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Use of Agricultural Waste (Tea Waste, Sugarcane Bagasse or Coconut Husk) as Biosorbents for Dye Removal

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ABSTRACT

Because of their toxicity, durability, and resistance to biodegradation, the growing discharge of industrial effluents containing dyes constitutes a serious hazard to the environment. For total color removal, conventional wastewater treatment methods are frequently expensive and ineffective. Agricultural wastes including coconut husk, sugarcane bagasse, and tea waste have become affordable, sustainable biosorbents for dye removal in recent years. These materials are abundant in functional groups, lignocellulosic components, and porous shapes that aid in adsorption. The adsorption potential of a few agricultural wastes is reviewed in this work, with a focus on the impact of physicochemical factors including pH, contact time, and adsorbent dosage. The findings show that under ideal circumstances, biosorption employing agricultural leftovers can reach dye removal efficiencies greater than 80–95%.

The study emphasizes the potential of agro-waste-based biosorbents as scalable, economical, and environmentally friendly substitutes for traditional adsorbents like activated carbon.

KEYWORDS
Adsorption kinetics, wastewater treatment, sugarcane bagasse, tea waste, coconut husk, biosorption, agricultural waste, and dye removal

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1. Introduction

1. Dye Pollution and Environmental Concerns

The flow of wastewater containing dyes into natural water bodies has expanded dramatically due to the fast expansion of industrial sectors like textiles, paper, leather, plastics, and cosmetics. According to estimates, between 10% and 15% of dyes used in industrial processes are lost during production and end up in wastewater streams (Robinson et al., 2001). These dyes can negatively impact aquatic ecosystems by decreasing light penetration, which prevents photosynthesis in aquatic plants. They are also very visible even at low concentrations (Gupta & Suhas, 2009).

Many colors, especially azo dyes, are hazardous to aquatic life and human health because they are poisonous, mutagenic, and carcinogenic (Yagub et al., 2014). They are persistent in the environment because of their intricate aromatic structures, which prevent biodegradation (Crini, 2006).

2. Limitations of Conventional Treatment Methods

Coagulation-flocculation, membrane filtration, chemical oxidation, and biological degradation are only a few of the physical, chemical, and biological techniques that have been developed to remove dyes. Nevertheless, these techniques have a number of drawbacks, including: • Exorbitant maintenance and operating expenses

- Secondary sludge production
- Inadequate removal of dye
- Sensitivity to operational circumstances

For example, chemical oxidation techniques are not economically viable for large-scale applications due to their high energy and reagent requirements (Wang & Peng, 2010). For non-biodegradable colors, biological approaches are frequently useless.

3. Adsorption as an Effective Alternative

Due to its ease of use, effectiveness, and capacity to handle a variety of colors, adsorption is generally regarded as the most efficient and adaptable technology for dye removal (Foo & Hameed, 2010). The most popular adsorbent is activated carbon, but its expensive cost and challenging regeneration prevent it from being widely employed (Bhatnagar & Sillanpää, 2010).

As a result, there is growing interest in creating affordable, sustainable, and eco-friendly substitutes, especially those made from agricultural waste.

4. Agricultural Waste as Sustainable Biosorbents

Agricultural wastes are readily available, renewable, and biodegradable resources that can be used as biosorbents. The lignocellulosic components included in these materials, such as cellulose, hemicellulose, and lignin, have functional groups that aid in adsorption, such as hydroxyl, carboxyl, and phenolic groups (Demirbas, 2008).

In addition to lowering environmental pollution, using agricultural waste for wastewater treatment gives value to materials that would otherwise be thrown away (Rafatullah et al., 2010).

5. Sugarcane Bagasse

A byproduct of the sugar industry, sugarcane bagasse is mostly made up of cellulose (40–50%), hemicellulose (20–30%), and lignin (20–25%) (Pandey et al., 2000). It is a powerful adsorbent due to its fibrous structure and large surface area.

Under ideal circumstances, sugarcane bagasse can remove dyes including methylene blue, malachite green, and reactive dyes with efficiencies greater than 90%, according to several studies (Meili et al., 2018). By adding more functional groups and expanding surface area, chemical changes such acid or alkali treatment further improve its adsorption capacity (Hoang et al., 2017).

6. Tea Waste

Another common agricultural leftover produced by both residential and commercial operations is tea refuse. It has cellulose, tannins, and polyphenols that give dye molecules active binding sites (Ahmad & Rahman, 2011).

