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Removal of Zinc Ion (Zn^{2+}) From Aqueous Solution Using Watermelon Rind (*Citrillus Lanatus*)

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Abstract

Metals such as Zinc (Zn) have been released into the atmosphere due to rapid industrial development. In this study, dry watermelon rind was used as a low-cost adsorbent to assess the removal of Zinc ions (Zn^{2+}) from aqueous media. Watermelon rind was characterized using Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDX), X-Ray Diffraction (XRD), Thermogravimetric Analysis (TGA) and Fourier Transform Infrared Spectroscopy (FTIR). According to the qualitative analysis, SEM shows a distinctly porous structure with significant surface area, for ideal adsorption processes, the EDX spectrum shows that the adsorbent mainly consists of light elements, with notable peaks for carbon, oxygen and nitrogen which together confirm its carbonaceous and oxygen-rich structure, the XRD was used to study the chemical composition of the watermelon rind before adsorption, at 2ϴ the watermelon shows 160 I cal (au). TGA shows that the watermelon rind was stable at 300˚C and as temperature increases there was degradation in weight %. FTIR analysis provided insights into the functional groups responsible for adsorption. A broad peak at 3200 cm^{-1} corresponds to O-H stretching vibrations, indicating hydroxyl groups that aids in metal binding, the peak at 2900 cm^{-1} reflects C-H stretching vibrations from aliphatic hydrocarbons enhancing surface interactions, A strong absorption at 1800 cm^{-1} corresponds to C=O, the carbonyl groups which contributes to metal ion complexation. The optimization of the dosage was studied between 0.5 g and 2.5 g and it shows that the optimum dosage was at 1.5 g achieving a maximum zinc removal efficiency of 88.09%. The optimization of the pH was studied between 2 and 10. In conclusion, watermelon rind shows strong potential as an effective, sustainable and affordable biosorbent for the removal of heavy metals such as zinc from contaminated water sources.

Keywords: Zinc Ion; *Citrillus Lanatus*; Watermelon Rind

Introduction

The presence of heavy metals in water is a pressing environmental concern because these pollutants are non-degradable, toxic, and accumulate in living systems. Zinc (Zn^{2+}), although needed in trace amounts for biological functions, becomes hazardous when concentrations rise, leading to ecological disturbances and health-related complications [7]. Traditional remediation methods such as precipitation, ion exchange, and membrane separation are capable of reducing zinc levels but are hindered by high energy requirements, expensive maintenance, and the challenge of secondary waste generation. For this reason, adsorption has emerged as a practical alternative, particularly when low-cost biosorbents derived from agricultural residues are employed. Such materials are attractive due to their efficiency, affordability, and eco-friendly characteristics [5, 7].

In recent years, adsorption-based methods have gained prominence as practical and eco-friendly alternatives for heavy metal removal. Adsorption processes, especially those utilizing biosorbents, are attractive because of their efficiency, low cost and environmental compatibility [14, 22]. Agricultural by-products are particularly valuable in this regard, as they are renewable, abundantly available and often discarded as waste. Their structural and chemical properties, including the presence of functional groups capable of binding metal ions, make them highly effective for remediation [3, 26].

Watermelon rind (*Citrullus lanatus*), which constitutes a large portion of the fruit and is often discarded, contains cellulose, hemicellulose, pectin, and a variety of functional groups (–OH, –COOH, C=O, $–NH_2$) capable of binding heavy metals. Studies have reported that both raw and modified rind show promising adsorption capacity toward Zn^{2+} and other contaminants, with performance strongly linked to morphological and chemical properties. Analytical techniques including FTIR, SEM, TGA, and XRD are commonly applied to characterize these properties and understand adsorption mechanisms [3, 20, 23].

Aim and Objectives

Aim

To study the efficiency of watermelon rind as a biosorbent for Zinc (Zn^{2+}) removal from aqueous solutions.

