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Evaluation of Mucilage from Saluyot (*Corchorus olitorius*) as Natural Coagulant for the Removal of Crystal Violet Dye from Simulated Textile Wastewater

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The textile industry is a major global contributor to environmental pollution, particularly through the discharge of untreated effluent containing toxic chemicals and dyes from processing operations. A critical challenge within the industry is the effective removal of colorants and dyestuffs from wastewater, particularly those arising from dyeing and finishing processes. Various treatment methods have been explored to address textile dyeing effluent, with coagulation being one of the most widely employed techniques for dye removal. Commercial coagulants, such as aluminum sulfate, are commonly utilized however, they are sensitive to pH variations and often generate substantial sludge volumes, which complicates waste management. This study explores the use of *Corchorus olitorius* (saluyot) as a natural coagulant for the removal of crystal violet dye from aqueous solutions. Mucilage was extracted from saluyot leaves using a conventional extraction method and characterized using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM) to confirm its functional properties. The effects of varying coagulant concentrations and initial dye concentrations on the color reduction of crystal violet solutions were investigated. Optimal dye removal of 72.56 % was achieved using 100 ppm saluyot mucilage at an initial dye concentration of 200 ppm and a pH of 6.25. The results suggest that saluyot mucilage, being non-toxic, abundantly available, and biodegradable, presents a promising alternative to conventional coagulants for the removal of crystal violet dye from aqueous solutions. These findings highlight the potential of utilizing plant-based coagulants as an environmentally sustainable and cost-effective solution for textile wastewater treatment.

1. Introduction

The textile industry's high-water consumption in production leads to significant volumes of wastewater containing both toxic chemicals and dyed components. During the dyeing process, approximately 10–15 % of these dyes are discharged into wastewater, often without adequate treatment (Dutta et al., 2022). This effluent is typically characterized by high coloration, chemical oxygen demand (COD), biological oxygen demand (BOD), and salt content, all of which pose risks to aquatic ecosystems and public health (Azanaw et al., 2022). Dyes reduce light penetration in water bodies, disrupt photosynthesis, and lower dissolved oxygen levels, affecting aquatic biodiversity (Moradihamedani, 2022). The complex and stable structure of dyes poses challenges for their degradation, which results in their persistence in the environment for extended periods (Wang et al., 2022) and difficult to eliminate by conventional methods of wastewater treatment (Correa-Mahecha et al., 2023). Among synthetic dyes, crystal violet (CV) — a cationic triphenylmethane dye widely used for dyeing textiles such as cotton, wool, and silk — is particularly problematic. Given its widespread use and toxicity, the effective removal of CV from wastewater remains a pressing environmental challenge.
Various physical, chemical, and biological technologies have been explored for dye removal, including membrane filtration, adsorption, advanced oxidation, and electrochemical treatment. However, many of these methods are expensive, energy-intensive, or generate secondary pollution (Butani and Mane, 2017).

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Coagulation-flocculation, in contrast, stands out for its operational simplicity, cost-effectiveness, and ability to handle large volumes of dye-laden wastewater. It is commonly applied either as a primary treatment or as a pre-treatment step (Mcyotto et al., 2021).

The coagulation-flocculation process involves three key steps: destabilization of suspended particles using a coagulant, agglomeration into larger flocs via flocculation, and removal through sedimentation or filtration (Ihaddaden et al., 2022). Despite its advantages, conventional coagulants like alum ($Al_2(SO_4)_3$) and ferric salts ($FeCl_3$, $FeSO_4$) are associated with significant drawbacks, including high sludge production, pH fluctuations, and potential health risks (Yin, 2010). These limitations have driven growing interest in natural plant-based coagulants, which offer advantages such as low toxicity, biodegradability, and reduced sludge volume (Mathuram et al., 2022).

Plant-derived mucilage, rich in polysaccharides, has emerged as a promising bio-coagulant. These natural polymers can form viscous gel-like structures in water and effectively destabilize colloids through charge neutralization and bridging mechanisms (Le et al., 2022). Among mucilaginous plants, okra (Abelmoschus esculentus) has been widely studied due to the presence of galacturonic acid, a key component in coagulation activity (Freitas et al., 2015). However, other underutilized plants with similar properties remain less explored.

