

# Ion exchange properties of onion skin and orange mesocarp: a sustainable approach to metal ion removal from aqueous solutions

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## ABSTRACT

Onion skin (OS) and orange mesocarp (OM) are agricultural wastes with potential for application in wastewater treatment. This review examines their ion exchange properties and their role in heavy metal removal from aqueous systems and wastewater. The presence of functional groups such as hydroxyl, carboxyl, and phenolic groups enables adsorption through ion exchange and surface interaction mechanisms. The performance of these materials is influenced by factors including pH, temperature, particle size, and contact time. Chemical modification improves adsorption capacity and stability. While these materials offer advantages such as low cost and availability, challenges remain in terms of variability, regeneration, and scalability. The review highlights their potential as sustainable alternatives to conventional ion exchange materials.

Keywords: biosorption, heavy metal removal, ion exchange, onion skin, orange mesocarp, wastewater treatment

## INTRODUCTION

The rapid development of the petrochemical and chemical industries has contributed to increasing environmental degradation (Peng et al., 2023). Water bodies are frequently contaminated with inorganic and organic pollutants, including dyes, phenolic compounds, and heavy metals (John & Amarachi, 2023). Among these, heavy metals remain a major concern due to their toxicity, persistence, and tendency to accumulate in the food chain (Alengebawy et al., 2021; Mitra et al., 2022). Their presence in wastewater from industrial and agricultural activities continues to pose risks to both ecosystems and human health (Singh et al., 2024; Tariq & Mushtaq, 2023; Weldemariam, 2023). The relative contribution of major industrial sources to these pollutants is presented in Fig. 1. The textile industry contributes significantly to both dye and heavy metal discharge, making it a major source of wastewater contamination.