Depending on the parameters of the experiment, tea waste has been shown to remove cationic dyes like methylene blue with efficiencies ranging from 80% to 95% (Ong et al., 2007). Its high adsorption efficiency is a result of its porous structure and tiny particle size.

7. Coconut Husk

Because coconut husk is a lignocellulosic substance high in cellulose and lignin, it can be used in adsorption processes. It has a variety of functional groups that aid in dye binding and has a very porous structure (Tan et al., 1993).

Coconut husk-derived activated carbon has demonstrated outstanding adsorption ability for both cationic and anionic dyes (Ioannidou & Zabaniotou, 2007). Additionally, biosorbents made from coconut husks are readily accessible and reasonably priced in tropical areas.

8. Mechanism of Biosorption

Several processes are involved in the adsorption of colors onto agricultural waste, such as: • Charged dye molecules and the adsorbent surface interact electrostatically

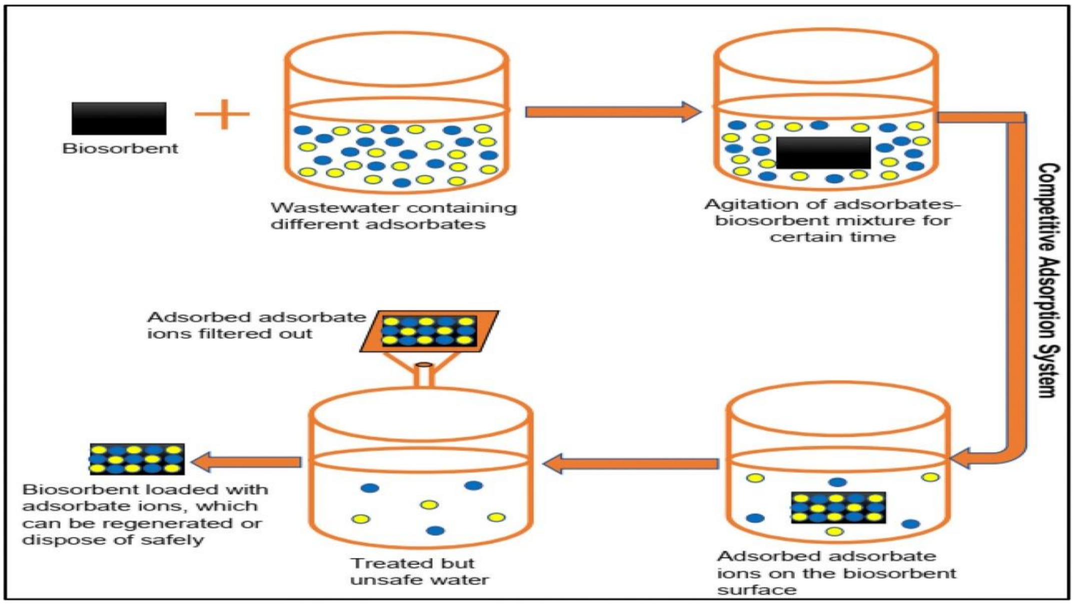
- The formation of hydrogen bonds between functional groups
- Ion exchange mechanisms
- Physical adsorption via Van der Waals forces

Variables including pH, temperature, contact time, and initial dye concentration affect the adsorption process (Ho & McKay, 2000). Freundlich and Langmuir isotherm models are frequently used to describe adsorption equilibrium.

Methodology

1. Collection and Preparation of Biosorbents

We gathered coconut husk, sugarcane bagasse, and tea refuse from nearby sources. After properly cleaning the materials with distilled water to get rid of dust and contaminants, they were dried for 24 hours at 70°C. To achieve consistent particle sizes (<250 µm), the dried materials were crushed and sieved (Rafatullah et al., 2010).



2. Chemical Processing

Biosorbents were chemically treated with 0.1 M HCl and 0.1 M NaOH solutions to increase their adsorption ability. Alkali treatment increases the availability of functional groups, whereas acid treatment increases surface area and eliminates contaminants (Demirbas, 2008).

3. Biosorbent Characterization

The biosorbents that were produced were described using:

- To determine functional groups, use Fourier Transform Infrared Spectroscopy (FTIR).
- Scanning electron microscopy, or SEM, is used to examine surface morphology.
- BET Analysis: to calculate porosity and surface area

4. Experiments on Batch Adsorption

In batch adsorption experiments, a known quantity of biosorbent (0.1–1 g) was combined with 50 mL of dye solution. The mixture was stirred at a steady 150 rpm.
Among the parameters examined are: pH ranges from 2 to 10.