Corchorus olitorius, commonly known as saluyot or Jew's mallow, is one such candidate. This tropical plant grows abundantly in regions like Southeast Asia and Africa, often without the need for intensive cultivation (Islam, 2013). Saluyot leaves produce mucilage with similar rheological and chemical characteristics to okra. A study by Oh and Kim (2022) found that *C. olitorius* mucilage is composed primarily of uronic acids (34.24 % w/w), along with rhamnose, galactose, and other sugars known to contribute to coagulating efficiency.

While plant-based coagulants and mucilages such as okra have been extensively studied for dye removal from wastewater, research on the use of *C. olitorius* mucilage particularly for removing the cationic dye CV is limited. Saluyot shares mucilaginous properties and chemical components similar to well-established natural coagulants, yet its application in coagulation-flocculation processes targeting synthetic dyes remains underexplored. Although some studies have examined its general potential in domestic wastewater treatment, its effectiveness specifically against textile dye effluents like CV has not been comprehensively investigated.

This study addresses this gap by isolating mucilage from *C. olitorius* and evaluating its coagulation-flocculation performance in removing CV dye from aqueous solutions. The research aims to contribute toward sustainable and cost-effective alternatives to conventional coagulants, particularly in regions where saluyot is locally available and widely cultivated.

2. Materials and Methods

2.1 Isolation of Saluyot Mucilage

The fresh leaves of saluyot were collected within the vicinity of Biñan City, Laguna. The leaves were washed with water to remove dirt and then sun-dried for 2 d. The dried leaves were powdered using a CPL-1060P blender, placed to a 1 L beaker containing distilled water, with 100 g of leaf material mixed at a 1:7 (w/v) ratio. The mixture was soaked for 5–6 h, boiled for 30 min, and then kept aside for 1 h for complete release of mucilage into the water. It was then squeezed using a three-fold cheese cloth to remove the residue, which was the leaves, from the solution. To precipitate the mucilage, 95 % ethanol was added to the filtrate at a 1:3 (v/v) ratio, in which one volume of filtrate was mixed with three volumes of ethanol. The mucilage was separated, dried in an oven at a temperature <50 °C for 12 h. To even out the texture of the obtained dried mucilage, CPL-1060P blender was used. The dried and powdered sample was stored in an airtight container with silica gel for further use. The percent recovery was calculated using Eq(1).

$$\%\,Recovery = \frac{weight\ of\ dried\ mucilage}{weight\ of\ dried\ leaves} \times 100 \tag{1}$$

2.2 Characterization of Saluyot Mucilage

Fourier Transform Infrared (FTIR) Spectroscopy was utilized to identify the functional groups present in the saluyot mucilage. To analyze the surface morphology, a Scanning Electron Microscope (SEM) was employed, providing detailed imaging of the mucilage's surface topography.

To estimate the pH at the point of zero charge (PZC), saluyot mucilage was dissolved in distilled water to prepare suspensions with concentrations of 1 %, 5 %, 10 %, 20 %, 30 %, and 40 % (w/w). The prepared solutions were placed in a beaker and were stirred for 24 h using magnetic stirrer at room temperature, with a volume of 30.0 mL. The pH of the suspensions was measured using a PH600 pH meter after 24 h of contact time, during which pH equilibrium was achieved across all concentrations. The pH readings were then plotted against their corresponding concentration values and pH at the point of zero charge (PCZ) of the mucilage was analyzed.

2.3 Preparation and Characterization of Crystal Violet (CV) Solution

To prepare a 500 ppm stock solution, 500 mg of crystal violet dye was dissolved in 1 L of distilled water. The prepared stock solution was then stored in an amber glass bottle. Working solutions were prepared by simple dilution. The initial pH of the CV solution was determined using PH600 pH meter and the initial color was determined using Hach spectrophotometer DR/890.

2.4 Determination of Optimum Concentration of Coagulant (Saluyot Mucilage)

Coagulant solutions were prepared at concentrations of 100, 150, 200, 250, and 300 ppm. The pH values of the coagulants were adjusted using 0.1 M HCl and 0.2 M NaOH at the desired pH value of 6.0. The effect of coagulant dosage on the removal of CV from aqueous solution was investigated by using 30.0 mL of 200 ppm CV solution. The solutions were stirred using magnetic stirrer for 3 min at 120 rpm, and then slowly mixed at 60 rpm for 30 min. The mixtures were left undisturbed for 30 minutes to allow particle aggregation, after which the supernatant was collected and filtered using Whatman No. 41 filter paper. The concentration of the remaining dye was measured using a DR/890 Hach colorimeter.