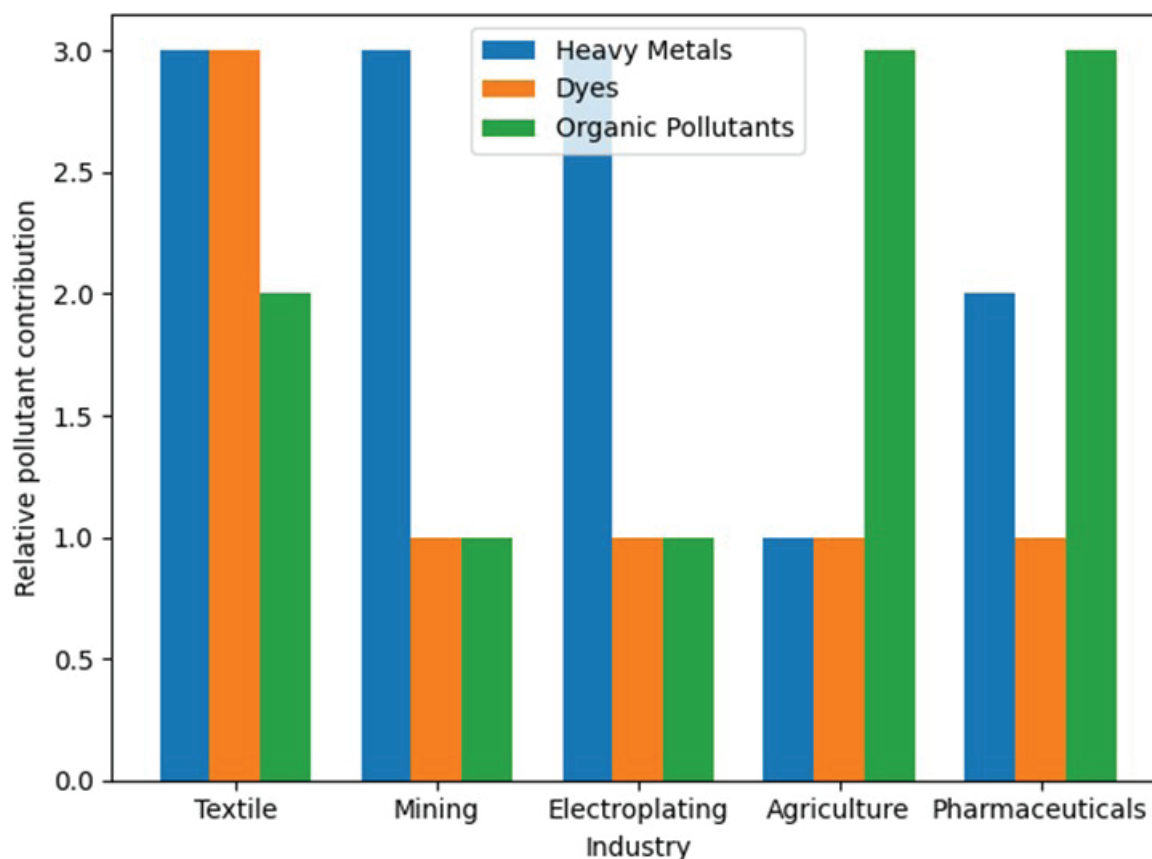


Fig. 1. Relative contribution of major industrial sources to wastewater pollution, highlighting heavy metals and dye discharge from the textile industry

Fig. 1 shows that industrial activities contribute differently to wastewater pollution, with the textile industry being a major source of both dyes and heavy metals. This reinforces the need for effective treatment strategies targeting mixed contaminants in aqueous systems. Several techniques have been applied for heavy metal removal, including ultrafiltration, reverse osmosis, electro dialysis, precipitation, and ion exchange (Ayach et al., 2024). However, these methods are often associated with high cost, energy demand, and the generation of secondary pollutants (Lizcano-Delgado et al., 2024). Adsorption has gained attention due to its simplicity, cost-effectiveness, and efficiency in removing contaminants from aqueous systems (Nascimento et al., 2014).

In response to these limitations, recent studies have focused on the use of agricultural wastes as low-cost and sustainable adsorbents (Gargiulo et al., 2024; Younas et al., 2024). Onion skin and orange mesocarp are abundant agro-wastes with functional groups such as carboxylic, phenolic, and hydroxyl groups that enable ion exchange and adsorption of metal ions (Hamad & Idrus, 2022; Kayranli, 2022; Kyei et al., 2021). These materials have shown potential for the removal of heavy metals from aqueous systems through mechanisms involving ion exchange, surface adsorption, and complexation (Ikodiya & Ibezim-ezeani, 2017; Ogali et al., 2008).

This review focuses on the ion exchange properties of onion skin and orange mesocarp, with emphasis on their structural characteristics, functional groups, and performance in metal ion removal. It also examines the mechanisms involved and the key factors influencing their efficiency, to clarify their suitability as sustainable alternatives to conventional ion exchange materials. This paper is structured as follows: Section 2 discusses the ion exchange properties of onion skin and orange mesocarp. Section 3 presents the mechanisms of metal ion removal. Section 4 examines the factors influencing removal efficiency. Section 5 highlights applications in environmental remediation, followed by advantages and limitations in Sections 6 and 7, respectively. This review is based on published

studies on the use of onion skin and orange mesocarp for metal ion removal. Relevant literature was selected based on relevance to ion exchange mechanisms, adsorption behaviour, and process parameters influencing performance. Emphasis was placed on recent studies and experimentally validated findings.

## ION EXCHANGE PROPERTIES OF ONION SKIN AND ORANGE MESOCARP

Ion exchange is a reversible process in which ions in solution are exchanged with ions bound to a solid material while maintaining electroneutrality (Jorgensen, 1989). In the context of agricultural waste-based adsorbents, this process is largely governed by the chemical composition and structural characteristics of the material. Onion skin (OSE) and orange mesocarp (OME) possess functional groups such as hydroxyl, carboxyl, and phenolic groups, which act as active sites for ion exchange (Adeola et al., 2023; Obuebite et al., 2023). These groups enable the binding and release of metal ions through electrostatic interaction and ion displacement mechanisms.

The structural features of these materials further influence their ion exchange behaviour. Onion skin consists of layered, fibrous structures that allow partial permeability to ions, while orange mesocarp contains porous, sponge-like tissues with interconnected cells that facilitate ion diffusion (Obuebite et al., 2023; Šafranko et al., 2023). These characteristics enhance surface interaction and increase the availability of active binding sites. The ion exchange capacity of these materials is largely dependent on the density and accessibility of functional groups. Chemical modification has been shown to enhance these properties by increasing surface charge density and improving binding affinity (Eke et al., 2022; Kyei et al., 2022, 2023).

In addition, the selectivity of onion skin and orange mesocarp towards specific metal ions is influenced by factors such as ionic radius, charge density, and solution conditions. Their performance in aqueous systems is therefore a function of both intrinsic material properties and environmental variables. The valorisation of onion skin and orange mesocarp as ion exchange materials supports sustainable waste management and aligns with circular economy principles (Ababio et al., 2026; Eke et al., 2022; Kyei et al., 2022, 2023). This will contribute to the achievement of the United Nations Sustainable Development Goals (SDGs) in many countries across the globe (Fig. 2).

