Journal Home Page:
https://e-journal.unair.ac.id/JKL

Jurnal Kesehatan Lingkungan
Journal of Environmental Health
Vol. 16 No. 4
DOI: 10.20473/jkl.v16i4.2024.312-320
ISSN: 1829 - 7285 | E-ISSN: 2040 - 881X

ORIGINAL RESEARCH Open Access

MITIGATING HEALTH RISKS THROUGH BIOSORPTION: EFFECTIVE REMOVAL OF NICKEL (II) AND CHROMIUM (VI) FROM WATER WITH ACID-TREATED POTATO PEELS

Northaqifah Hasna Mohamed Khir[1,2], Nur Fatien Muhamad Salleh[1]*, Noraini Abdul Ghafar[1], Nurasmat Mohd Shukri[1]

[1]School of Health Sciences, Universiti Sains Malaysia, Health Campus,Kubang Kerian 16150, Malaysia
[2]Faculty of Applied Sciences, Universiti Teknologi MARA, Terengganu Branch, Bukit Besi Campus, Dungun 23200, Malaysia

Corresponding Author:
*) nurfatiensalleh@usm.my

Article Info

Submitted : 19 August 2024
In reviewed : 2 September 2024
Accepted : 7 October 2024
Available Online : 31 October 2024

Keywords : *Biosorption, Chromium, Health risk, Nickel, Potato peel*

Published by *Faculty of Public Health Universitas Airlangga*

Abstract

Introduction: *Nickel (Ni(II)) and chromium (Cr(VI)) are associated with serious health risks, including respiratory problems, kidney damage, and cancer, along with potential threats to ecosystems. Given their persistence and significant toxicity, effective removal from contaminated water is essential to mitigate these health risks. This study explores the efficacy of acid-treated potato peels (ATPP) as an economical and readily accessible biosorbent for the removal of Ni(II) and Cr(VI) from water solutions.* ***Methods:*** *The study explored two biosorbents: raw potato peels (RPP) and ATPP. Fourier Transform Infrared (FTIR) spectroscopy was utilized to analyze changes in surface functional groups. Batch biosorption experiments were performed using distinct contact times (30-180min), pH (3–11), and biosorbent dosages (0.1–0.5 g). The Mann-Whitney U test was applied for the statistical analysis.* ***Results and Discussion:*** *The FTIR analysis indicated an enhancement in carboxyl groups on the ATPP surface after acid treatment, with stronger transmittance peak at 1645 cm^{-1}. ATPP showed significant improvements in biosorption capacity compared to RPP, removing 18.23% of 10 mg/L Ni(II) at pH 5 in 120minutes using 0.5 g of ATPP. For Cr(VI), 52.28% removal was achieved at pH 7 with 0.2 g of ATPP within the same time frame. Statistical analysis confirmed the superior performance of ATPP in removing Ni(II) (p = 0.024) and Cr(VI) (p = 0.004).* ***Conclusion:*** *ATPP offers significantly higher biosorption capabilities than RPP attributed to the increased presence of carboxyl groups on the modified surface, indicating potential for eco-friendly effective material in mitigating the heavy metal pollution's health risks.*

INTRODUCTION

Rapid industrialization is necessary for economic growth and development but poses a high risk of heavy metal pollution without preventive measures and strict regulations. Various anthropogenic processes, including agricultural, electroplating, mining, leather tanning, and battery manufacturing, introduce these metals into the environment (1-8). In Malaysia, river pollution has intensified as industrial and domestic waste discharges continue unabated, affecting regions like Kedah, Pulau Pinang, Selangor, Kuala Lumpur, Johor, and Sarawak by 2024 (9-12).

The most common heavy metals found in industrial wastewater include nickel, chromium, lead, zinc, arsenic, cadmium, selenium, and uranium. These heavy metals present substantial risks to the environment and human health because of their poor-biodegradability, harmful effects, and ability to accumulate in living organisms. Once released, they have the potential to pollute water bodies, soil, and air, causing harmful impacts on ecosystems and human well-being (2,4,6).

