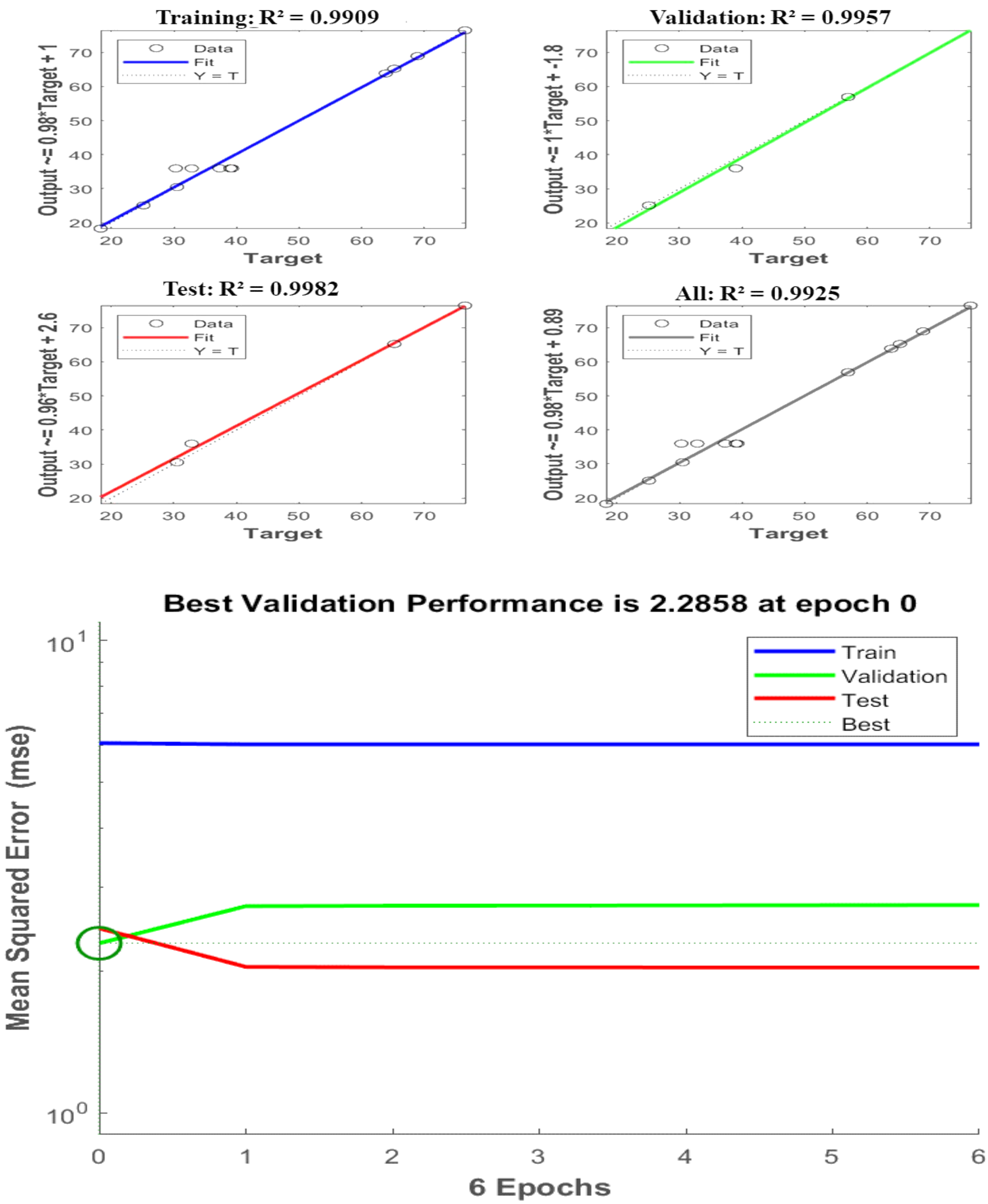


Fig. S7. Training plots, validation regression, and performance plots for biochar yield for ANN model