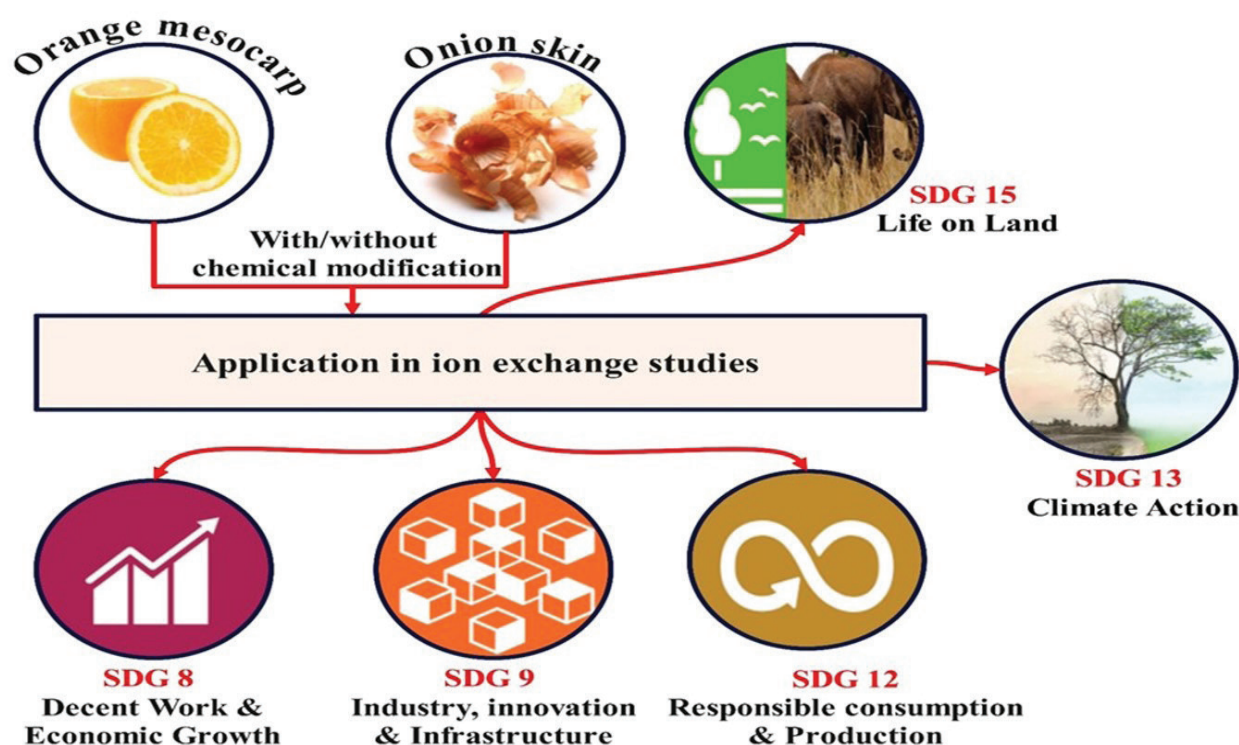


Fig. 2. Application of OSE/OME in ion exchange studies and SDGs

In Fig. 2, we present a conceptual framework for the valorisation of agrowaste (i.e., orange mesocarp and onion skin), which underscores the potential to use agrowaste (raw or chemically modified) to enhance its adsorption performance. Selected SD Goals linked to this application include SDGs 8, 9, 12, 13 and 15. This emphasises the relationship between environmental remediation research, sustainability and circular economy principles.

Analysis of the phytochemical composition of orange mesocarp and onion skin shows that they contain high levels of flavonoids (rutin), phenolic acids, glycosides, saponins, organic acids, steroids, esters, alcohols, and alkaloids, as well as a high moisture content that promotes microbial growth. Due to their antioxidant, anti-inflammatory, and antibacterial properties, orange mesocarp and onion skin are extensively utilised in the food, medical, and pharmaceutical industries. Despite indications of potential foaming properties in their phytochemical composition, they have not been explored as potential natural surfactants (Adeola et al., 2023; Obuebite et al., 2023). The sponge-like layer of the orange mesocarp consists of numerous pore gaps and interconnected colourless cells (Obuebite et al., 2023). The onion skin consists of thin, multilayered, papery scales that protect the bulb while enabling some ions and water to pass through. These structural features aid in ion exchange. Moreover, functional groups (such as hydroxyl and carboxyl groups) on the surface of the cell walls of onion skin can function as ion exchange sites, allowing the binding and release of cations and anions. The mesocarp of oranges includes juice vesicles packed with water and solutes (Šafranko et al., 2023), forming a wet surface that facilitates the passage of ions into and out of the cells.

