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Moringa Olifera-Based Magnetic Biocoagulant Application to Mitigate Congo Red Parameters

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Abstract

The population growth rate has been demonstrated to have a direct impact on the increase in pollutant concentrations released into water bodies. One of the pollutants that has been identified in water bodies is Congo red. This necessitates the implementation of effective management strategies to mitigate the adverse effects of pollutants. A methodology that has been demonstrated to be effective in mitigating the impact of Congo red is the coagulation-flocculation process. The objective of this study is to employ biocoagulants and magnetic biocoagulants derived from *Moringa oleifera* as mass separation agents to mitigate the adverse effects of Congo red. The effectiveness of the mass separation agents was evaluated with varying initial concentrations of Congo red. The augmentation of the initial Congo red concentration yielded consistent results for both biocoagulants and magnetic biocoagulants. The highest results were obtained at an initial Congo red concentration of 100 ppm, with a value of 97.34% for the magnetic coagulant. The coagulation-flocculation process can occur through several mechanisms, including charge neutralization, floc formation, and sedimentation.

Keywords: Biocoagulant, Coagulation-flocculation, Congo red, Magnetic biocoagulant, *Moringa oleifera*

1. Introduction

Water is an essential element for all living organisms. However, contemporary challenges arise from water stress, which is precipitated by the deterioration of water quality. This has the potential to disrupt the utilization of water resources (Li et al., 2020). The issue of poor water quality is attributable to population growth, which has led to an increase in pollutants released into the environment by industrial activities. The improper treatment of pollutants has been demonstrated to have deleterious effects on the environment and to diminish the quality of life (Amtul Bari et al., 2024). One contaminant that has been identified in various water bodies is Congo red.

Congo red, a diazo dye, is a prevalent compound in the textile, paper, and rubber industries (Sudarsan et al., 2025). Congo red's unique characteristics, which are impervious to photodegradation and biodegradation, along with its exceptional thermal, physicochemical, and optical properties, are particularly noteworthy (Grouli et al., 2024). The aforementioned properties of Congo red have potential carcinogenic effects on humans, as well as mutagenic effects on organisms inhabiting the aquatic environment (Getahun et al., 2024; Shi et al., 2022). This is due to the initial formation of a red colloidal solution, subsequently followed by the breakdown of Congo red into benzidine within the aqueous medium (Mahmoud et al., 2023; Yu et al., 2023). The negative impact caused requires an appropriate solution, and it is essential to address this issue in a timely and effective manner.

It is imperative to exercise control over Congo red to ensure that its concentration does not exceed the prescribed limit. A method that has been demonstrated to reduce Congo red concentrations in water is the coagulation-flocculation process. This method has several advantages, including its affordability, ease of execution, low energy consumption, and reliable treatment technology. Collectively, these factors contribute to its efficacy in reducing Congo red parameters (Ehteshami et al., 2016; Siswoyo et al., 2023). Natural coagulants can be selected as separating agents in the coagulation-flocculation process (Ramadani et al., 2025). Natural coagulants have been shown to have several beneficial characteristics that make them a suitable choice for use in water treatment. These coagulants have been found to produce less sludge, and they are capable of being easily degraded by natural processes. Additionally, they are low in toxicity, which makes them safe for aquatic organisms in water bodies (Agarwal & Saini, 2022; Jebakumar Immanuel Edison et al., 2020; Kristianto et al., 2018).

A natural coagulant that has been identified as a potential candidate for use in the coagulation-flocculation process is *moringa oleifera* (Dos Santos et al., 2018). *Moringa oleifera*, a plant cultivated in South Asia and Africa, exhibits remarkable coagulation and adsorption capabilities (Araújo et al., 2010; Meneghel et al., 2013; Shahzad et al., 2013). The cationic proteins present in *Moringa oleifera* can generate sludge that poses a reduced safety concern when compared with inorganic coagulants (Fatima et al., 2025). Furthermore, a multitude of studies have demonstrated an augmentation in the procoagulant activity of *moringa oleifera*, notably in the context of its extraction in saline solution and sonication application (Mohamed Noor et al., 2022). Recent research on functionalized magnetic nanoparticles (MNPs) has inaugurated promising new directions for innovative research