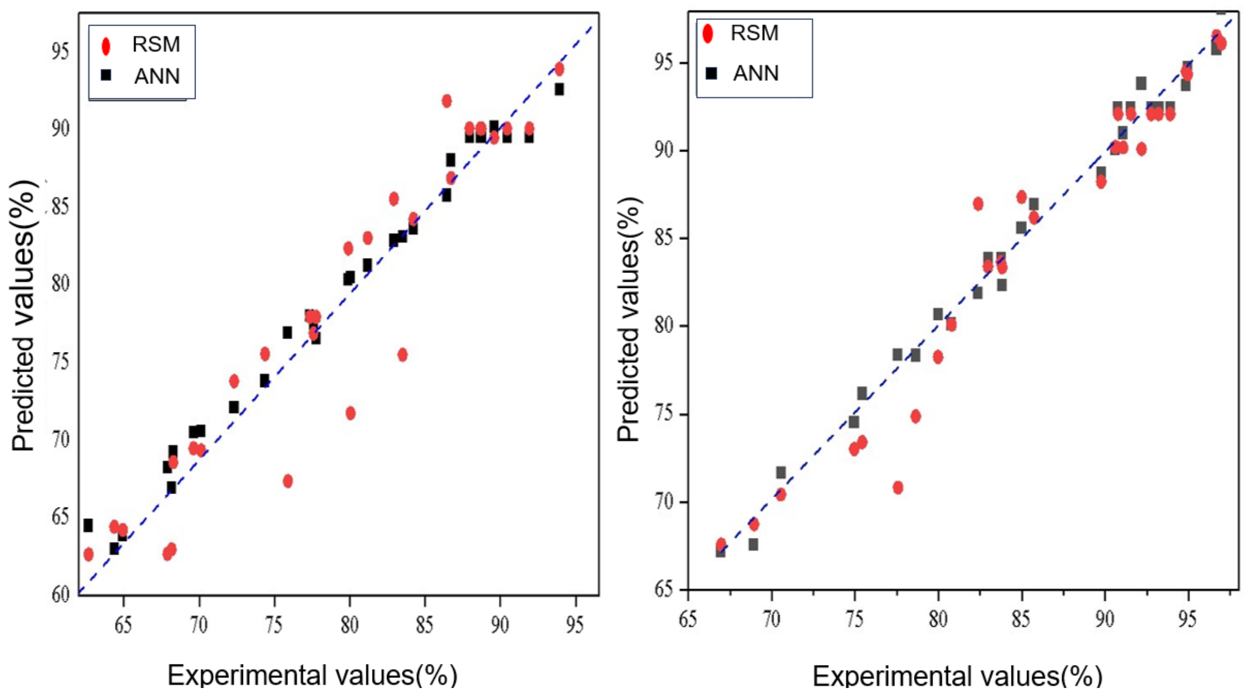


Fig. S8. Comparison of experimental removal efficiencies and predicted removal efficiencies by RSM and ANN for (a) dye and (b) turbidity

Table S1. Comparison of coagulation-flocculation/pyrolysis system performance with other treatment methods for textile wastewater reported in the literature

Ref.	Study objective	Coagulant	Removal (%)		Research gap	Research gap covered
			Color	Turbidity		
[1]	To optimize the process of coagulation-flocculation using *Moringa oleifera* seed powder (MOSP) as a natural coagulant and investigate the interactive effects of each experimental factor on the treatment of dye and turbid wastewater.	*Moringa oleifera* seed powder (MOSP)	98.5	92.2	The management of spent coagulant was not illustrated	Prepare and characterize water hyacinth coagulant, sludge, and sludge-derived biochar
[2]	To evaluate the potential and application of chickpea (*Cicer arietinum*) as a natural organic coagulant for the treatment of POME and to determine its optimum operating parameters.	chickpea (*Cicer arietinum*)	-	86	Only the response surface methodology (RSM) was applied to address the correlation between inputs and outputs	Artificial neural network (ANN) and RSM were employed to determine the optimum experimental condition.
[3]	To make a comparison between natural coagulants in the treatment of textile wastewater by coagulation	*Eirchorrnia crassip* *Strychnos potatorum*	-	53.85 23.07	The treatment cost by the coagulation/flocculation process was undefined	Representing techno-economic estimation of treating textile wastewater followed by sludge pyrolysis

