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Pineapple Peel As A Natural Biosorbent A Low-Cost Solution To Textile Dye Pollution

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Abstract: The release of synthetic dyes from textile mills is a major environmental issue because the dyes are persistent, toxic, and refractory. Traditional treatments are inadequate because they are costly and not very efficient. In this investigation, the ability of pineapple peel, which is an inexpensive agro-waste, to act as a low-cost and environmentally friendly biosorbent for the removal of dyes from textile effluents is examined. Pineapple peels were ground to fine powder and employed for batch adsorption experiments to assess the influence of particle size, adsorbent dose, contact time, and pH on removal efficiency of the dye. Results showed that the lowest particle size (100 µm) recorded the highest removal of dye (70%), and the best adsorbent dose was 0.1 g, which removed 76%. Maximum adsorption was realized at 150 minutes of contact time (89.2%) and at neutral pH (pH 7). These results emphasize the potential of pineapple peel as a promising biosorbent, providing a green alternative for wastewater treatment from dye-contaminated wastewater and in line with waste valorization and circular economy principles.

***Keywords* -** Pineapple peel, Biosorption, Textile wastewater, Synthetic dyes, Adsorption, Agro-waste, Dye removal, Eco-friendly adsorbent, Wastewater treatment, Low-cost adsorbent.

I. Introduction

The fast pace of industrialization and growth of the textile industry has been a major contributor to economic growth but has also, at the same time, created significant environmental issues. Of these, the release of synthetic dyes from wastewater of textile industries is a serious issue given their persistence, toxicity, and possible carcinogenicity. Worldwide, approximately 700,000 tons of dyes are estimated to be manufactured every year, and almost 10–15% of them are discharged as effluents into water bodies without proper treatment (Yagub et al., 2014).

The conventional techniques of dye removal, such as chemical precipitation, membrane filtration, and advanced oxidation processes, tend to be energy-consuming, costly, and potentially yield secondary pollutants (Crini, 2006). Consequently, emphasis is put on sustainable, inexpensive, and environmentally friendly solutions. Biosorption has become a potential technique, with the passive adsorption of pollutants onto the surface of biological substrates.

Biosorption is the process by which biological materials—particularly agro-waste—are capable of adsorbing contaminants from aqueous solutions through physical and chemical interactions like ion exchange, complexation, and hydrogen bonding (Vijayaraghavan & Yun, 2008). Agricultural by-products have been interesting materials as biosorbents due to their abundance, low prices, and renewable nature. Cell walls of such materials usually have functional groups like hydroxyl, carboxyl, and amino groups, which support adsorption.

Pineapple (Ananas comosus) skin, a fruit processing industry by-product, is produced in high volumes all over the world. Pineapple is one of the most widely grown tropical fruits in the world, and its skin accounts for about 30–35% of the fruit's total weight (Jadhav & Mahadik, 2016). Usually wasted, pineapple skin is rich in cellulose, hemicellulose, lignin, and pectin—substances reported to have dye-binding properties.

The morphology and chemistry of pineapple peel render it an excellent biosorbent. Its porous matrix, along with the availability of several functional groups, increases the adsorption surface area. Its biochemical composition, high in fiber and low in protein and fat, also offers a perfect matrix for functional modification and dye attachment (Oseghale et al., 2019).

A number of studies have underscored the biosorbent potential of fruit peels like banana, orange, and pomegranate, and in recent times, pineapple peel has come under consideration given its similar physicochemical properties. For instance, research has revealed that acid or base-treated pineapple peel possesses enhanced dye removal efficiencies through increased exposure of active sites and porosity (Ali & Gupta, 2007).

Moreover, using pineapple peel aligns with the principles of circular economy and waste valorization, offering dual benefits of waste management and water remediation. The reuse of such agro-waste not only reduces environmental pollution but also minimizes the cost burden associated with commercial adsorbents like activated carbon.

Synthetic dyes, especially azo dyes, are used extensively in the textile industry because they are stable and diverse. The dyes, though, resist biodegradation and tend to bypass traditional treatment mechanisms. Their multi-ringed aromatic structure plays a part in water-body high persistence, which results in acute and chronic toxicity to aquatic species and humans (Robinson et al., 2001). Their exposure is associated with mutagenic, carcinogenic, and allergenic effects (Chung, 2016).