Cr(VI) is a potent carcinogen, with extensive evidence linking it to lung cancer, liver damage, and respiratory problems. Its high solubility and the ability to penetrate biological membranes allow it to easily infiltrate cells, generating reactive oxygen species which trigger oxidative stress, deoxyribonucleic acid damage, and, eventually, cancer (2,4,6,13-14). Ni(II) exposure has also been known to cause kidney damage, lung cancer,

Cite this as :
Khir NHM, Salleh NFM, Ghafar NA, Shukri NM. Mitigating Health Risks Through Biosorption: Effective Removal of Nickel (II) and Chromium (VI) from Water with Acid-Treated Potato Peels. *Jurnal Kesehatan Lingkungan*. 2024;16(4):312-320. https://doi.org/10.20473/jkl.v16i4.2024.312-320

and dermatitis. This is because it can disrupt cellular functions through oxidative stress and inflammation (1–6). Chronic exposure to these heavy metals, even at low levels, highlights the critical need for efficient remediation solutions that minimize the associated risks to health.

Hence, the wastewater system has a very important role especially for industries that discharge heavy metals into the environment in order to meet USEPA and WHO standards in the preservation of human life. Current standard limits for nickel in drinking water have been set by the USEPA at 0.1 mg/L and for WHO at 0.07 mg/L. At the same time there are set guideline values for the total chromium in drinking water at 0.1 mg/L and 0.05 mg/L according to USEPA WHO (15-16). Therefore, an integrated strategy of prevention, remediation and public health intervention is necessary to safeguard ecosystems and human health against the threat of Cr(VI) and Ni(II) in waters. Environmental pollution may be minimized through enhancement of the laws and ensuring compliance to the standardized industrial discharge parameters, encouraging the adoption of less toxic production procedures and materials (17-18).

Due to these health risks, sustainable and cost-effective Cr(VI) and Ni(II) removal from contaminated water sources is a priority. Ion exchange, chemical precipitation, and electrochemical treatment are expensive, ineffectual at low metal concentrations, and produce secondary contaminants that must be addressed (13-14,19). Biosorption, which employs agricultural waste as biosorbents, removes heavy metals from water cheaply and sustainably, benefiting humans and ecosystems. Agricultural waste, which often accumulates due to improper disposal, can be recycled into wastewater pollution removal materials (13-14). By turning byproducts into biosorbents, waste management issues can be solved while delivering an environmentally acceptable and cost-effective wastewater treatment solution.This dual advantage emphasizes agricultural wastes' ability to encourage sustainable environmental practices and advance remedial technology (13-14,19).

Previous research has shown that various agricultural wastes, such as coconut husks, fruit peels, and sugarcane bagasse, are superior at removing heavy metals from water-based solutions due to their large surface area and abundance of functional groups capable of adsorbing metal ions (19-26). Synergistic combinations of different agricultural wastes, modifications with magnetism or polymeric compounds also give attention to biosorbents in environmental remediation (27-31). This study focuses on potato peels as an agricultural waste that aligns to the principles of green chemistry and sustainable development, offering a low-cost and ecologically friendly method of water purification. Furthermore, the high concentration of lignin and cellulose, biopolymers found in potato peels, promotes metal binding via complexation and ion exchange pathways (22-26).

Chemical treatments, such as acid treatment, can improve the effectiveness of potato peels in biosorption by increasing surface area and introducing additional functional groups such as carboxyl, hydroxyl, and phenolic groups, which have a high affinity for metal ions and thus improve biosorption efficiency (32-33). These alterations improve the chemical reactivity and surface area of the biopolymer, thus turning biosorbents more efficient and environmentally friendly for the removal of heavy metals from water sources, hence optimizing ecologically friendly cleanup operations (32-34). Even though few researches have been made to dedicate research in acid-treated agricultural residues, information pertaining to the application of ATPP in removing Ni(II) and Cr(VI) is scanty (13,32,35). The purpose of this study is to determine the potential of ATPP biosorbents in the removal of Ni(II) and Cr(VI) in aqueous solution with consideration of factors including contact time, pH, and biosorbent dose. The research seeks to evaluate the hypotheses regarding a significant difference in the biosorption rates of Ni(II) and Cr(VI) across different conditions such as contact time, pH, and the amount of biosorbent used. Furthermore, it is suggested that ATPP shows a notably higher percentage of removal for Ni(II) and Cr(VI) when compared to RPP. This study emphasizes on the effectiveness of potato peels as cost effective and effective means of treating water and remediating health risks associated with heavy metal pollution, by comparing RPP and ATPP biosorbents. The results can aid developing countries experiencing rapid industrialization and pollution since the approach offers a low-cost method of water purification. The method utilizes the agricultural waste hence minimizing pollution while at the same time eradicating pollution from Cr(VI) and Ni(II) to reduce the public health risks. This intervention supports the United Nations Sustainable Development Goals (SDGs); specifically SDG 6 for clean water and sanitation, SDG 12 for sustainable consumption and production, and SDG 14 for life below water (34).