## METAL ION REMOVAL MECHANISMS

Metal ion removal using onion skin and orange mesocarp is governed by mechanisms that are directly linked to their functional groups and structural properties. Fig. 3 presents the

sustainable removal of heavy metals with chemically modified onion skin extract (MOSE) and modified orange mesocarp extract (MOME). These include ion exchange, surface adsorption, and complexation. In ion exchange, metal ions such as  $\text{Cd}^{2+}$ ,  $\text{Cu}^{2+}$ ,  $\text{Pb}^{2+}$ , and  $\text{Ni}^{2+}$  are exchanged with ions associated with functional groups on the biosorbent surface. This process is influenced by the availability of active sites and the surface charge of the material.

Surface adsorption occurs when metal ions interact with functional groups such as hydroxyl and carboxyl groups, forming bonds through electrostatic attraction or coordination. The porous nature of the orange mesocarp and the layered structure of onion skin enhance this interaction by increasing surface area and accessibility.

Chemical modification of these materials improves their performance by increasing the number of active sites and enhancing binding strength. This leads to improved removal efficiency and allows for regeneration and reuse of the adsorbent. These mechanisms operate simultaneously and are influenced by environmental conditions, which determine the overall efficiency of the process. Understanding these mechanisms is critical for enhancing the biosorption process and increasing the efficiency of metal ion removal.

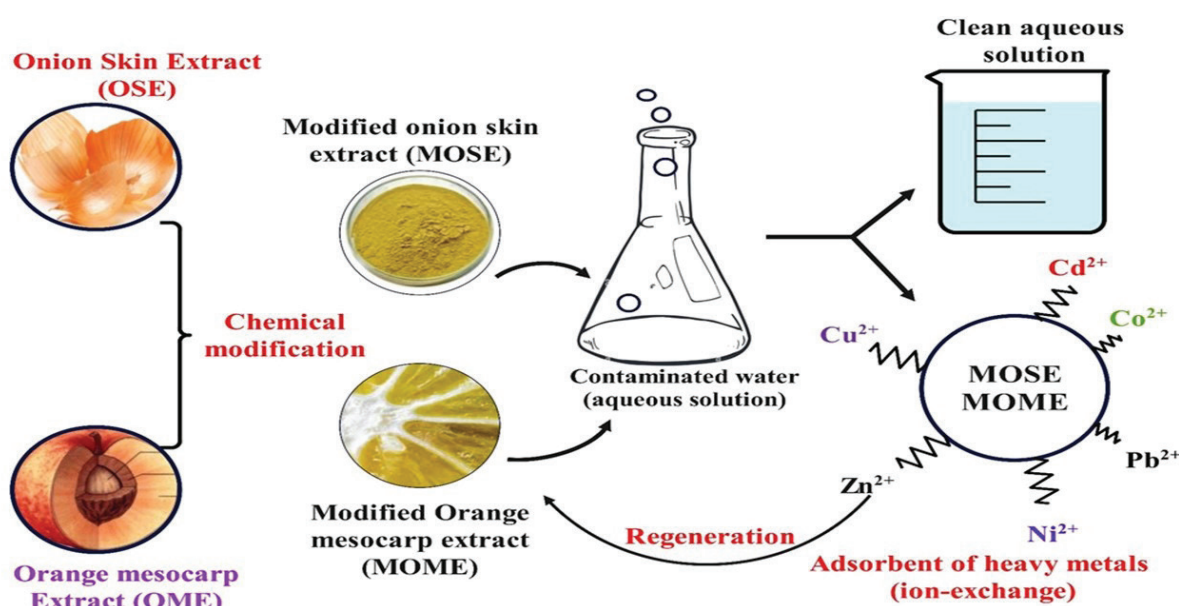


Fig. 3. Sustainable removal of ion metal via ion-exchange mechanism with OSE/OME

### ***Ion exchange***

Ion exchangers are utilised in a two-step procedure known as adsorption and elution to enable the reversible exchange of ions between their liquid and solid phases (Zhu et al., 2023). Adsorption is a method that employs ion exchangers to eliminate certain ions from liquids by exchanging them for more mobile ions. Ion exchange systems utilise elution to effectively recycle and reuse ion exchangers by releasing the specific ions that have been placed onto them back into the liquid. The ion exchange system uses a combined adsorption and elution process to separate and retrieve crucial components from solutions effectively. Ion exchange resins, composed of synthetic materials, are utilised to eliminate or replace ions inside a solution. These resins possess the characteristics of being solid, insoluble, and porous.