2.5 Determination of Color Reduction Against Varying Dye Concentration

CV solutions with concentrations of 300, 400, and 500 ppm were prepared and treated using the optimal concentration of the coagulant determined in the previous step. The treatment process followed the method outlined in the previous procedure, and the pH for the different dye concentrations remained consistent with that described earlier.

3. Results and Discussion

3.1 Physical Characteristics and Yield of Saluyot Mucilage

The mucilage extracted from saluyot demonstrated a percent recovery of 6.21% on a dry weight basis. This value is lower than reported in Oh and Kim (2022) which was 10.24 %. The lower mucilage recovery observed in this study may be attributed to several factors. Environmental growth conditions, including soil quality, temperature, and moisture, can influence mucilage biosynthesis in saluyot, resulting in variability in yield. Notably, Oh and Kim (2022) utilized saluyot cultivated in Egypt, where distinct environmental and agricultural conditions may have contributed to the higher mucilage content reported. The maturity stage at harvest likely affected mucilage accumulation, as polysaccharide content can vary throughout plant development. Differences in extraction procedures, including sample-to-solvent ratios, precipitation conditions, and drying parameters may also contribute to discrepancies in recovery efficiency. Genetic variation among saluyot cultivars used may further explain the observed differences. Lastly, variations in sample handling and drying methods could impact the measured dry weight, thereby influencing the reported mucilage yield. It also exhibited a brownish hue and was characterized by a distinctive, pungent odor.

3.2 Point of zero charge of saluyot mucilage

Understanding the pH at which a coagulant's surface charge is neutralized is crucial for optimizing its performance in coagulation processes. The point of zero charge (PZC) refers to the pH at which the coagulant's surface has an overall neutral charge, resulting in no net electrostatic attraction or repulsion. Below this point, the surface carries a positive charge, while above it, the surface becomes negatively charged. In this study, the coagulant exhibited a PZC of 5.9, slightly acidic due to the presence of uronic acids, which is consistent with the value of 5.6 reported by Oh and Kim (2022). Thus, at pH values above 5.9, the coagulant assumes a net negative charge, which is favorable the charge stabilization of positively charged crystal violet dye molecules. To maximize coagulation efficiency, the pH should be adjusted to above the PZC, ensuring the coagulant carries a negative surface charge conducive to electrostatic interaction with the dye.

3.3 Characterization of saluyot mucilage

The predominant functional groups, as shown in Figure 1, confirm the presence of peak characteristics typical of polysaccharides, aligning with the findings reported by Oh and Kim (2022). The peak in the region of 1033.85 cm^{-1} denotes C–O ring vibrations of the main carbohydrates and could be associated with the presence of uronic acids. The band at 1,259.52 cm^{-1} can be attributed to acetyl groups associated with pectic residues. The peaks near the region of 1,537.27 cm^{-1} refer to the stretching of the C=O (carboxylic acid carbonyl) bond. The peaks in the region of 2,920. 23 cm^{-1} indicative of C–H asymmetric stretching, typically arising from methyl and methylene groups within monosaccharide structures. The distinct peak at 3,603.03 cm^{-1} corresponds to O–H stretching and bending vibrations, characteristic of hydroxyl groups. The presence of carboxylic acid carbonyl groups, aromatic rings, and hydroxyl groups in saluyot mucilage corresponds to its composition of polysaccharides, tannins, and galacturonic acid. These components have been studied in okra mucilage, where they are responsible for its coagulation activity (Freitas et al., 2015). Given the similarity in composition between saluyot and okra mucilage, it is reasonable to consider that these groups also contribute to its coagulation ability.