METHODS

A total of 10 g of Solanum tuberosum potato peels were collected from Café Murni, which is located at the Universiti Sains Malaysia (USM) Health Campus in Kelantan, Malaysia. The research encompassed two varieties of potato peels: untreated (RPP) and acid-treated (ATPP).

An experimental design was utilized, consisting of batch biosorption experiments conducted in a controlled laboratory setting. The performance of RPP and ATPP was compared under various conditions, including contact times (30, 60, 90, 120, 150, 180 minutes), pH levels (3, 5, 7, 9, 11), and biosorbent dosages (0.1, 0.2, 0.3, 0.4, 0.5 g) in controlled initial concentration of Ni(II) and Cr(VI) aqueous solutions.

FTIR spectroscopy, Flame Atomic Absorption Spectrophotometer (FAAS) was used for the characterization and the quantification of Cr(VI) and Ni(II) ions in the aqueous solutions. Data were analyzed using IBM Statistical Package for the Social Sciences (SPSS) Statistics 26, specifically employing the Mann-Whitney U Test to compare the performance of RPP and ATPP. These methods provided a comprehensive assessment of the biosorption capacity of ATPP, emphasizing their potential as effective and sustainable biosorbents for Ni(II) and Cr(VI) removal, thus minimizing the health risks associated with Ni(II) and Cr(VI) pollution.

Chemicals

Nickel (II) chloride salt ($NiCl_2$), chromium (VI) oxide salt (CrO_3), sodium hydroxide (NaOH), and hydrochloric acid (HCl) were obtained from Merck. Reagents of all the elements are of an analytical grade purity and were used as it is except that, pH of solution was adjusted to by using 1M HCl and 1M NaOH. The solvents utilized were laboratory-made distilled and deionized water.

Preparation of Biosorbents

The preparation of RPP involved a modification method by thoroughly washing the obtained potato peels to remove any adhering dirt before drying in an oven at 60°C. The drying process was carried out until a constant weight was achieved. The dried peels were finely ground and stored in airtight containers for further use (35).

Acid treatment with 0.1 M HCl was employed for the preparation of ATPP to enhance the biosorption capacities. The steps involved mixing 10% (w/v) of RPP powder with a 0.1 M HCl solution. The mixture was stirred continuously for 24 hours at room temperature. After the acid treatment, the mixture was then filtered, and the solid residue was washed several times with distilled water to remove any excess acid. The residue was then dried in an oven at 60°C and stored in airtight containers for further use.

Characterization of Biosorbents

The chemical characterization of RPP and ATPP biosorbents was performed utilizing the KBr pellet technique, scanning from 400 to 4000 cm-1 on the FTIR Bruker Tensor 27 Spectrometer. The FTIR spectra of both biosorbents were recorded and compared to identify changes in functional groups induced by acid treatment.

Batch Biosorption Study

A batch biosorption system was studied to assess the influence parameters of contact time at 30-minutes interval (30, 60, 90, 120, 150, 180 minutes), pH (3, 5, 7, 9, 11), and biosorbent dosage (0.1, 0.2, 0.3, 0.4, 0.5g) to investigate the efficacy of RPP and ATPP towards Ni(II) and Cr(VI) biosorption. 1.0 g of RPP and ATPP were added in two different 250 mL beakers containing 100 mL of a 10 mg/L Ni(II) ion solution. The solution was then stirred at 30°C using a magnetic stirrer before being collected in falcon tubes. The steps were repeated using a Cr(VI) solution.

FAAS by Perkin Elmer Analyst FAAS, Perkin Elmer Analyst 800 was used to determine the concentrations of heavy metal Ni(II) and Cr(VI) ions before and after biosorption. Blank experiments were conducted to ensure the accuracy and precision of the measurements. For all the parameters, the process was replicated three times to get a sample size of n = 18 for each parameter.