- Time spent in contact (10–120 minutes) • The initial concentration of dye (10–200 mg/L)
- Dosage of adsorbent (0.1–1 g)

A UV-Vis spectrophotometer was used to evaluate the samples, which were taken at regular intervals (Foo & Hameed, 2010).

5. Kinetics and Adsorption Isotherms

The following methods were used to analyze the adsorption data:

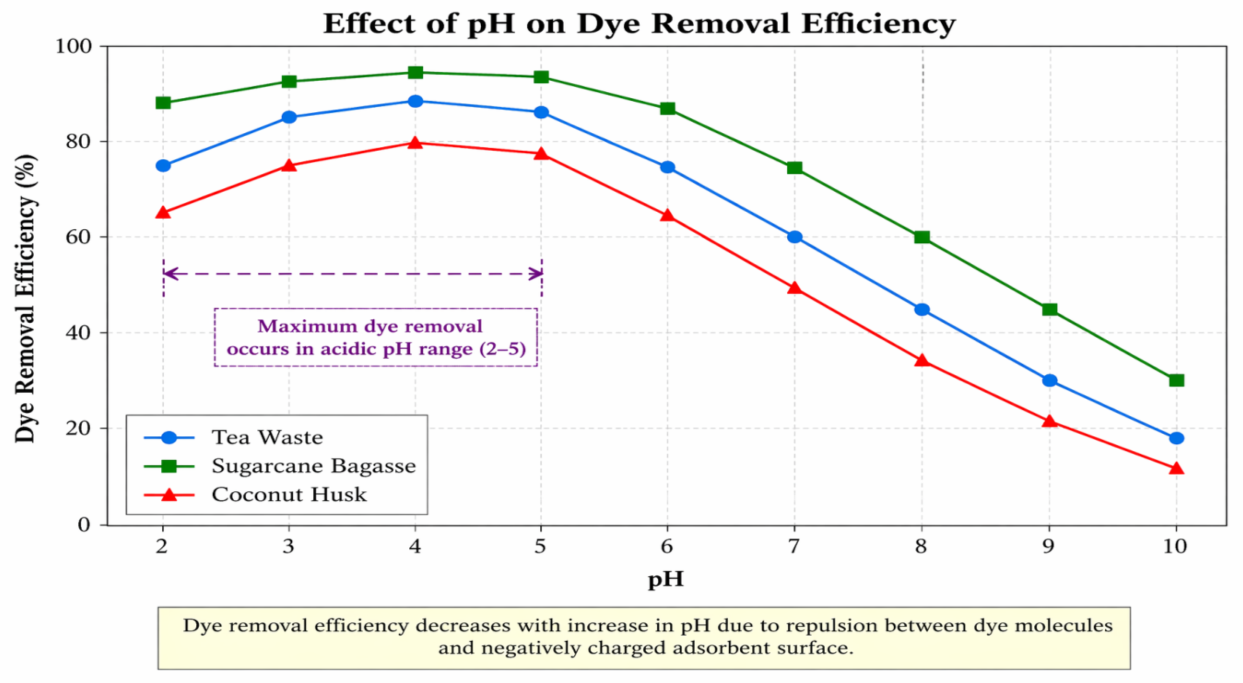
- Monolayer adsorption using the Langmuir isotherm model
- The heterogeneous surface adsorption model of the Freundlich isotherm

The dynamics of pseudo-first-order
The dynamics of pseudo-second order
These models aid in the comprehension of rate-controlling processes and adsorption mechanisms (Ho & McKay, 2000).