(Fatima et al., 2025; Mohamed Noor et al., 2022). *Moringa oleifera*, when supplemented with magnetic nanoparticle functional groups, offers several advantages, including high efficiency, reduced use of chemical products, and rapid flocculation time due to its magnetic properties and low-cost raw materials (Lakshmanan & Kuttuva Rajarao, 2014). This phenomenon can be attributed to its biocompatibility with functional groups of organic compounds, including carboxylic acids, dopamine, phosphonic acids, trimethoxysilane, amines, and cysteine (Dias et al., 2011; Okuda et al., 1999).

A reduction in the levels of pollutants has been achieved through the implementation of *Moringa oleifera-based* magnetic biocoagulants. This study evaluated the effect of the initial dose of Congo red on the reduction of Congo red concentration in solution. The separation agents utilized in this study were natural biocoagulants and magnetic biocoagulants.

2. Materials and methods

2.1. Material

The synthesis of magnetic biocoagulants involved the use of various materials, including *moringa oleifera*, NaOH (Merck), HCl 37% (Merck), NaCl (Merck), $FeCl_3.6H_2O$ (Merck), $FeCl_2.4H_2O$ (Merck), distilled water, and NH_4OH 25% (Merck). The dye utilized in this study was Congo red (Merck). The coagulation-flocculation process was carried out using a jar test apparatus.

2.2. Methods

Moringa oleifera is subjected to peeling, drying to a constant weight, and grinding to 80 mesh. Protein is extracted from *Moringa oleifera* through a process of sonication. *Moringa oleifera* seeds are dissolved in a sodium chloride (NaCl) solution at a ratio of 1:20 (w/v). The seeds are then extracted using an ultrasonic probe, separated, and dried to completion (Cojbasic et al., 2024; Ribeiro et al., 2023). At this stage, a *Moringa oleifera-based* biocoagulant is obtained. The synthesis of magnetic biocoagulants entails a precipitation method that involves the amalgamation of $FeCl_3.6H_2O$, $FeCl_2.4H_2O$, and the biocoagulants (Karami et al., 2024). The solution is subjected to a process of precipitation and subsequent drying, which is carried out within an oven. The utilization of magnetic biocoagulants and biocoagulants as separating agents was conducted through the implementation of the jar test method. The Congo red concentration employed in this study ranged from 100 to 550 mg/L. The coagulant dose utilized was 125 mg/L. The results of the coagulation-flocculation process were analyzed using UV-spectrophotometry at a wavelength of 497 nm.

3. Results and discussion

The present study utilized biocoagulants and magnetic biocoagulants to reduce the concentration of Congo red. The coagulation process was evaluated using variations in the initial concentration of Congo red. As illustrated in Figure 1, the efficiency of Congo red removal exhibited a positive correlation with the initial concentration range of 0 to 550 ppm, utilizing biocoagulants as the removal agent. An increase in the initial concentration of Congo red has been observed to result in a concomitant decrease in removal efficiency, yielding consistent results. Under these conditions, the highest efficiency was achieved at a Congo red concentration of 100 ppm, with a value of 96.21%, and the lowest at 550 ppm, with a value of 96.05%. A comparable outcome was exhibited by the utilization of magnetic biocoagulants in diminishing Congo red, as demonstrated in Figure 2. The utilization of magnetic biocoagulants resulted in a removal pattern analogous to that of conventional biocoagulants, exhibiting consistent removal efficiency when the initial Congo red concentration was augmented. In these conditions, the maximum removal efficiency was attained at 100 ppm, with a value of 97.34%. The incorporation of magnetic functional groups into the bioflocculant did not diminish its capacity to interact with Congo red. A slightly divergent result has also been reported by other researchers. They observed a decrease in efficiency when the initial concentration of Congo red was increased (Hadadi et al., 2022; Kristianto et al., 2022).