Biosorption Calculation and Data Analysis

The removal percentage (%), was calculated using the following Eq. 1 (35-36).

$$\% = \frac{C_o - C_e}{C_o} \times 100$$

where C_0 and C_e are the initial and equilibrium concentrations (mg/L)

Data were analyzed using SPSS Statistics 26 and the Mann-Whitney U Test as a non-parametric statistical test to assess significant differences in biosorption capacities between Ni(II) and Cr(VI) under various conditions.

Manuscript Assistance

The drafting of the initial literature review and discussion sections was supported by OpenAI's GPT-4 model. The AI was used to generate concise reviews of relevant literature and write preliminary discussions based on experimental results. The authors critically analyzed, modified, and supplemented the AI model's generated content to ensure scientific rigor, coherence, and conformity with the study's findings.

RESULTS

The effectiveness of potato peels (RPP and ATPP) as biosorbents for the removal of Ni(II) and Cr(VI) was analyzed under various influence parameters, including contact time, pH levels, and biosorbent dosage, utilizing FAAS for the analysis. FTIR spectra for both RPP and ATPP were compared to identify the functional groups present in potato peels and understand their roles in biosorption behavior.

FTIR Analysis

FTIR spectra of both RPP and ATPP were illustrated in Figure 1 in the region of 4000-400 cm^{-1}.

Figure 1 reveals significant changes in the surface chemistry and biosorption capabilities of ATPP. Both biosorbents exhibited similar IR absorption bands, indicating shared common functional groups. A broad transmittance band was observed at 3399 cm^{-1} is attributed to the presence of hydroxyl (–OH) groups, suggesting the presence of water or alcohol. The transmittance band at 3399 cm^{-1} for RPP is broader than that of ATPP, indicating a higher absorption of water on the surface of RPP (35). C-H stretching vibrations are observed at 2921 cm^{-1}. The transmittance band at 1645 cm^{-1} shows that carboxyl (–COOH) groups are present. In the range of 800–1360 cm^{-1}, there's a band peaking at 1028 cm^{-1}, indicated to the stretching of C–O–C and C–C bonds in the carbohydrate ring which are more pronounced for ATPP.

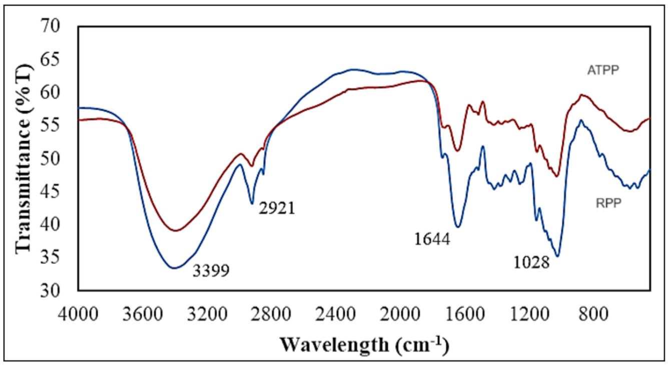

Figure 1. FTIR Spectra of RPP and ATPP Biosorbents

However, there are significant differences in the functional group compositions between RPP and ATPP. ATPP exhibits higher percent transmittance of -COOH and moderate C–O–C and C–C band at 1645 cm^{-1} and 1028 cm^{-1}, respectively compared to RPP due to the esterification during acid treatment. These peaks are more pronounced in ATPP, reflecting modifications in surface chemistry and structure due to HCl treatment which enhances the biosorbent's ability to interact with metal ions. The FTIR-KBr spectra confirmed the presence of cellulose and lignin in potato peels.

Batch Biosorption Findings

A comparative investigation was performed to assess the removal percentage of Ni(II) and Cr(VI) by RPP and ATPP, involving three influence parameters: contact time, pH and biosorbent dosage.