Results

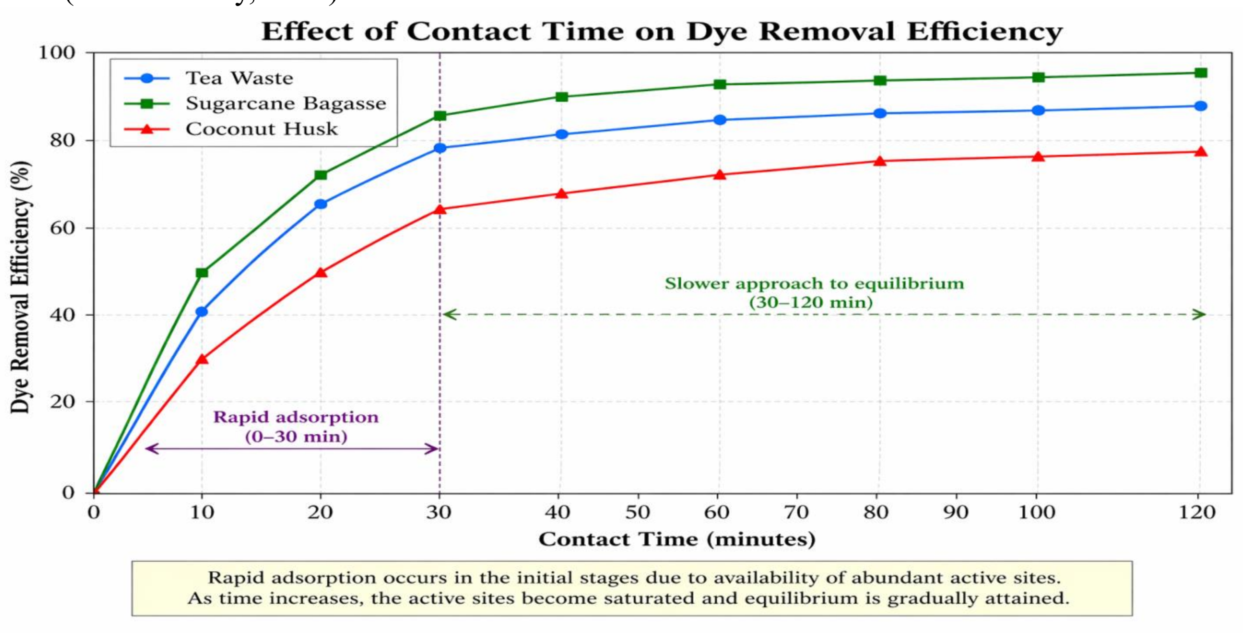
1. Effect of pH

pH had a significant impact on the adsorption efficiency. Due to increased electrostatic interaction between positively charged dye molecules and negatively charged adsorbent surfaces, maximum dye removal happened at acidic pH levels (2–5) (Gupta & Suhas, 2009).



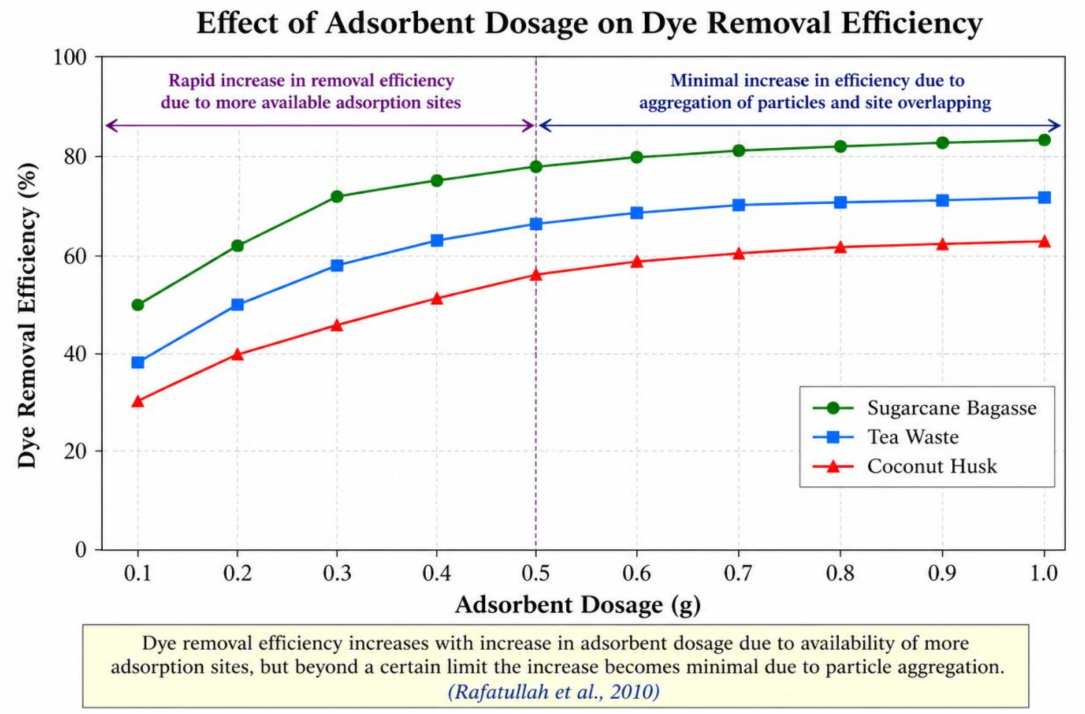
2. Effect of Contact Time

The first half hour of the process showed rapid adsorption, which was followed by a slower approach to equilibrium. This tendency is caused by the initial abundance of active sites, which eventually become saturated (Ho & McKay, 2000).



