SUSTAINABLE ADSORPTION OF TEXTILE DYES USING AGRICULTURAL WASTE

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Background

Methylene Blue

A synthetic cationic dye widely used in the textile industry. Resistant to natural degradation and poses serious environmental risks.

Aquatic Ecosystem

- ➢ Blocks sunlight; prevents photosynthesis
- ➢ Reduces oxygen levels in water

Toxicity

- ➢ Oxidative stress in aquatic organisms
- ➢ Damages cellular membranes

Human Health

- ➢ Nausea; methemoglobinemia
- ➢ Central nervous system distress

Agricultural Byproducts as Adsorbents

Agricultural byproducts contain natural polymers (cellulose, hemicellulose, lignin) with functional groups (–OH, –COOH) that bind cationic pollutants.

Common Byproducts

Banana Peels | **Coconut Husks** | **Corn Husks**

Rice Husks | **Mango Peels**

Advantages

- ➢ Low cost and wide availability
- ➢ Reduces agricultural waste disposal
- ➢ Minimal environmental impact vs. synthetic materials

Methodology

Adsorbent Engineering

Raw Powder (control)

➢ Peels cut, washed & dehydrated at 105°C / 24h
➢ Pulverized & sieved to particle size < 2 mm
➢ Used directly as control; no further treatment

Heat Treated Biochar

➢ Slow pyrolysis in muffle furnace: 500°C for 2h
➢ Volatile organics removed → porous carbon scaffold

Magnetization

➢ Biochar + $FeSO_4$ + 25% NH_3 (ammonia)
➢ In-situ co-precipitation deposits Fe_3O_4 on surface
➢ Magnetic separation of treated water enabled

Batch Adsorbtion Experiments

Experimental Setup	Data Collection
➢ 0.1 g adsorbent added to 50 mL MB solution (50 mg/L) ➢ Agitated at 150 rpm · constant temperature 25°C ➢ Both adsorbent types tested per biomass	➢ Samples extracted at: 5, 15, 30, 45, 60, 90 minutes ➢ Absorbance measured by UV-Vis at λ = 665 nm ➢ Beer-Lambert Law used to calculate residual Ct (mg/L)

Results: Raw Powder (Control)

40%

Max removal efficiency

Raw Mango

10 MG/G

Peak adsorption capacity

Raw Mango

50%

Max removal efficiency

Raw Banana

14.15 MG/G

Peak adsorption capacity

Raw Banana

Overall

Raw Mango Powder

- ➢ Ct reached minimum of 30 mg/L at 45 min
- ➢ Maximum adsorption capacity: q_{max} = 10 mg/g · Max removal efficiency: 40%
- ➢ Beyond 45 min: fluctuations observed (Ct rising to 37 mg/L) → weak physisorption

Raw Banana Powder

- ➢ Concentration profile: Ct dropped from 50 → 23.5 mg/L almost immediately
- ➢ After 15 min, removal rate stabilized around 50%; robust initial uptake (q_t = 13.25 mg/g)
- ➢ Final adsorption capacity: 14.15 mg/g at 90 min

Results: Heat-Treated Magnetized Biochar

~94 %

Max removal efficiency

HT Mango

23.5 MG/G

Peak adsorption capacity

HT Mango

98%

Max removal efficiency

HT Banana

24.52 MG/G

Peak adsorption capacity

HT Banana

Overall

HT Mango Powder

- ➢ Within 15 min, ~85% of contaminant removed — no leaching (active sites available)
- ➢ Ct declined rapidly from 50 mg/L to below 10 mg/L within 20 min; stabilized at ~3 mg/L
- ➢ Peak removal efficiency: ~94% by end of 90-minute trial

HT Banana Powder

- ➢ Highest removal efficiency of all four materials tested in this study
- ➢ Removal efficiency quickly stabilized at 95–98% range in initial phase
- ➢ Residual Ct stayed below 5 mg/L for most of the experiment
- ➢ Minimal fluctuation in adsorption behavior → stable surface interactions, high active-site density

Results: Comparative Analysis & Statistical Significance

Two-Way ANOVA (Fruit × Treatment, n = 5 per group)

Factor	F-Value	p-Value	Conclusion
Heat Treatment	$F(1,16) = 98.14$	$p < 0.001$	Dominant factor; highly significant
Fruit Type	$F(1,16) = 12.03$	$p = 0.003$	Significant
Interaction (Fruit × Treatment)	$F(1,16) = 5.95$	$p = 0.027$	Significant; unequal treatment effects
Time (15–90 min)	----	$p = 0.278$	Not significant; rapid equilibrium

Key Findings from Post-Hoc Analysis (Tukey HSD)

Heat Treated Groups: Retained significantly LESS dye — Mango: 5.41 ± 2.74 mg/L · Banana: 2.33 ± 1.37 mg/L

Raw (Control) Groups: Retained significantly MORE dye — Mango: 42.40 ± 12.86 mg/L · Banana: 24.70 ± 2.20 mg/L

Tukey HSD Result: No significant difference between the two heat-treated groups ($p = 0.885$) — thermal processing elevated both biosorbents to comparably high efficiency

Conclusions & Future Outlook

Conclusions

- ➢ The lignocellulosic matrix of banana and mango serves as a highly effective precursor for sequestering synthetic dyes from aqueous solutions
- ➢ The comparative analysis confirms that upcycling tropical agricultural waste into functional adsorbents can mitigate the ecological damage caused by industrial textile discharge
- ➢ This study is novel in conducting a comparative analysis of specific tropical byproducts for the synthesis of engineered biochar for water quality restoration
- ➢ Better optimization of low-cost, bio-based adsorbents will help prepare for sustainable water management in developing regions like Bangladesh

Future Outlook

- ➢ Implement adsorbents at industrial scale to remove recalcitrant dyes that standard primary treatments fail to capture
- ➢ Expand experimental matrix to test biochar efficiency against heavy metals commonly found in textile wastewater
- ➢ Investigate desorption capacity of spent biochar via mild chemical washes to enable multi-cycle reuse and reduce cost

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