Effect of Contact Time

The effect of contact time on the percentage removal of Ni(II) and Cr(VI) ions is illustrated in Figure 2 and 3, respectively. Using 0.3 g of RPP and ATPP biosorbents with an initial concentration of 10 mg/L at pH 7, the removal efficiency for both metals increases with contact time, reaching equilibrium around 120 minutes. Using 0.3 g of RPP and ATPP biosorbents with an initial concentration of 10 mg/L at pH 7, the removal efficiency for both metals increase with contact time and plateaus after 120 minutes, indicating this as the optimum contact time for the removal of Ni(II) and Cr(VI). Beyond this point, improvements in efficiency become minimal. For Ni(II), the percentage removal rises from 7.9% to 12.1% for RPP and from 18% to 23.3% for ATPP. Similarly, for Cr(VI), the removal efficiency increases from about 12.4% to 22.5% for RPP and from 25.6% to 38.3% for ATPP. By 120 minutes, ATTP is able to remove 23.34% of Ni(II) and 38.34% of Cr(VI), while RPP achieves approximately 12.05% and 22.48% removal rates for Ni(II) and Cr(VI) respectively. Higher percentage removal exhibited by ATPP indicates a higher biosorption capacity compared to RPP for both Ni(II) and Cr(VI) removal.

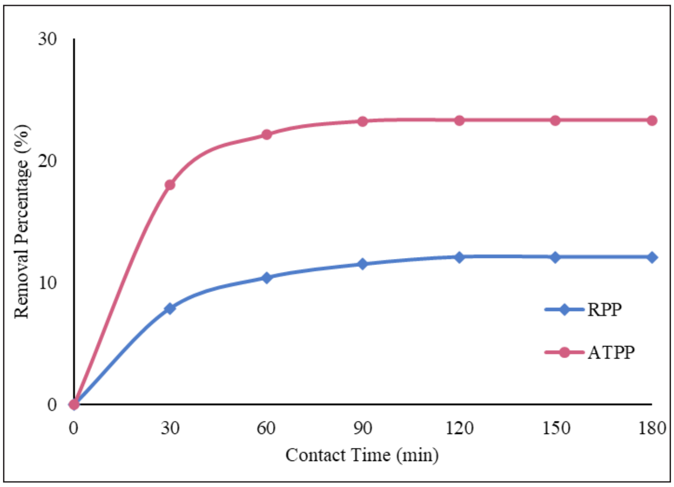

Figure 2. Effect of Contact Times (30 – 180 Minutes) on Percentage Removal of Ni(II) using 0.3 g RPP and ATPP Biosorbents with 10 mg/L Initial Concentration at pH 7

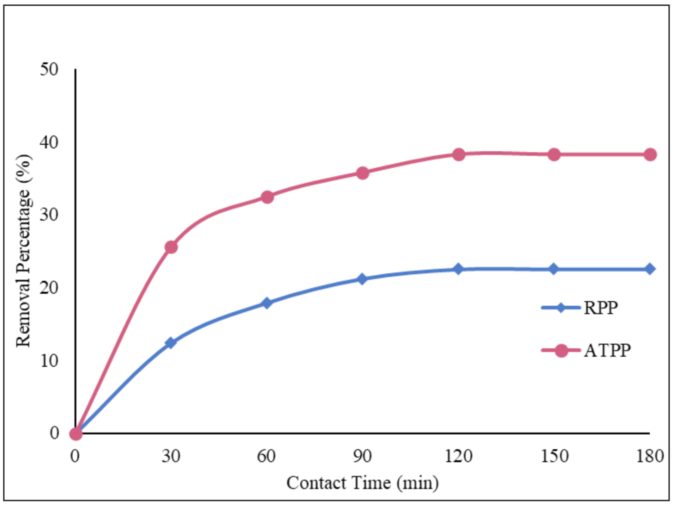

Figure 3. Effect of Contact Times (30 – 180 Minutes) on Percentage Removal of Cr (VI) using 0.3 g RPP and ATPP Biosorbents with 10 mg/L Initial Concentration at pH 7

Effect of pH

The influence of pH on the removal efficiency of Ni(II) and Cr(VI) ions using 0.3 g of ATPP biosorbents with an initial concentration of 10 mg/L is depicted in Figure 4. The best removal efficiencies were observed at pH 5 and 11 for Ni(II) and pH 7 for Cr(VI), achieving 73-74% and 48.01% removal, respectively. However, pH 11 for Ni(II) cannot be utilized as an optimum pH because metal ions Ni (II) were observed to have precipitated at pH 11, forming nickel (II) hydroxides. These findings highlight pH 5 and pH 7 as critical for maximizing the biosorption capacity of ATPP towards the removal of Ni(II) and Cr(VI) ions in aqueous solutions.