Most of these resins are composed of organic polymers that possess a three-dimensional network structure. There are two categories of these networks: anion exchangers, which handle negatively charged ions, and cation exchangers, which handle positively charged ions (Hosseinzadeh & Petersen, 2024).

Agro-wastes are highly effective at binding heavy metal ions in aqueous solutions (Shaikhiev et al., 2022). Ion exchange uses resins to replace metal ions in aqueous solutions with sodium ions. This non-selective mechanism removes various heavy metal ions and is generally pH-dependent. Synthetic organic exchange resins are the most widely utilized exchangers, and this method is highly efficient when employed with low-concentration metal solutions. Even though ion exchange enables significant component modification, its drawback is the limited number of metal ions (Ogunlalu et al., 2021). Metal sequestration is a complex process involving the synthesis of cationic metals and ligands on the cell wall, as well as ionic interactions, leading to deposition on the cell surface (Kainth et al., 2024).

## **SURFACE ADSORPTION**

Agricultural waste materials contain cellulose, which has the potential to adsorb contaminants. Other components of agricultural waste materials include hemicellulose, lignin, extractives, lipids, proteins, simple sugars, water, hydrocarbons, and starch. These components have functional groups, including phenolic, amido, amino, sulphhydryl, carboxyl, alcohol, and ester groups that can bond with contaminants and aid in removing toxins from aqueous solution/wastewater (Kainth et al., 2024). Onion skin and orange mesocarp contain cellulose, vitamins, proteins, and flavonoids, making them useful for water treatment using surface adsorption techniques (Adeola et al., 2023; Mohsin et al., 2022). When these functional groups interact with metal ions in a solution, they can form complexes either by contributing an electron pair or by replacing hydrogen ions with metal ions. Due to their substantial binding groups, agricultural waste may be utilised as an adsorbent to eliminate heavy metals from water or wastewater (Kwikima et al., 2021).

## **FACTORS INFLUENCING THE EFFICIENCY OF METAL ION REMOVAL**

The efficacy of ion metal removal from aqueous solutions is influenced by several factors, including pH, ionic strength, temperature, competing ions, initial concentration of adsorbate and adsorbent, particle size of the adsorbent, as well as other environmental factors and variables. In Fig. 4, we present a summary of the characterisation of OSE/OME resins and the variation of these factors in ion-exchange studies.