Objectives

- To collect and prepare watermelon rind adsorbent.
- To characterize watermelon rind adsorbent using Scanning Electron Microsopy with Energy- Dispersive X-ray(SEM-EDX), Thermogravimetric Analysis (TGA), X-ray Diffraction (XRD) and Fourier-Transform Infrared Spectroscopy (FTIR).
- To quantify for the zinc metal in aqueous solution using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES).

Materials and Method

Materials

Watermelon Rind Collection: The watermelon rinds used in this study were collected from local fruit vendors at Iyana-iba market. The rinds were collected immediately after consumption of the fruit to ensure freshness and reduce microbial contamination.

Chemicals and Reagents: All chemicals used in this study were of analytical grade and obtained from reputable suppliers. The main reagents include:

- Zinc sulfate heptahydrate ($ZnSO_4{\cdot}7H_2O$) – used to prepare the zinc ion stock solution and test solution.
- Tetraoxosulphate (VI) acid (H_2SO_4, 0.1 M) – for pH adjustment.
- Sodium hydroxide (NaOH, 0.1 M) – for pH adjustment.
- Distilled water – used throughout the study for all solution preparations and rinsing of apparatus.

Apparatus and Equipment:

- Weighing balance (±0.01 g accuracy)
- Electric Blender (for pulverizing the rinds)
- Mesh Seive (mesh size: 2 mm)
- pH meter
- Electronic shaker
- Conical flasks (250 mL)
- Beakers
- Spatula
- Filter paper (Whatman No. 1)

Methods

Preparation of Adsorbent: The collected watermelon rinds were washed thoroughly with tap water followed by rinsing with distilled water to remove dirt and soluble impurities. The properly washed rinds were cut into small pieces and air-dried for 1 month. The dried rinds were ground using a blender and sieved to obtain a uniform particle size of 2 mm. The prepared adsorbent was stored in a clean airtight container for subsequent use.

Preparation of Glass wares: All glass wares used were properly washed with water and detergent, they were rinsed thoroughly with distilled water to get rid of impurities.

Preparation of Stock Solution: The stock solution used in this study was prepared using zinc sulphate heptahydrate ($ZnSO_4{\cdot}7H_2O$). A molar concentration of 0.1 M was required for the adsorption experiments. To prepare the stock solution, 28.76 g of zinc sulphate heptahydrate was accurately weighed using an analytical balance. The measured salt was then dissolved in 1 L of distilled water in a beaker and stirred thoroughly to ensure complete dissolution. The resulting solution was transferred into a 1000 mL volumetric flask, and the volume was made up to the mark with distilled water to give exactly 1L of 0.1 M $ZnSO_4.7H_2O$ solution. The prepared stock solution was properly stoppered and stored at room temperature for further experimental use.

Preparation of Test Solution: A test solution was prepared by measuring 100 mL of the previously prepared 0.1 M zinc sulphate heptahydrate ($ZnSO_{4.}7H_2O$) stock solution. This was then transferred into a 100 mL volumetric flask, and the volume was brought up to the mark by adding 900 mL of distilled water, resulting in a diluted zinc solution. From the resulting solution, 50 mL was accurately measured and used as the working test solution for the batch adsorption experiment with the synthesized adsorbent.

Batch Adsorption Experiments: Batch adsorption experiments were carried out to evaluate the efficiency of watermelon rind in removing zinc ions from aqueous solutions. The effects of various parameters such as initial zinc concentration, adsorbent dosage and solution pH were examined.

Adsorbent Dosage

Different masses of adsorbent (0.5, 1, 1.5, 2 and 2.5) g were weighed into different conical flasks and 50 mL of Zn^{2+} test solution was added to each and shaken for 3 hours. After 3 hours, the resulting solution was filtered into different sampling bottles and sent to the laboratory for ICP-OES analysis.

pH of solution

50 mL of Zn^{2+} test solution was added to five different conical flasks; the pH was adjusted from pH 2 to 10 using 0.1 M H_2SO_4 or 0.1 M NaOH. 1.5g of biosorbent was added to each 50 mL of the test solution in a 250 mL conical flask. The mixture was shaken for 3 hours. After shaking, the solution was filtered and sent to the laboratory for ICP-OES analysis.