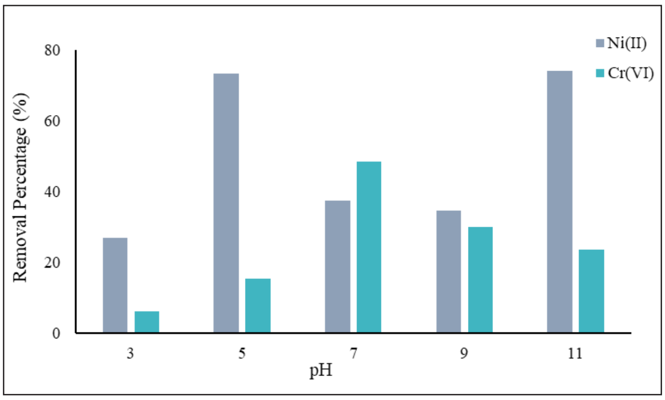

Figure 4. Effect of pHs (3 – 11) on Percentage Removal of Ni(II) and Cr(VI) Ions using 0.3 g ATPP Biosorbents with 10 mg/L Initial Concentration

Effect of Biosorbent Dosages

The effect of biosorbent dosage on the removal efficiency of Ni(II) and Cr(VI) ions using ATPP at pH 5 and 7, respectively. Specifically, the highest removal efficiency of 18.23% was achieved with 0.5 g of biosorbent, while the lowest efficiency was observed with 0.1 g at pH 5 for Ni (II). Similarly, the biosorption efficiency of Cr(VI) ions exhibited dependence on biosorbent dosage, as shown in Figure 5. Across the same range of biosorbent dosage, 0.2 g of ATPP demonstrated the highest removal efficiency at 52.28% in 150 ml of Cr(VI) solution at pH 7. In contrast, higher dosages (0.3 g, 0.4 g, and 0.5 g) led to a gradual loss in removal efficiency. Based on these batch biosorption evaluations, it has been found that ATPP is an efficient biosorbent for removing 10 mg/L aqueous solutions of Ni(II) and Cr(VI) at pH 5 and pH 7, respectively, when utilized at optimal doses of 0.5 g and 0.2 g.

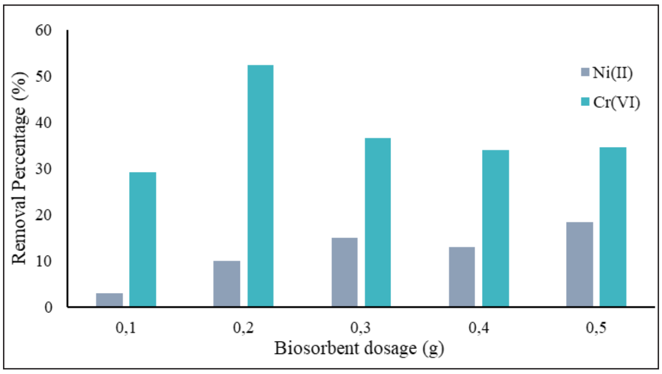

Figure 5. Effect of Biosorbent Dosage (0.1 - 0.5 g) on Percentage Removal of Ni(II) and Cr(VI) Ions using ATPP with 10 mg/L Initial Concentration at pH 5 and pH 7

Statistical Analysis

Table 1 provides a statistical comparison of the median percentage removal of Ni(II) and Cr(VI) between RPP and ATPP using the Mann Whitney U test. Results revealed an enhancement in biosorption capacity after acid activation, rejecting the null hypothesis. Specifically, ATPP exhibited a higher median Ni(II) removal (13.72%, IQR 1.809) compared to RPP (11.82%, IQR 2.455) with a Z statistic of -2.250 and a p-value of 0.024 (<0.05). Similarly, for Cr(VI) ion biosorption, ATPP exhibited a significantly higher median removal percentage (36.96%, IQR 8.921) than RPP (21.68%, IQR 6.450). The Mann Whitney U test yielded a Z statistic of -2.892 and a p-value of 0.004 (<0.05), also indicating a rejection of the null hypothesis and confirming substantial differences in Cr(VI) biosorption capacity between the two biosorbents.