[4]	To optimize the performance of *pomegranate seeds* as a novel natural flocculant for paper recycling wastewater treatment	*Pomegranate seeds*	-	98	The study should explore the correlation between wastewater treatment and the three pillars of sustainability	The study determines the sustainable development goals (SDGs) allied with dual coagulation/flocculation and pyrolysis of textile wastewater management
[5]	Prediction and optimisation of coagulation-flocculation process for turbidity removal from aquaculture effluent using *Garcinia kola* extract	*Garcinia kola* extract	76.89	74.23	The study should find solutions for coagulation sludge disposal	The second experiment focused on the pyrolysis of the spent coagulant to produce biochar, enabling waste sludge valorization
[6]	To use okra pod powder in removing turbidity from paint wastewater and optimizing the process using response surface methodology (RSM)	Okra pod powder	-	90.44	The study focused on synthetic wastewater	Real experiments were conducted using textile industrial effluent
This study	To optimize the integrated CF/pyrolysis processes using an artificial intelligence technique and response surface methodology (RSM) for the dual benefit of textile wastewater (TW) treatment and biochar production.	Water hyacinth	√	√	RSM & ANN optimization, waste reusability, and economic analysis	ANN and RSM optimization, economics, and waste reusability to biochar

Table S2. ANOVA results of the developed quadratic regression models for predicting biochar yield from spent coagulant (sludge) pyrolysis, where the temperature and heating time ranges were 325 – 575 °C and 30 – 120 min

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	3966.90	5	793.38	17.62	0.0008	significant
A-Temperature	2258.78	1	2258.78	50.18	0.0002	
B-Time	707.63	1	707.63	15.72	0.0054	
AB	315.24	1	315.24	7.00	0.0331	
A^2	393.28	1	393.28	8.74	0.0212	
B^2	381.34	1	381.34	8.47	0.0226	
Residual	315.11	7	45.02			
Lack of Fit	251.36	3	83.79	5.26	0.0714	Insignificant
Pure Error	63.75	4	15.94			
Cor Total	4282.00	12				

Table S3. A 3^4 full Box-Behnken experimental design matrix for dye and turbidity removal using jar-test experiment

Run	A: Initial pH	B: WH dosage (g/L)	C: Settling time (min)	D: Slow-mixing speed (rpm)
1	6	2.8	105	40
2	6	2.8	105	40
3	6	5	30	40
4	9	2.8	105	70
5	6	2.8	105	40

6	6	0.6	180	40
7	3	2.8	105	70
8	3	5	105	40
9	3	2.8	180	40
10	6	5	105	70
11	6	2.8	180	10
12	9	2.8	105	10
13	3	2.8	30	40
14	6	5	180	40
15	6	0.6	105	70
16	6	2.8	180	70
17	3	2.8	105	10
18	9	0.6	105	40
19	6	5	105	10
20	9	2.8	180	40
21	6	2.8	30	70
22	6	2.8	30	10
23	6	0.6	30	40
24	6	2.8	105	40
25	6	0.6	105	10
26	3	0.6	105	40
27	9	5	105	40
28	6	2.8	105	40
29	9	2.8	30	40

Table S4. ANOVA for predicting dye removal effeciency from textile wastewater treatment by coagulation/flocculation using water hyacinth coagulant