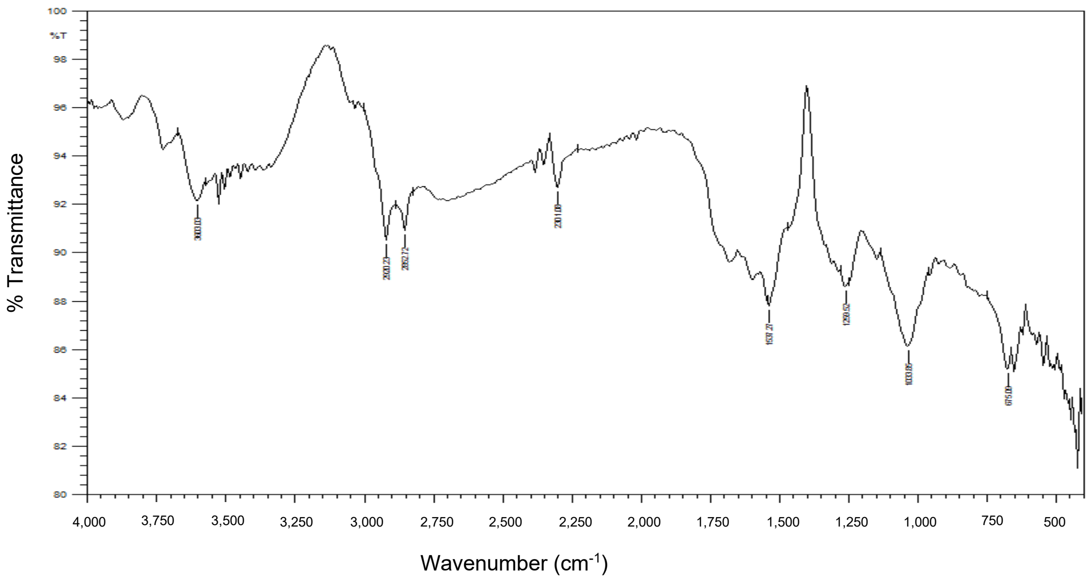

Figure 1: FT-IR Spectrum of saluyot mucilage (Corchorus olitorious)

The surface morphology of saluyot mucilage, as observed under SEM (Figure 2), exhibits an irregular structure characterized by visible voids and porous-like regions. Although quantitative analysis was not conducted, these morphological features suggest a relatively high surface area that may facilitate the adsorption of dye molecules. This observation aligns with previous reports on plant-derived mucilaginous coagulants, which commonly exhibit porous microstructures that enhance their flocculation and adsorption performance. SEM micrographs of *Salvia hispanica* (chia seed) mucilage, have revealed a network-like architecture with open channels and fibrous matrices, which have been associated with elevated adsorption capacity and surface activity (Darwish et al., 2018). The similarity in morphological characteristics supports the potential of saluyot mucilage to act as an effective biocoagulant in dye removal applications.

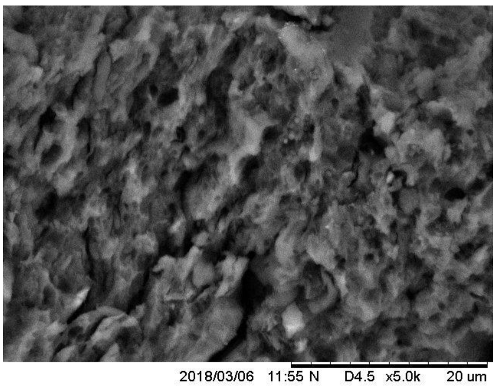

Figure 2: SEM micrograph of saluyot mucilage (Corchorus olitorious)

3.4 Characterization of simulated textile wastewater.

The prepared 200 ppm CV aqueous solution had an initial pH of 6.5 and an initial total color unit (TCU) of 344 ppm.

3.5 Effect of coagulant dosage on color reduction

The influence of coagulant dosage on CV removal was investigated across dosages ranging from 100 ppm to 300 ppm at pH 6.0. This was conducted using 30 mL of 200 ppm CV solution, stirred initially at 120 rpm for 3 min, followed by 60 rpm for a contact time of 30 min at room temperature. The results are illustrated in Table 1.