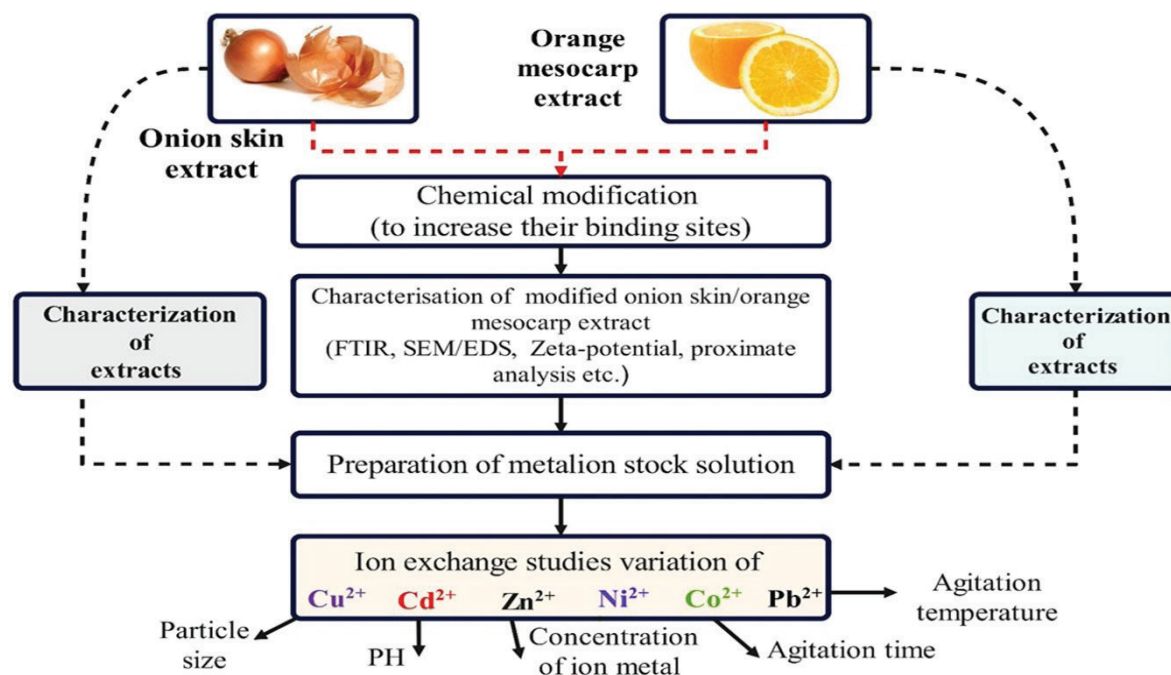


Fig. 4. Characterisation of resins (OSE/OME) and ion exchange studies

#### 4.1 pH

Developing an appropriate pH range is critical to the uptake of heavy metals in aqueous systems. The pace at which ions are adsorbed depends on the pH value of the media, which directly affects the surface charge of the adsorbing material, and the concentration of metal ions on the active groups of the adsorbing material (Obuebite et al., 2023). The influence of pH is made clear by the discovery that the metal binding effectiveness on the substrate increases as pH increases (Species, 1999). Increasing the pH reduces the concentration of  $\text{H}^+$  in the solution and competition between ions, allowing more positively charged ions to diffuse faster to the active binding site. This leads to an increase in the percentage of metal ions removed (Ikodiya & Ibezim-ezeani, 2017).

#### 4.2 Temperature

Effective surveillance of working temperature improves the effectiveness of the ion exchange process and helps in avoiding alterations in some operating factors like the degree of ionization, the diffusion rate of ions, the solubility of ions, the conductivity of ions, the relative affinity of ions, rate of hydrolysis, the viscosity of the medium, and chemical potential (Albezim-Ezeani & Okon, 2016). Scientists in the subject of biosorption have undertaken several studies examining the relationship between temperature and the adsorption of metal ions. Changes in solution temperature have an impact on both the rate of diffusion and the solubility of metal ions. The adsorption capacity of agro-waste is significantly influenced by temperature, which is dependent on the surface functional groups of the waste (Hosseinzadeh & Petersen, 2024; Kwikima et al., 2021).

### **4.3 Particle size**

The adsorption capacities of agro-waste biosorbents may be influenced by variations in particle size, as the total surface area required for metal adsorption varies (Kwikima et al., 2021). Moreover, the particle size of the ion exchanger impacts both the efficiency and the time required to achieve equilibrium conditions (Ibezim-ezeani et al., 2012). Several studies have indicated that reducing the particle size enhances both the capacity and the pace at which the sorbate is removed (Khatri et al., 2017; Lizcano-Delgado et al., 2024). The reason for this is that smaller particles have a greater surface area, resulting in more surface contact (Al-Anber & Al-Anber, 2008).

### **Agitation time**

To optimise the interaction between metal ions in solution and the exchange sites, agitation is employed to facilitate the effective transport of metal ions to the binding sites. To enhance the ion exchange rate, one might employ agitation or elevate the temperature of the solution. Increasing the agitation speed improves the removal of ions, especially nickel and cobalt ions (Abd El-Latif & Elkady, 2011). Increasing the agitation rate decreases the impedance to mass transfer between the bulk phase and the adsorbent component. Muthusamy et al. (2024) found that the existence of several active sites, a high driving force, and little mass transfer resistance due to agitation all contribute to the enhancement of adsorption.

### **Initial concentration**

The initial metal concentration can provide a driving force that facilitates the movement of heavy metal ions from solutions to the surfaces of biosorbents. The initial metal concentration can catalyze the migration of heavy metal ions from solutions to biosorbent surfaces. The probability of the sorbate encountering an available sorption site increases as the metal concentration increases (Kwikima et al., 2021) hydroxyl, sulphhydryl, and amido present in these Agricultural waste-based biosorbents (AWB). An increased concentration of sorbate in the solution results in a faster occupation of the biosorbent's active sorption sites on its surface, resulting in saturation of the biosorbent and a reduction in the percentage of metal ion removal (Lizcano-Delgado et al., 2024). According to studies, there is a decrease in the proportion of metal ions absorbed as their concentrations increase (Lankapati et al., 2021).