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	2339.17	14	167.08	80.16	< 0.0001	Significant
A-Initial pH	142.42	1	142.42	68.33	< 0.0001	
B-Dosage	43.13	1	43.13	20.69	0.0005	
C-Settling time	1240.74	1	1240.74	595.27	< 0.0001	
D-Slow-mixing speed	179.18	1	179.18	85.97	< 0.0001	
AB	0.2756	1	0.2756	0.1322	0.7216	
AC	8.61	1	8.61	4.13	0.0615	
AD	4.24	1	4.24	2.04	0.1755	
BC	2.36	1	2.36	1.13	0.3057	
BD	0.4032	1	0.4032	0.1935	0.6668	
CD	2.96	1	2.96	1.42	0.2533	
A^2	390.73	1	390.73	187.46	< 0.0001	
B^2	244.74	1	244.74	117.42	< 0.0001	
C^2	288.69	1	288.69	138.51	< 0.0001	
D^2	175.74	1	175.74	84.31	< 0.0001	
Residual	29.18	14	2.08			
Lack of Fit	18.76	10	1.88	0.7203	0.6940	Insignificant
Pure Error	10.42	4	2.60			
Cor Total	2368.35	28				

Table S5. ANOVA for predicting turbidity removal effeciency from textile wastewater treatment by coagulation/flocculation using water hyacinth coagulant

Source	Sum of Squares	df	Mean Square	F-value	P-value	
Model	2197.24	14	156.95	89.10	< 0.0001	Significant
A-Initial pH	963.20	1	963.20	546.80	< 0.0001	
B-Dosage	115.13	1	115.13	65.36	< 0.0001	
C-Settling time	507.65	1	507.65	288.19	< 0.0001	
D-Slow-mixing speed	258.26	1	258.26	146.61	< 0.0001	
AB	0.2304	1	0.2304	0.1308	0.7230	
AC	0.2601	1	0.2601	0.1477	0.7066	
AD	30.42	1	30.42	17.27	0.0010	
BC	1.38	1	1.38	0.7838	0.3909	
BD	0.4489	1	0.4489	0.2548	0.6215	
CD	28.30	1	28.30	16.07	0.0013	
A^2	171.72	1	171.72	97.48	< 0.0001	
B^2	71.83	1	71.83	40.78	< 0.0001	
C^2	126.16	1	126.16	71.62	< 0.0001	
D^2	74.01	1	74.01	42.01	< 0.0001	
Residual	24.66	14	1.76			
Lack of Fit	18.25	10	1.83	1.14	0.4892	Insignificant
Pure Error	6.41	4	1.60			
Cor Total	2221.90	28				

Table S6. Performance of derived ANN models based on the different numbers of neurons for the hidden layer and the back-propagation training algorithm for the dye model in the CF process. (Bold font represents the optimized ANN architectural structure)

ANN architecture	Training function	MSE	Coefficient of determination (R^2)			
			Training	Validation	Testing	Overall
4-4-1	trainlm	32.567	0.6770	0.985	0.899	0.830
4-5-1	trainlm	25.839	0.870	0.952	0.499	0.780
4-6-1	trainlm	7.071	0.873	0.864	0.984	0.861
4-7-1	trainlm	1.776	0.915	0.657	0.320	0.610
4-8-1	trainlm	0.851	0.994	0.994	0.991	0.989
4-9-1	trainlm	1.436	0.834	0.129	0.924	0.432
4-10-1	trainlm	5.314	0.871	0.981	0.867	0.837
4-11-1	trainlm	27.231	0.646	0.996	0.785	0.727
4-8-1	traingdm	39.613	0.812	0.943	0.814	0.821
4-8-1	trainbfg	1.772	0.928	0.989	0.647	0.899
4-8-1	traincgb	5.853	0.910	0.368	0.803	0.834
4-8-1	traincgf	30.785	0.935	0.938	0.833	0.915
4-8-1	trainscg	56.704	0.845	0.537	0.864	0.644
4-8-1	trainoss	1.136	0.921	0.978	0.955	0.913

Table S7. Performance of derived ANN models based on the different numbers of neurons for the hidden layer and the back-propagation training algorithm for the turbidity model in the CF process. (Bold font represents the optimized ANN architectural structure)