Among the different classes of synthetic dyes, reactive, direct, and disperse dyes are especially troublesome because they have high solubility and low biodegradability. Hence, efficient and environmental-friendly techniques for the removal of these dyes from wastewater are increasingly needed. Low-cost biosorbents such as pineapple peel are especially helpful in developing countries, where textile industries are on the rise and water pollution is a serious issue. This method not only provides an effective solution for dye remediation but also inspires eco-friendly waste utilization. The results of this research may lead to large-scale applications in industrial wastewater treatment facilities and inspire the implementation of green technology.

II. AIM

The main objective of this research is to examine the viability and effectiveness of employing pineapple peel-derived biosorbent in the removal of synthetic dyes from textile wastewaters. The study aims to find out the efficacy of pineapple peel to minimize dye pollution as well as enhance water quality through the adsorption process.

III. MATERIALS AND METHODS

1. Collection of Pineapple peel

Pineapple fruit peels were employed as the adsorbents which were obtained from the nearby juice shop and home. The peels were gathered in dry, clean and transparent plastic bags and transported to the lab.

2. Preparation of Pineapple peel adsorbent

Pineapple peels, often wasted, were gathered and treated with an eco-friendly process. Pineapple peels were rinsed well with deionized water to remove dirt and other impurities. The peels were then air-dried at room temperature for three days. The peels were subsequently cut into small pieces and arranged separately on a tray before oven-drying at 90 °C for two hours. The peels were then dried and powdered using a domestic mixer to make them ready for adsorption tests. The powder's weight was taken, and the material was placed in plastic bags and kept in a cold room for storage (Azamzam et al., 2022; Ben-Ali, 2021; Shaharom, 2019). It should be noted that the yield of sorbent was adequate for all the experiments and characterizations planned. For the collection of different particle sizes for the purpose of study, powdered material was sieved using 300 µm, 200 µm, and 100 µm mesh sizes. All the materials were immersed in 1N HCl for 5 hrs and then washed with distilled water, dried, and utilized for the study.

Fig 1 : Pineapple peel for adsorbent preparation

3. Textile effluent collection

Sample of waste water was collected from textile dyeing unit, Tirupur district. Translucent plastic bottle containing effluent was tightly capped. Sample was stored at room temperature until use.

4. Batch Adsorption Study

Batch adsorption experiments were performed in order to investigate maximum removal of color from textile wastewater. The impact of different parameters was studied in this research, including the use of adsorbent quantity, contact time, pH values, and the influence of particle size. The sample solution of 50 mL was used for each trial run, and an equivalent amount and/or needed amount of different concentrations of the adsorbent was added at room temperature. The bottles were maintained in orbital shaker at 300C temperature at 150 rpm. Aliquots were removed from every batch at regular time intervals and filtered with whatman filter paper no. 42 to divide the solid adsorbent and the liquid phase. The optimum dose of adsorbent and the equilibrium time were optimized by conducting the same experiment under different conditions. The above supernatant solutions obtained were then scanned with a UV spectrophotometer to determine the absorbance that gave information on the concentration of the adsorbate that remained. Percentage removal was determined using the equation

4.1 Impact of adsorbent dosage

Various adsorbent doses i.e. pineapple peel used like 0.025g to 0.4 g (0.025, 0.05, 0.1, 0.2 and 0.4 g) with 50 ml textile wastewater in polyethylene bottle in orbital shaker at around 30 0C and 150 rpm.

4.2 Impact of time

In order to examine the influence of time on effective colour removal from textile waste, the research was conducted. Influence of contact time was explored at 30, 60, 90, 120, 150 and 180 minutes at pH 7.

IV. RESULTS AND DISCUSSION

Physicochemical properties of local textile dye effluent are

Colour- dark blue, odour -odourless, pH -10.

4.1 Effect of Particle Size of adsorbent

Adsorbate particle size in adsorption has crucial role because the adsorption process has a complete reliance on surface area of the adsorbent material. Adsorbent dose (0.075 g) and contact time (1 hr) were maintained the same in every batch. Particle sizes were also changed from 300µm, 200µm and 100µm. Removal percentages of dye were quantified for different particle sizes. Table. 1 shows the results for maximum colour removal of dyes with varying particle sizes of adsorbent.

Table 1: Effect of Particle Size of adsorbent

S. No	Particle Size of Adsorbent	Colour removal of dyes (%)
1	100 µm	70
2	200 µm	57
3	300 µm	49

size of the adsorbent. The maximum removal of color (70%) was obtained with the smallest particle size (100 µm), whereas minimum removal (49%) was observed with the largest particle size (300 µm).