Results and Discussion

FTIR Analysis

The FTIR spectra of the raw and zinc-loaded watermelon rind adsorbent revealed significant changes in functional groups following adsorption. The raw material exhibited a broad absorption band between 3200–3500 cm^{-1}, corresponding to –OH stretching

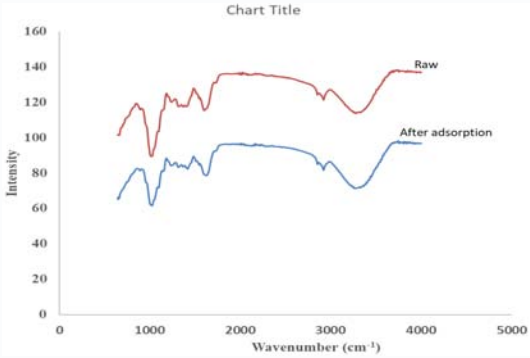

Figure 1: FTIR Spectrum of watermelon rind before and after zinc adsorption.

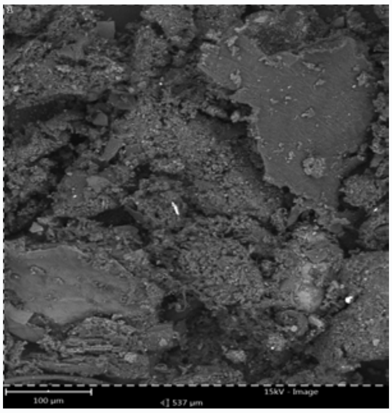

Figure 2: SEM image of raw watermelon rind before zinc adsorption.

vibrations of hydroxyl groups in cellulose, hemicellulose, and lignin. Peaks observed near 2850–2950 cm^{-1} were associated with aliphatic C–H stretching, while a distinct band around 1700–1750 cm^{-1} was assigned to C=O stretching of carboxyl or ester groups. Additionally, absorption in the region of 1000–1200 cm^{-1} indicated C–O stretching vibrations from alcohols, ethers, and polysaccharides. After zinc adsorption, these bands exhibited noticeable shifts and reductions in intensity, particularly in the –OH and C=O groups, suggesting their active involvement in binding zinc ions through electrostatic attraction, ion exchange, or surface complexation. This observation aligns with previous findings where oxygen-containing groups such as hydroxyl, carbonyl, and carboxyl were identified as the dominant sites responsible for heavy metal uptake in agro-waste-based adsorbents [2, 13, 18] (Figure 1).

SEM Analysis: Surface Morphology

The SEM image of the adsorbent shows a distinctly rough and porous structure with cavities and irregular surface features. Such morphological characteristics are highly beneficial for adsorption because they provide a large surface area, which increases the number of active binding sites available for zinc ions. The presence of both micropores and mesopores suggests that the material can accommodate metal ions through different adsorption pathways, thereby enhancing uptake efficiency [10, 22]. This observation indicates that the adsorbent is structurally well suited for heavy metal removal from aqueous solutions (Figure 2).

EDX Analysis: Elemental Composition

The EDX spectrum demonstrates that the adsorbent mainly consists of light elements, with notable peaks for carbon (C), oxygen (O), and nitrogen (N), which together confirm its carbonaceous and oxygen-rich structure. Smaller signals for elements such as phosphorus (P), sodium (Na), magnesium (Mg), potassium (K), calcium (Ca), and silicon (Si) were also detected, reflecting the natural mineral composition of the material. These minerals contribute additional active sites that can enhance heavy metal binding. The lack of strong peaks at higher energies indicates that the biomass is relatively free of metallic contaminants.

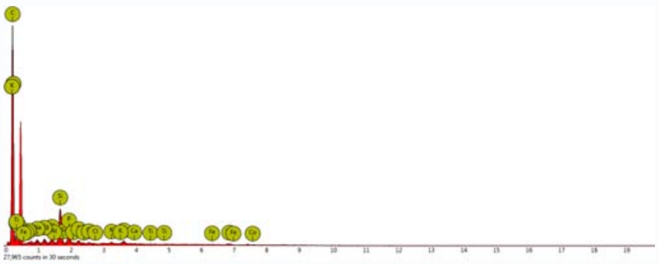

Figure 3: EDX spectrum of watermelon rind before zinc adsorption.