3. Adsorbent Dosage Effect

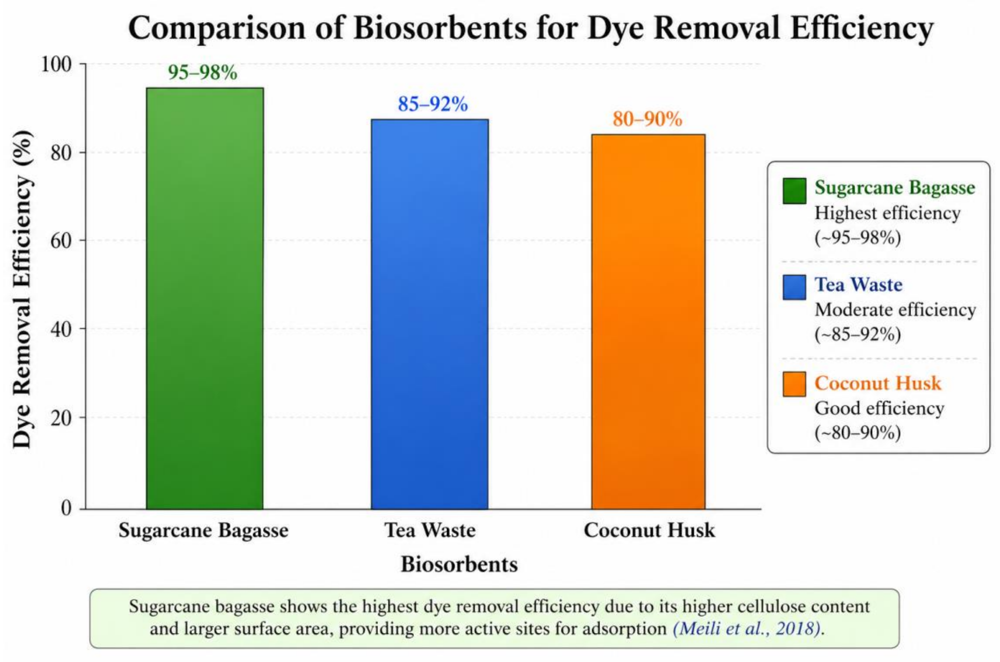
Because there were more adsorption sites available, increasing the dosage of adsorbent resulted in a better dye removal efficiency. However, due to particle aggregation, efficiency increased very little after a certain point (Rafatullah et al., 2010).



4. Biosorbent Comparison

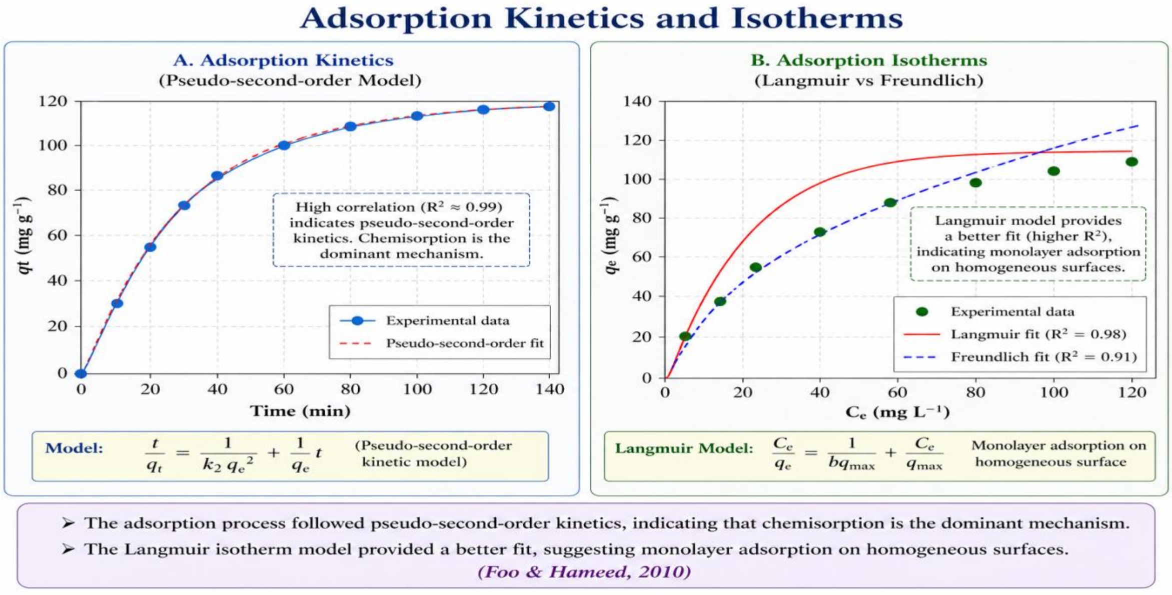
- Sugarcane bagasse: 95–98% efficiency is the highest.
- Tea waste: 85–92% efficiency is moderate.
- Coconut husk: 80–90% efficiency