## **APPLICATIONS IN ENVIRONMENTAL REMEDIATION**

Both onion skin and orange mesocarp effectively treat industrial wastewater containing heavy metal ions such as copper, lead, cadmium, and zinc (Onyeogulu & Ibezim-Ezeani, 2019; Uzoamaka et al., 2019). These ion exchange resins, derived from agricultural waste, can selectively attach to metal ions, thereby removing them from the water and minimizing the environmental impact of industrial effluents (Jadaa, 2024; Ponnaiah et al., 2024). The mining industry frequently produces wastewater with high quantities of metal ions, which can represent substantial environmental concerns if released untreated (Matebese et al., 2024; Zhang et al., 2023). The use of resins derived from onion skin and orange mesocarp to treat mining effluents is an effective method for selectively capturing metal ions and reducing their presence in discharged water (Jadaa, 2024; Ponnaiah et al., 2024).

Studies have shown that OSE/OME have diverse applications in environmental remediation spanning the treatment of aqueous solutions or wastewater polluted with heavy metals. Table

1 summarises selected studies on the use of onion skin and orange mesocarp for metal ion removal, highlighting key findings and process conditions.

Table 1. Applications of onion skin and orange mesocarp in metal ion removal

Reference	Metal ions removed	Key findings	Key process parameters	Applications
Lizcano-Delgado et al. (2024)	Co <sup>2+</sup>	Effective removal via ion exchange and chemisorption; high adsorption capacity observed	pH 7.0; 30 °C; particle size 300–800 µm; 120 min	Waste water treatment
Uche & Onyebuchi, (2023)	Ni <sup>2+</sup> , Pb <sup>2+</sup>	Modified and unmodified onion skin extract showed improved removal with increasing adsorbent dose	20 mg/L concentration; adsorbent dosage effect	Environmental remediation
Orji et al. (2016)	Pb <sup>2+</sup> , Cd <sup>2+</sup>	Chemical modification enhanced adsorption; succinic acid treatment was most effective	Type of modifying agent: acid treatment	Waste water remediation
Uzoamaka et al. (2019)	Cr <sup>6+</sup>	Removal is influenced by agitation time, temperature, and concentration	Contact time, temperature, and initial concentration	Chromium removal from wastewater
Ibezim-ezeani et al. (2012)	Co <sup>2+</sup> , Ni <sup>2+</sup> , Cu <sup>2+</sup> , Zn <sup>2+</sup>	Orange mesocarp resins are effective for multi-metal removal; kinetics are affected by particle size	Particle size; agitation time	Aqueous solution treatment

Table 1 shows that both onion skin and orange mesocarp are effective in removing a range of heavy metal ions, including Co<sup>2+</sup>, Ni<sup>2+</sup>, Pb<sup>2+</sup>, Cd<sup>2+</sup>, Cr<sup>6+</sup>, Cu<sup>2+</sup>, and Zn<sup>2+</sup>. The studies consistently indicate that adsorption performance is influenced by key process parameters such as pH, temperature, particle size, contact time, and initial metal concentration. Chemical modification of the biomass is also shown to enhance removal efficiency by improving the availability of active binding sites.

Overall, the findings demonstrate that these materials can be applied across different aqueous systems, with their effectiveness depending on both material properties and operating conditions.

## ADVANTAGES OF USING SUSTAINABLE MATERIALS FOR METAL ION REMOVAL

Bioadsorbents offer various advantages over standard approaches. These affordable biofilter materials have a high affinity and capacity for metal ions and are widely available. Some adsorbents have a broad range of metal ion-binding properties, whereas others are selective for specific metal ion types (Mohsin et al., 2022). Fig. 5 presents the advantages of employing onion skin extracts and orange mesocarp for metal-ion removal. Using onion skin and orange mesocarp as adsorbents to remove harmful metal ions from the aqueous environment will decrease wastewater treatment expenses. They are readily available, cheap, and environmentally friendly biomaterials (Obuebite et al., 2023; Yusuff et al., 2021).

