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Research Article

Ginger Waste as Heavy Metal Remover from Wastewater

Nor Rezkina Afandee[1], and Siti Amira Othman[2,*]

[1] Faculty of Applied Sciences and Technology, Universiti Tun Husssein Onn Malaysia, Pagoh, Johor

[2] Faculty of Applied Sciences and Technology, Universiti Tun Husssein Onn Malaysia, Pagoh, Johor; sitiamira@uthm.edu.my

* Correspondence: sitiamira@uthm.edu.my

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Abstract: *Heavy metal contamination in wastewater represents a significant environmental concern due to the toxicity, persistence and potential accumulation of metallic pollutants in aquatic ecosystems. This study investigates the potential of ginger waste (Zingiber officinale) as a sustainable biosorbent for removing heavy metals from contaminated wastewater. Ginger waste is selected as an alternative adsorbent because of its availability, low cost and naturally occurring functional groups that may facilitate metal-ion binding. The proposed approach involves collecting, cleaning, drying and processing ginger waste into an adsorbent material. Its physicochemical properties are evaluated using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). Batch adsorption experiments are conducted to investigate the effects of pH, contact time, adsorbent dosage and initial metal concentration. Heavy metal removal efficiency and adsorption capacity are determined to assess treatment performance. This innovation promotes agricultural waste valorisation and offers a potentially economical and environmentally sustainable approach to wastewater treatment.*

1. INTRODUCTION

Heavy metal contamination in wastewater is a major environmental issue associated with industrial activities, including electroplating, metal processing, mining, battery manufacturing and chemical production. Metals such as lead (Pb), copper (Cu), cadmium (Cd), chromium (Cr) and nickel (Ni) may enter aquatic environments through industrial wastewater discharge. Unlike many organic pollutants, heavy metals cannot be readily degraded through biological processes. Their persistence and potential accumulation in living organisms may result in adverse environmental and human health effects (Ahmad and Kumar, 2010).

Conventional wastewater treatment technologies include chemical precipitation, ion exchange, membrane filtration, electrochemical treatment and activated carbon adsorption. Although these methods can effectively remove certain contaminants, their implementation may involve high operational costs, chemical consumption and the generation of secondary waste.

Biosorption has emerged as an alternative wastewater treatment approach using biological materials to bind and remove metal ions from aqueous solutions (Hashem et al., 2024).

Agricultural waste materials have attracted attention as potential biosorbents because they contain naturally occurring functional groups, including hydroxyl, carboxyl and other oxygen-containing groups that may interact with metal ions. Ginger (*Zingiber officinale)* is widely consumed as a food ingredient and medicinal plant. Its processing generates substantial quantities of residual materials, including peel and fibrous residues (Nguyen et al., 2013). These materials may be converted into useful adsorbents rather than being discarded. The proposed research investigates the application of ginger waste as a biosorbent for heavy metal removal from wastewater. By integrating agricultural waste utilization with environmental remediation, this research supports sustainable wastewater management and circular economy practices.

1.1 Research Objectives

1. To develop a low-cost biosorbent from ginger waste for wastewater treatment.
2. To characterize the physicochemical and surface properties of ginger-based adsorbent using FTIR and SEM.
3. To investigate the effects of pH, contact time, adsorbent dosage and initial metal concentration on heavy metal removal.
4. To determine the adsorption capacity and removal efficiency of ginger waste.
5. To evaluate the potential application of ginger-based adsorbent in sustainable wastewater treatment.

2. LITERATURE REVIEW

2.1 Heavy Metal Contamination in Wastewater

Heavy metals are among the major pollutants found in industrial wastewater. Their presence is associated with several industrial processes, particularly electroplating, metal finishing, textile production and mining (Sud et al., 2008). The environmental impact depends on the type of metal, its concentration, chemical form and exposure pathway. The removal of these contaminants before wastewater discharge is essential for environmental protection.