This is because the surface area increases with a decrease in particle size. Finer particles yield greater surface area and greater active adsorption sites, which facilitate greater interaction among dye molecules and adsorbent. The larger particles are characterized by lower surface area and fewer accessible sites, which reduce efficiency in adsorption.

These results corroborate with past research that indicated smaller particles of the adsorbent tend to enhance adsorption efficiency through enhanced mass transfer and greater surface contact between the adsorbate and the surface of the adsorbent. Hence, the optimization of particle size of the adsorbent is an important parameter in enhancing the efficiency of dye removal in wastewater treatment processes.

4.2 Influence of adsorbent dose

Adsorbent dose is an effective factor in the removal of dye. Various doses of adsorbent i.e. Pineapple peel taken like 0.025 g to 0.2g with 50 ml textile effluent in conical in orbital shaker for 1 hr at around 30°C and 150 rpm. The results are given in table 2.

Table 2: Influence of adsorbent dosage on dye removal efficiency

S. No	Adsorbent dose	Color removal of dyes (%)
1	0.025 g	49
2	0.050 g	58
3	0.100 g	76
4	0.2 g	65
5	0.4 g	62

From the data, it can be seen that the removal efficiency of the dye increases with the rising adsorbent dose initially, up to a maximum of 76% at an adsorbent dose of 0.100 g. After the optimal dose, there is a continuous fall in removal efficiency, with 65% and 62% removal at 0.200 g and 0.400 g, respectively.

The increased removal of the dye in the initial stages can be explained by the higher number of active adsorption sites available as more adsorbent is added to the system. Nevertheless, beyond a specific dosage (0.100 g), increased dosages of adsorbent cause a drop in removal efficiency. This may be caused by adsorbent particle agglomeration at higher dosages, which lowers the total surface area available for the adsorption process. Moreover, at increased concentrations, inter-particle interactions and potential saturation of adsorbate molecules can be responsible for inhibiting effective dye uptake.

These observations indicate that there exists an optimum adsorbent dose, above which the efficiency does not increase but could even decrease. For this reason, optimization of the adsorbent dose is critical to attain maximum dye removal in adsorption-based treatment processes.

4.3 Impact of contact time

Effects of contact time on adsorption were investigated and the results are presented in table 3. The experiment was carried out with varying contact time (30-180 minutes), textile effluent solutions (50 mL) were shaken with pineapple peel adsorbent of dosage (0.1g) in conical flask. Sample was drawn off from beaker at predetermined time interval of 30 min each and the results are compared to initial colour concentration of waste water in order to find colour removal efficiency of adsorbents.

Table 2: Influence of contact time towards the dye removal efficiency

S. No	Adsorbent Contact time	Colour removal of dyes (%)
1	30 min	58
2	60 min	74
3	90 min	82
4	120 min	88.5
5	150 min	89.2
6	180 min	87

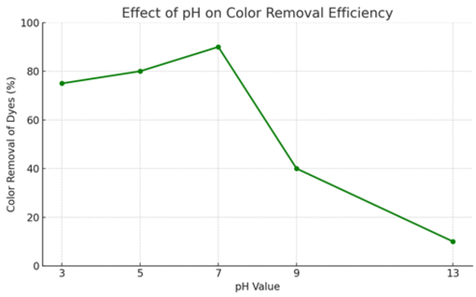
The findings reveal that the efficiency of color removal grows with contact time to a maximum of 89.2% at 150 minutes. Initially, the rapid adsorption is because of the presence of numerous active binding sites on the adsorbent surface. Between 30 and 120 minutes, an excellent increase in the removal of dye is encountered, reflecting active adsorption.

Nonetheless, after 150 minutes, the colour removal rise becomes insignificant, and there is a slight drop at 180 minutes (87%). It is an indication that equilibrium had almost been achieved at 150 minutes, and the majority of the adsorption sites had been occupied. The minimal drop afterwards may be attributed to desorption or reorganization of dye molecules, or saturation of the adsorbent surface.

These results suggest that 150 minutes is the best contact time for the highest removal of dye through the prepared pineapple peel adsorbent. Extending the contact time past this point does not much improve removal efficiency and could not be economically practical for large-scale processes.