Table 1: Shows elemental composition of raw watermelon rind obtained from EDX analysis.

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
6	C	Carbon	77.44	70.35
7	N	Nitrogen	18.07	19.14
14	Si	Silicon	1.83	3.88
15	P	Phosphorus	0.70	1.65
27	Co	Cobalt	0.30	1.33
13	Al	Aluminium	0.36	0.74
11	Na	Sodium	0.36	0.63
12	Mg	Magnesium	0.34	0.62
20	Ca	Calcium	0.19	0.59
16	S	Sulfur	0.22	0.54
17	Cl	Chlorine	0.12	0.31
19	K	Potassium	0.05	0.16
22	Ti	Titanium	0.02	0.07
26	Fe	Iron	0.00	0.00

This elemental distribution aligns with previous findings on raw watermelon rind, which has been reported to contain high proportions of carbon and oxygen along with trace minerals [1, 27]. In modified forms of watermelon rind, activation treatments have been shown to increase porosity and expose more oxygenated functional groups while retaining beneficial mineral components [6, 11]. Thus, the spectrum supports the potential of watermelon rind as a sustainable biosorbent for zinc removal from aqueous solutions (Figure 3) (Table 1).

TGA

The thermal decomposition profile of the adsorbent follows a multi-stage pattern that is characteristic of lignocellulose biomass. The slight weight reduction observed below 150 °C is mainly due to moisture evaporation, which agrees with trends previously reported for agro-waste-based materials [11]. The most significant mass loss occurs between 200 and 500 °C and is associated with the degradation of hemicellulose and cellulose, along with partial breakdown of lignin. Similar behavior has been documented for fruit peels and

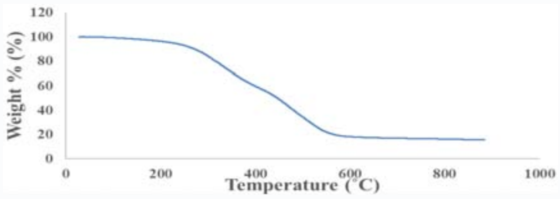

Figure 4: TGA curve of raw watermelon rind.

other agricultural residues used as biosorbents [6, 27].

A slower decomposition is recorded after 500 °C, reflecting the gradual breakdown of lignin and carbonaceous structures, while the remaining 10–15% residue at higher temperatures suggests the presence of stable mineral constituents and fixed carbon. Comparable findings have been reported for raw and modified watermelon rind, as well as other plant-derived biosorbents, which retain mineral ash even under elevated thermal conditions [3, 16]. This confirms that the material possesses sufficient thermal stability to be applied in aqueous adsorption systems (Figure 4).

XRD Analysis

The XRD profile of the watermelon rind displays a broad peak near 20° (2θ), which is typical of amorphous materials such as cellulose, hemicellulose, and lignin. This feature reflects the low crystallinity of the biomass, a property that increases the availability of functional groups for adsorption. Smaller, less intense peaks between 30° and 60° suggest the presence of trace minerals like silica, calcium, and magnesium compounds that naturally occur in the rind. Similar broad peaks around 20° (2θ) have been reported in other agro-waste adsorbents, confirming the amorphous carbonaceous nature of these materials [3, 11, 27] (Figure 5).

Effect of adsorbent dosage on zinc removal using watermelon rind

The effect of adsorbent dosage on zinc removal is presented in the graph. Zinc removal efficiency increased from about 78% at 0.5 g to approximately 87% at 1.5 g, after which the curve plateaued, with only minor changes observed up to 2.5 g. The initial increase in removal efficiency can be attributed to the greater availability of surface area and active sites as more adsorbent was introduced, which enhanced interaction between the zinc ions and the adsorbent surface [3, 10].