Table 1. Heavy metal and its environmental concern

Heavy metal	**Potential industrial source**	**Environmental concern**
Lead (Pb)	Battery manufacturing	Toxicity and bioaccumulation
Copper (Cu)	Electroplating	Aquatic toxicity at elevated concentrations
Cadmium (Cd)	Metal processing	Kidney toxicity and persistence
Chromium (Cr)	Leather and metal industries	Toxicity depends on oxidation state
Nickel (Ni)	Electroplating and alloys	Toxicity and potential sensitization

2.2 Biosorption as a Wastewater Treatment Technique

Biosorption involves the accumulation or binding of dissolved metal ions onto biological materials through physicochemical interactions. The mechanisms may include ion exchange, electrostatic attraction, complexation, surface adsorption and coordination with functional groups (Demirbas et al., 2008). Agricultural waste materials such as rice husk, coconut shell, banana peel,

orange peel and sugarcane bagasse have been investigated as alternative adsorbents. These materials offer potential advantages in terms of availability, low cost and waste reduction.

2.3 Ginger Waste as a Potential Biosorbent

Ginger waste is a lignocellulosic biomass containing cellulose, hemicellulose and lignin, together with other naturally occurring organic constituents. Its surface chemistry may provide functional groups capable of interacting with metal ions. The potential adsorption mechanisms include:

1. Hydroxyl groups (–OH): May participate in interactions with dissolved metal ions.
2. Carboxyl groups (–COOH): May provide metal-binding sites through ion exchange or complexation.
3. Other oxygen-containing groups: May contribute to surface interactions depending on the biomass composition and treatment conditions.

FTIR analysis can be used to investigate changes in these functional groups before and after adsorption. SEM analysis can provide information about the surface morphology and physical characteristics of the adsorbent. However, the actual metal-binding performance of ginger waste must be established experimentally rather than assumed from its chemical composition.

2.4 Factors Affecting Heavy Metal Adsorption

The performance of ginger-based adsorbent may depend on several experimental parameters. Among these parameters, pH is particularly important because it affects both the chemical form of the metal ions and the surface charge of the biomass.

Table 2. The parameters and expected influence

Parameter	**Expected influence**
Solution pH	Influences metal speciation and surface charge
Contact time	Determines adsorption equilibrium
Adsorbent dosage	Influences the number of available binding sites
Initial metal concentration	Affects adsorption driving force
Particle size	Influences accessible surface area
Temperature	May influence adsorption thermodynamics

2.5 Research Gap and Innovation

Although agricultural biomass has been widely investigated for wastewater treatment, the use of ginger processing waste as a low-cost heavy metal biosorbent deserves further systematic evaluation (Febrianto et al., 2009). The proposed research emphasizes the conversion of discarded ginger residues into a functional wastewater treatment material. Its innovation combines biomass preparation, surface characterization and adsorption performance evaluation to establish the feasibility of ginger-based biosorption.

3. METHODOLOGY

The research methodology consists of six stages, beginning with ginger waste preparation and ending with evaluation of heavy metal removal efficiency.

3.1 Preparation of Ginger Waste Adsorbent

Ginger waste will be collected from food processing activities, restaurants or local markets. The preparation process involves:

1. Collecting ginger peel and residual ginger biomass.
2. Washing with distilled water to remove impurities.
3. Drying the biomass in an oven until constant weight.
4. Grinding the dried ginger waste into powder.
5. Sieving to obtain a relatively uniform particle size.
6. Storing the prepared adsorbent in an airtight container.

4. FINDINGS

The expected findings will demonstrate the potential of ginger waste as a sustainable biosorbent for heavy metal removal.

4.1 Characterization of Ginger Waste

FTIR analysis is expected to identify several oxygen-containing functional groups on the ginger waste surface. The changes in absorption peaks before and after adsorption will help investigate possible interactions between the adsorbent and heavy metal ions (Volesky, 2001). SEM analysis will be used to examine the surface morphology and determine whether changes occur after adsorption.

4.2 Effect of Adsorbent Dosage

Increasing the adsorbent dosage may improve the percentage removal because more available binding sites are introduced into the wastewater system. However, the adsorption capacity per unit mass may decrease at higher dosages due to unused adsorption sites or particle aggregation.