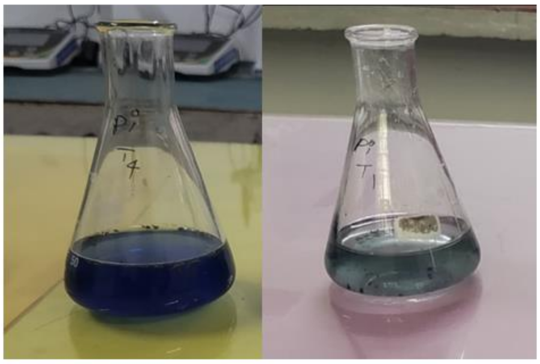
4.4 Effect of pH

The hydrogen ion concentration (pH) mainly influences the extent of ionization of the dye and the nature of the adsorbent surface. These, consequently, cause changes in the quantity of the dye removed. In order to investigate the influence of pH on colour removal capability of Pineapple peel, colour removal was investigated at pH between 3 and 13 (pH 3, 5, 7, 9, 13) by regulating pH of waste water sample with dil. HCL and NaOH solution. The maximum decolourisation of waste water is at pH 7. The removal is pH-dependent to some extent and it is observed that most of the adsorbent exhibits variation in adsorption capacity with the change in pH. At pH greater than 7, the adsorption was found to be negligible. But by



decreasing the pH, the removal of dye was increased (Fig 2).

Fig 2. Effect of pH on the adsorption of dyes



A **B**

Fig 3. Bio-adsorbent

A) Pre-treatment by pineapple peel adsorbent and

B) Post-treatment by pineapple peel adsorbent for textile effluent dye removal efficiency

V. CONCLUSION

The current research examines the effectiveness of pineapple peel powder as a cheap, environmentally friendly natural adsorbent for dye removal from wastewater. The adsorbent was synthesized through a green route by beginning with the collection and extensive washing of pineapple peels with deionized water. The peels were dried at room temperature for three days, and then oven-dried at 100°C for two hours. The material was then ground into a powder with a domestic mixer and then sieved with 50 µm, 100 µm, and 200 µm mesh to obtain particles of varying sizes for adsorption experiments.

Batch adsorption experiments were carried out to examine the effect of various factors, that is, particle size, adsorbent dosage, contact time, and pH, on the efficiency of dye removal. The findings of each parameter are presented below.

Three particle sizes (100 µm, 200 µm, and 300 µm) were tested. The findings illustrated that smaller particles (100 µm) removed the maximum amount of dye (70%), while larger particles (300 µm) performed with less efficiency at 49%. The enhanced performance with smaller particles is due to their larger surface area and higher active binding sites for adsorbing dyes.

Dose variation of the adsorbent from 0.025 g to 0.4 g revealed that the efficiency of removal of the dye increased with dose to 0.100 g, where 76% maximum removal was obtained. Surprisingly, increase in dose beyond this resulted in a decline in removal efficiency (down to 62% at 0.4 g), probably because of particle aggregation and lower surface area per unit weight, restricting adsorption.

Adsorption experiments performed with varying contact times (30 to 180 minutes) showed a continuous increase in dye removal as a function of time, with a maximum of 89.2% at 150 minutes. A decrease was seen after this, implying adsorption equilibrium was achieved. This implies that 150 minutes is a suitable contact time for effective dye removal.

The pH of the dye solution was also adjusted between 3 to 13 to determine its impact on efficiency of adsorption. The findings indicated that the highest color removal was achieved at neutral pH (pH 7). Acidic pH (pH 3 and 5) also favored the removal of the dye but by a lesser margin. At low pH values (≥9), the removal efficiency dropped drastically and went to zero at pH 13. This is because of variations in the ionization state of the dye molecules as well as the surface charge of the adsorbent, which influence electrostatic interactions.

The results of this research show that pineapple peel powder can be used as a good and eco-friendly adsorbent for dye removal from wastewater. The activity of the adsorbent depends on a number of factors. Particle Size: Adsorption is improved with smaller particles due to the greater surface area. Adsorbent Dose: There is a maximum dose (0.100 g) after which the efficiency can decrease. Contact Time: Adsorption varies with contact time and equilibrium at about 150 minutes. pH Level: Adsorption is pH-sensitive, with best efficiency at pH 7. These findings indicate that pineapple peel, a crop waste material, can be reused as a potential material for water treatment purposes, aiding waste management and pollution abatement in an economical and eco-friendly way. Additional research can investigate the regeneration and recyclability of the adsorbent, and its effectiveness using actual industrial effluents, to confirm its applicability in practice.

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