The plateau beyond 1.5 g suggests that adsorption equilibrium had been reached, with most zinc ions already removed from solution. Similar behavior has been reported in earlier studies, where further increases in adsorbent dosage produced little to no additional benefit once binding sites were saturated [15, 26]. Hence, 1.5 g can be considered the optimum dosage for zinc removal under the experimental conditions, since higher dosages are not economically efficient [22] (Figure 6).

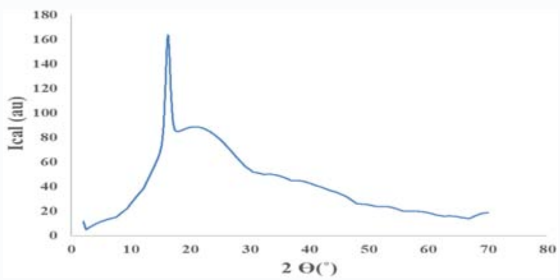

Figure 5: XRD curve of watermelon rind.

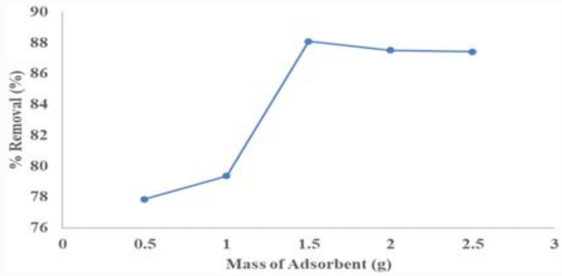

Figure 6:

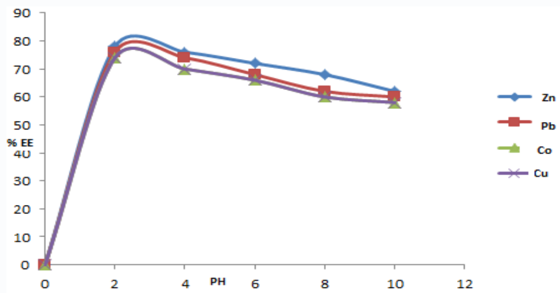

Figure 7: pH curve.

Effect of pH on zinc removal using watermelon rind

The influence of pH on the extraction or adsorption efficiency of Zn, in the presence of coexisting ions Pb, Co, and Cu using watermelon rind as an adsorbent shows a marked dependence: very low pH (0-1) yields almost no extraction, while moving into mildly acidic pH (4-5) triggers a steep rise in removal, reaching an optimum. Beyond this range, especially in alkaline conditions, efficiency declines, likely due to metal precipitation and reduced availability of free metal ions. Zn consistently exhibits the highest extraction efficiency, while Co tends to perform least among the four. These patterns agree with recent findings [4]. Chitosan-based hydrogels achieved near-maximum Cu (II) removal at pH 6, with efficiency dropping as the solution became more acidic. Similarly, [24] found that residual soil-derived zeolite adsorbed Zn (II), Pb (II), and Cu (II) most effectively under mid-pH to slightly acidic conditions, with competitive adsorption effects also influencing the efficiency (Figure 7).

Conclusion

The study confirmed that watermelon rind, a readily available agricultural residue, can serve as an efficient and sustainable biosorbent for eliminating zinc ions from aqueous media. Analytical results from SEM, FTIR, TGA, and XRD highlighted the structural and chemical properties responsible for adsorption, including surface morphology, functional groups, thermal behavior, and crystallinity. Experimental findings further revealed that solution pH, contact time, initial concentration, and adsorbent dosage play crucial roles in determining zinc removal efficiency.

Both untreated and modified forms of watermelon rind showed meaningful zinc adsorption capacities, with treated samples performing better due to enhanced surface and chemical characteristics. This demonstrates that watermelon rind provides an environmentally friendly and low-cost option compared to conventional treatment technologies, while also contributing to the valorization of agricultural waste.

Overall, the results point to watermelon rind as a promising material for zinc ion remediation. Nevertheless, further research is recommended to evaluate its regeneration potential, multi-cycle reusability, and efficiency in treating actual wastewater, which will be critical for scaling up its application.

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