4.3 Effect of pH and Contact Time

The pH of the solution is expected to influence the adsorption process by changing the surface charge of the ginger biomass and the chemical form of dissolved metal ions. The contact time will determine how quickly adsorption equilibrium is reached (Utomo and Salim et al., 2009). A higher adsorption rate may be observed during the initial contact period due to the availability of unoccupied binding sites.

4.4 Comparison with Previous Research

An important supporting study by Dagde and Ndaka (2019) investigated ginger and garlic particles for Pb, Cd and Cr removal. Their reported maximum adsorption capacities for ginger particles were as in Table 3.

Table 3. Maximum adsorption capacity

Metal	Maximum adsorption capacity
Pb	2.9011 mg/g
Cd	2.3121 mg/g
Cr	1.9543 mg/g

The study reported an equilibrium time of approximately 60 minutes under its experimental conditions. These values provide useful literature benchmarks, not predicted results for the present experiment. Another study by Onwuka et al. (2022) investigated ginger root waste for removing Pb^{2+} and Cd^{2+}. FTIR and SEM analyses were used to characterize the adsorbent before and after adsorption.

5. DISCUSSION

The proposed research demonstrates the potential of agricultural waste valorisation through the conversion of ginger residues into an environmentally friendly adsorbent. The presence of cellulose, hemicellulose and lignin in plant biomass provides a potential source of functional groups for metal-ion interactions. In particular, hydroxyl and carboxyl groups may participate in adsorption through ion exchange, complexation and electrostatic interactions.

The findings from previous research support the potential application of ginger-based materials for removing dissolved contaminants. Onwuka et al. (2022) demonstrated that ginger root waste could adsorb lead and cadmium ions from aqueous solutions. Similarly, Dagde and Ndaka (2019) reported the adsorption of lead, cadmium and chromium using ginger particles. Their findings demonstrated that adsorption performance depended on the initial metal concentration, adsorbent dosage and contact time.

These findings provide a scientific foundation for further investigating ginger waste as an alternative biosorbent. One important consideration is the influence of pH. At low pH, hydrogen ions may compete with metal ions for available adsorption sites. At higher pH, deprotonation of surface functional groups may improve the binding of certain positively charged metal ions. However, excessive pH may cause metal hydroxide precipitation, which can lead to misleading removal results if precipitation is not independently controlled.

Furthermore, FTIR and SEM analyses will provide complementary information regarding the adsorption mechanism. Changes in FTIR absorption peaks may indicate the involvement of specific functional groups, while SEM may reveal changes in surface morphology. From an environmental innovation perspective, ginger waste provides an opportunity to transform an agricultural by-product into a useful material for wastewater treatment. The approach may reduce the quantity of organic waste requiring disposal while providing a potentially economical alternative to conventional commercial adsorbents.

Nevertheless, further investigations are required to establish the feasibility of large-scale implementation. These should include regeneration and reuse studies, competitive adsorption in multi-metal wastewater, leaching tests and treatment of actual industrial effluent. The spent ginger adsorbent must also be handled and disposed of appropriately because it contains concentrated heavy metals and should not be treated as ordinary organic waste.

6. CONCLUSION

This research proposes the utilization of ginger waste (*Zingiber officinale)* as a sustainable biosorbent for removing heavy metals from wastewater. The proposed approach integrates biomass preparation, physicochemical characterization and batch adsorption experiments to investigate the effectiveness of ginger waste in removing selected heavy metal contaminants. The evaluation of pH, contact time, adsorbent dosage and initial metal concentration will provide information regarding the optimum adsorption conditions.

FTIR and SEM analyses will help investigate the functional groups and surface characteristics responsible for metal-ion interactions. The proposed innovation offers an opportunity to convert agricultural waste into a value-added environmental treatment material, supporting waste minimization and circular economy principles. Overall, ginger-based biosorbent has potential as an alternative material for wastewater treatment, although further experimental validation, regeneration studies and real wastewater testing are necessary before practical implementation.

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