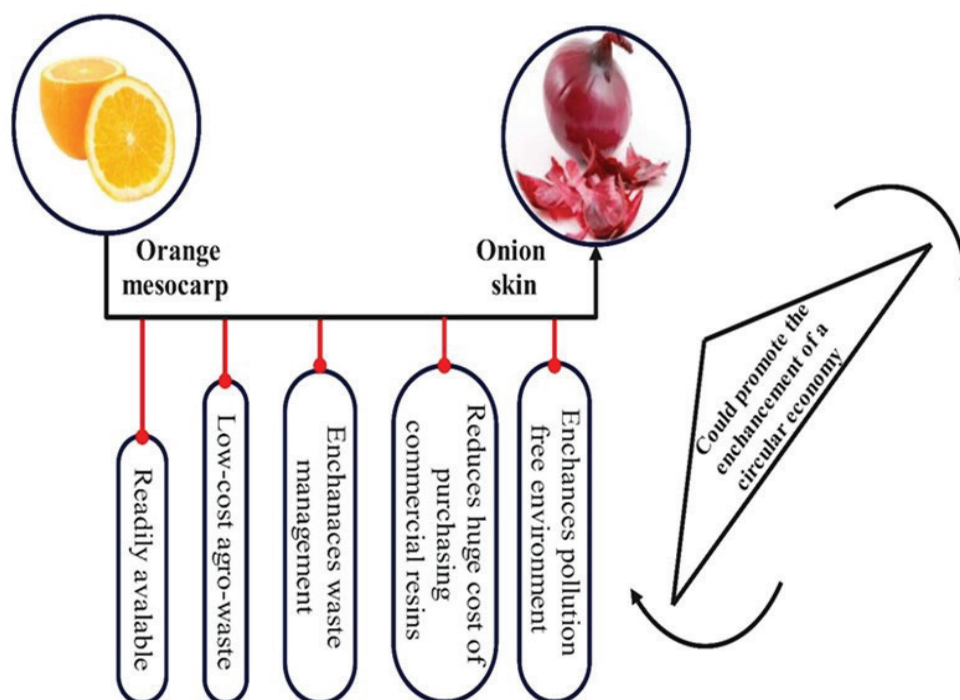


Fig. 5. Advantages of using OSE/OME for metal removal from aqueous solution

## CHALLENGES AND LIMITATIONS

The application of onion skin and orange mesocarp as ion exchange materials is associated with several limitations that are specific to their nature as agricultural wastes. One major challenge is variability in composition. The chemical and structural properties of these materials can vary depending on source, processing conditions, and storage, which may affect their performance. In many cases, pre-treatment or chemical modification is required to enhance adsorption capacity and stability (Salazar Sandoval et al., 2024). This introduces additional processing steps and may increase operational complexity. Furthermore, the mechanical strength and long-term stability of these materials may be lower than that of conventional synthetic resins. This can affect their reuse and performance in continuous systems. Regeneration efficiency is another concern, as repeated adsorption–desorption cycles may reduce binding capacity over time. Addressing these challenges is essential for the

large-scale application of onion skin and orange mesocarp in wastewater treatment systems. Future work should focus on scaling up the use of these materials for industrial applications. This includes ensuring consistent material quality, improving regeneration efficiency, and integrating these adsorbents into existing wastewater treatment systems. Regulatory considerations and long-term performance evaluation will also be required to support practical implementation.

## CONCLUSIONS

This review has examined the ion exchange properties of onion skin and orange mesocarp and their application in the removal of metal ions from aqueous systems. The presence of functional groups such as hydroxyl, carboxyl, and phenolic groups enables these materials to participate in ion exchange and adsorption processes. The performance of these materials is influenced by factors such as pH, temperature, particle size, and initial metal concentration. Chemical modification has been shown to improve their adsorption capacity and overall efficiency. While onion skin and orange mesocarp offer advantages such as low cost, availability, and environmental compatibility, their practical application is limited by variability in composition and the need for pre-treatment. Overall, these materials present a viable option for sustainable wastewater treatment. Further work is required to improve their stability, regeneration capacity, and scalability for industrial applications.

## AUTHOR CONTRIBUTIONS

Sampson Kofi Kyei: Conceptualisation, methodology, writing – review and editing; Harriet Kwakye Boateng: writing—original draft prep; Onyewuchi Akaranta: Supervision, validation, review. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Institutional Review Board Statement: Not Applicable

Informed Consent Statement: Not Applicable

Conflicts of Interest: The authors declare no conflict of interest.

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