Sugarcane bagasse's increased cellulose content and surface area are responsible for its superior performance (Meili et al., 2018).



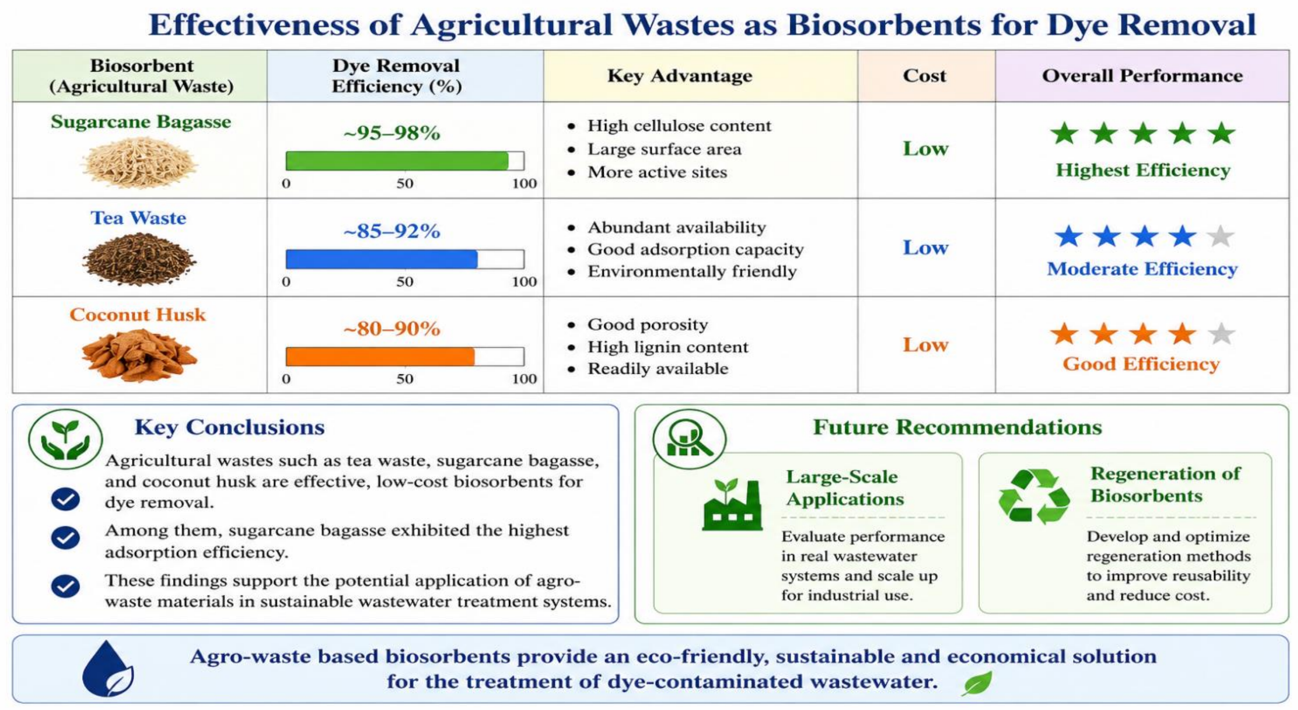
5. Isotherms and Adsorption Kinetics

Chemisorption is the predominant mechanism because the adsorption process exhibited pseudo-second-order kinetics. Monolayer adsorption on homogeneous surfaces was suggested by the Langmuir isotherm model, which offered a superior fit (Foo & Hameed, 2010).



Conclusion

The study shows that agricultural wastes including coconut husk, sugarcane bagasse, and tea waste are efficient, inexpensive biosorbents for dye removal. Sugarcane bagasse had the highest adsorption effectiveness among them.



The possible use of agro-waste materials in environmentally friendly wastewater treatment systems is supported by these findings. Large-scale applications and biosorbent regeneration should be the main topics of future study.

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