The mechanisms encompassed by the coagulation-flocculation process consist of charge neutralization, floc formation, and sedimentation (Azoulay et al., 2023). Congo red dye, which possesses a negative charge, will bind to proteins that have a positive charge. Charge neutralization transpires as a consequence of the interplay between compounds present within the coagulant, which facilitate the adhesion of colloids to the aqueous waste. Charge neutralization occurs due to the interaction between compounds in the coagulant that bind colloids in liquid waste. The operation of this mechanism is facilitated by the attractive force between the negative ions of the Congo red dye and the positive ions present within the magnetic coagulant. These attractive forces cause small suspended particles in the solution to stick together and form larger flocs. These flocs exhibit properties of substances that are insoluble in water, and they can be separated through the process of sedimentation (Jami et al., 2020).

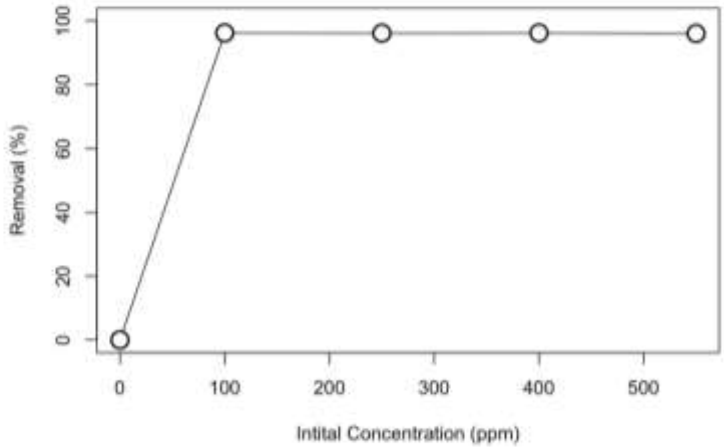

Figure 1. Efficiency of Congo red removal with varying initial concentrations using biocoagulants

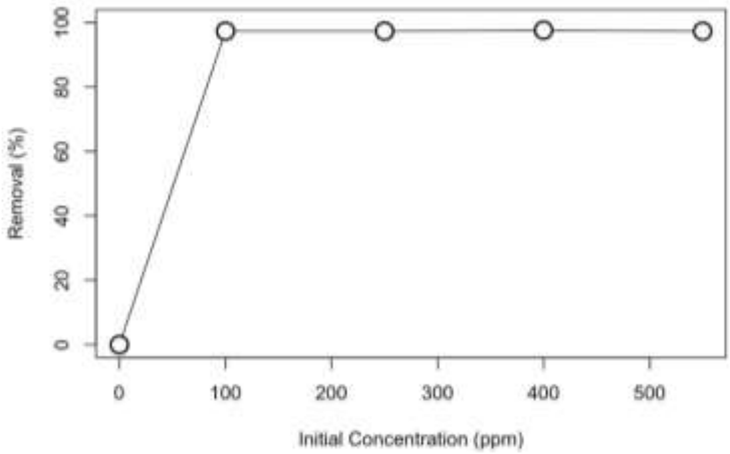

Figure 2. Efficiency of Congo red removal with varying initial concentrations using magnetic biocoagulants

4. Conclusion

The development of biocoagulants and magnetic biocoagulants derived from *moringa oleifera* has yielded positive outcomes. The findings revealed that magnetic biocoagulants exhibited superior outcomes, attaining a maximum efficiency of 97.34% at an initial concentration of 100 ppm. The augmentation of the initial concentration yielded consistent outcomes with regard to removal efficiency for both biocoagulants and magnetic biocoagulants. The coagulation-flocculation process is a complex series of reactions involving charge neutralization, floc formation, and sedimentation.

Credit authorship contribution statement

Tarikh Azis R: Conceptualization, Writing – review & editing. **Meilinda Eka Fatmawati**: Methodology, Investigation. **Novi Eka Mayangsari**: Conceptualization, Supervision, Writing – review & editing. **Ulvi Pri Astuti**: Conceptualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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