ANN architecture	Training function	MSE	Coefficient of determination (R^2)			
			Training	Validation	Testing	Overall
4-4-1	trainlm	25.576	0.630	0.703	0.432	0.677
4-5-1	trainlm	8.281	0.815	0.923	0.573	0.820
4-6-1	trainlm	4.628	0.895	0.985	0.913	0.878
4-7-1	trainlm	3.845	0.948	0.988	0.502	0.945
4-8-1	trainlm	1.077	0.871	0.997	0.961	0.988
4-9-1	trainlm	1.524	0.891	0.918	0.826	0.800
4-10-1	trainlm	2.545	0.945	0.994	0.943	0.954
4-11-1	trainlm	40. 321	0.9416	0.741	0.872	0.901
4-8-1	traincgf	36.98	0.802	0.857	0.393	0.269
4-8-1	traincgb	14.028	0.949	0.314	0.223	0.816
4-8-1	traingdm	3.904	0.886	0.988	0.518	0.874
4-8-1	trainscg	3.124	0.741	0.986	0.976	0.802
3-8-1	trainoss	13.454	0.756	0.620	0.892	0.747

Table S8. Characterization of raw and treated real textile wastewater using water hyacinth coagulant

Parameters	Unit	Before	After	Removal (%)	Permissible standard
COD	mg/L	940	485	48.404	100
pH	-	8.13	6.25	-	6-9
TDS	mg/L	3930	4450	-	-
Conductivity	mms	5.93	6.44	-	-
TSS	mg/L	1049	707	32.602	60
Turbidity	NTU	48.4	22.26	54.008	50
Color	Co-pt	2760	1390	49.638	-

References

[1] J. El Gaayda, F. Titchou, I. Barra, I. Karmal, H. Afanga, H. Zazou, P.-S. Yap, Z. Abidin, M. Hamdani and R. Akbour, "Optimization of turbidity and dye removal from synthetic wastewater using response surface methodology: Effectiveness of Moringa oleifera seed powder as a green coagulant," *Journal of Environmental Chemical Engineering,* vol. 10, no. 1, p. 106988. https://doi.org/10.1016/j.jece.2021.106988, 2022.

[2] B. Choong Lek, A. Peter, K. Qi Chong, P. Ragu, V. Sethu, A. Selvarajoo and S. Arumugasamy, "Treatment of palm oil mill effluent (POME) using chickpea (Cicer arietinum) as a natural coagulant and flocculant: Evaluation, process optimization and characterization of chickpea powder," *Journal of Environmental Chemical Engineering,* vol. 6, no. 5, pp. 6243-6255. https://doi.org/10.1016/j.jece.2018.09.038, 2018.

[3] G. Prabhakaran, M. Manikandan and M. Boopathi, "Treatment of textile effluents by using natural coagulants," *Materials Today: Proceedings,* vol. 33, no. 7, pp. 3000-3004. https://doi.org/10.1016/j.matpr.2020.03.029, 2020.

[4] H. Shabanizadeh and M. Taghavijeloudar, "A sustainable approach for industrial wastewater treatment using pomegranate seeds in flocculation-coagulation process: Optimization of COD and turbidity removal by response surface methodology (RSM)," *Journal of Water Process Engineering,* vol. 53, p. 103651. https://doi.org/10.1016/j.jwpe.2023.103651, 2023.

[5] C. Igwegbe, J. Ighalo, K. Iwuozor, O. Onukwuli, P. Okoye and A. Al-Rawajfeh, "Prediction and optimisation of coagulation-flocculation process for turbidity removal from aquaculture effluent using Garcinia kola extract: Response surface and artificial neural network methods," *Cleaner Chemical Engineering,* vol. 4, p. 100076. https://doi.org/10.1016/j.clce.2022.100076, 2022.

[6] B. Okolo, P. Nnaji, M. Menkiti and O. Onukwuli, "Process Optimization for Turbidity Removal from Paint Wastewater Using Bio-Coagulant," *Journal of Engineering and Applied Sciences,* vol. 12, no. 1, 2017.