Table 1: Effect of coagulant dosage on the removal of CV from aqueous solution

Coagulant Dosage (ppm)	Average Final TCU (ppm)	Average Removal (%)	Average Final pH
100	93.2	72.56	6.25
150	118.0	65.35	6.50
200	146.4	57.67	5.65
250	204.8	40.23	5.95
300	311.6	9.07	6.45

The experimental results indicate that increasing the coagulant dosage decreases the average percentage of CV removed from the aqueous solution. A coagulant dose of 100 ppm yielded the highest removal efficiency at 72.56 %. This demonstrates that saluyot mucilage coagulant effectively treats 200 ppm of simulated textile wastewater at pH 6.0, reaching its maximum coagulation capacity. At 300 ppm of coagulant concentration, there was a sudden decrease in color reduction, indicating overdosing during the coagulation-flocculation process. Overdosing reduces supernatant quality by causing color particles to restabilize, hindering effective coagulation. Excessive coagulant concentration can lead to excessive polymer adsorption, potentially reversing particle charge (Obiora-Okafo and Onukwuli.2017). Excessive coagulant dosage can lead to the restabilization of dye solutions, especially with highly soluble-reactive dyes, which is a well-known issue in the flocculation process. When the coagulant concentration exceeds what is necessary for effective coagulation, it can increase repulsive forces between the coagulant and the dye in solution. This interference hampers the formation of flocs, reducing the efficiency of color reduction (de Souza et al., 2014). Furthermore, the absence of significant changes in final pH following treatment suggests that saluyot mucilage exhibits pH-neutral behavior, which is advantageous for maintaining water quality without additional pH adjustment.

3.6 Effect of dye concentration on color reduction

Following the determination of the optimal coagulant concentration (100 ppm), its effectiveness in reducing color was tested at varying initial dye concentrations of 300, 400, and 500 ppm. The results are presented in Table 2.

Table 2: Color Removal Efficiency of Optimized Coagulant Dose at Varying Initial Dye Concentrations

Initial CV Concentration (ppm)	Initial TCU (ppm)	Average Final TCU (ppm)	Average Removal (%)	Average Initial pH	Average Final pH
300	787.2	265.0	66.34	6.9	6.80
400	1,570.2	414.0	73.58	4.9	4.95
500	1,990.4	574.4	71.14	5.7	6.05

Increasing the dye concentration from 200 ppm to 300 ppm resulted in a decrease in removal efficiency from 72.56 % to 66.34 %. This decline is primarily due to the formation of particle–polymer–particle complexes, where the polymeric coagulant acts as a bridging agent between dye molecules. The polymer's functional groups adsorb onto dye or colloidal surfaces, leaving free segments to bind additional particles and facilitate flocculation. However, this mechanism's effectiveness depends on the availability of active sites, which become saturated at higher dye concentrations (Mishra and Bajpai, 2005). When the dye loading exceeds the coagulant's adsorption capacity, unadsorbed dye particles remain in solution, reducing color removal efficiency and hindering sedimentation (Yin, 2010). At 400 ppm and 500 ppm, the pH values (4.9 and 5.7, respectively) fall below the pKa of crystal violet (5.31), as a consequence of the solution preparation rather than intentional pH adjustment. Under these acidic conditions, the dye exists predominantly in its fully protonated cationic form, enhancing electrostatic attraction to the anionic polymeric coagulant and improving flocculation. The highest removal efficiency (73.58 %) was observed at 400 ppm, where both pH and concentration conditions favored strong dye–polymer interactions. At 500 ppm, removal efficiency slightly decreased to 71.14 % likely due to due to saturation of the coagulant's flocculation capacity. In contrast, the 200 ppm and 300 ppm solutions, with pH values above the dye's pKa, contained partially deprotonated dye molecules. This reduced the dye's cationic character and weakens interaction with the polymeric coagulant, resulting in lower removal efficiencies. Notably, the final pH values remained largely unchanged after treatment, suggesting that saluyot mucilage exhibits pH-neutral behavior and does not significantly affect the solution's acidity or alkalinity.

4. Conclusions

The mucilage extracted from saluyot leaves exhibited polysaccharide-like functional groups and a porous surface morphology, as shown by FT-IR and SEM analyses. At an optimal dosage of 100 ppm, it achieved 72.56 % removal of crystal violet (CV) from a 200 ppm solution. Optimal removal of crystal violet dye is achieved when the dye is fully protonated and the coagulant's active sites remain unsaturated, highlighting the critical balance between pH, dye concentration, and adsorption capacity in maximizing flocculation efficiency. Removal efficiencies remained consistent at higher dye concentrations, indicating stable performance within a moderate range. The mucilage did not significantly alter the treated solution's pH, suggesting pH-neutral behavior. While these results highlight its potential as a natural coagulant, the study was limited to simulated wastewater and a single dye. Further research is needed to evaluate cost, sludge generation, reusability, and performance in real wastewater systems.

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