Table 1. Comparison of Median Percentage Removal of Ni(II) and Cr(VI) between RPP and ATPP

Variable	Median (IQR)		Z statistic	P value*
	Raw	Acid-Treated		
Ni(II) removal (%)	11.82 (2.455)	13.72 (1.809)	-2.250	0.024
Cr(VI) removal (%)	21.68 (6.450)	36.96 (8.921)	-2.892	0.004

**Mann Whitney U test*

DISCUSSION

The removal of heavy metals like Chromium (Cr(VI)) and Nickel (Ni(II)) from wastewater is crucial due to their severe toxicological effects on human health. Cr(VI) and Ni(II) are among the most harmful pollutants which linked to cancer, nephrotoxicity, and pulmonary issues. Chronic exposure to heavy metals, even at low levels, poses important public health issues, necessitating effective remediation solutions not just for environmental compliance but also for mitigating the associated health hazards (1-9).

Potato peels have emerged as a sustainable and cost-effective biosorbent for heavy metal removal from water, which aligns with SDG 6 for clean water and sanitation, SDG 12 for sustainable consumption and production, and SDG 14 for life below water (15-16,34). The structural features of potato peels, particularly their high lignin and cellulose content, are important to the biosorption process. These biopolymers facilitate the adsorption of heavy metals through complex molecular interactions, with lignin acting as a binding agent and cellulose providing the structural integrity needed for effective biosorption.

The presence of functional groups in potato peels, notably –OH and –COOH, plays a crucial role in their capacity to adsorb heavy metals. Specific functional groups of –OH and –COOH that adsorb heavy metals belongs to potato peels, observed in Figure 1 at 3399 cm^{-1} and 1645 cm^{-1} for both RPP and ATPP which are crucial for forming strong complexes with metal ions. –COOH groups can form strong complexes with metal ions, which improve biosorption via electrostatic interactions. While –OH groups, present in cellulose and lignin, participate in hydrogen bonding and increase the binding capacity for metal ions (33). As lignin act as binding agent, it can also hinder the accessibility of cellulose, making it difficult for adsorbates to interact with the cellulose. Thus, acid treatment gives helps by breaking down the structural barriers and reduces inhibitory substances while enhancing the release of functional groups, increase the surface area and porosity of biosorbents that boost biosorption capacity (23,25-26).

Figure 1 distinctly show significant differences between RPP and ATPP, particularly in the enhancement of functional groups critical for biosorption. Sharper band observed at 3399 cm^{-1}, associated with –OH groups, reflects the reduced presence of surface-bound water and the increased availability of hydroxyl groups for metal ion interaction. The prominent increase in the peak at 1645 cm^{-1} in the ATPP spectrum corresponds to a higher concentration of –COOH groups, indicating that acid treatment significantly increases the number of active binding sites. These –COOH groups are essential for metal ion chelation, directly contributing to the superior adsorption capacity of ATPP compared to RPP. A moderate band peaking at 1028 cm^{-1}, indicated to the C–O–C and C–C stretching vibrations in the carbohydrate ring specifically in cellulose, which substantiate the enhanced biosorption performance of ATPP for Cr(VI) and Ni(II) removal (14,19,21-22,35). ATPP's improved performance from the enhanced functional group after acid treatment is important in terms of public health, as effective removal of Cr(VI) and Ni(II) is directly proportional to a reduction in the risk of cancer, kidney damage, and other metal-related health issues (2,4,6). ATPP's ability to reduce toxic metal concentrations to levels below regulatory limits substantially improves both environmental sanitation and public health. This increased efficiency is crucial for effectively lowering metal concentrations in contaminated water, minimizing the potential of chronic health problems caused by these hazardous metals (4). The batch biosorption experiments with contact times ranging from 30 to 180 minutes and an initial concentration of 10 mg/L of Ni(II) and Cr(VI) on 0.3 g of RPP and ATPP biosorbents highlight the importance of optimizing contact time for metal removal. The observed plateau in removal effectiveness after 120 minutes for both Ni(II) and Cr(VI) suggests that extending the duration yields negligible improvement. The equilibrium for both biosorbents is reached at 120 minutes, indicating that this time frame is ideal for maximizing removal efficiency. After this phase, the process stabilizes, and any further time becomes inefficient.

ATPP consistently outperformed RPP, with maximal efficiency of removal for both metals at 120 minutes, suggesting significant metal ion-biosorbent interaction. This rapid collapse in metal concentrations is crucial for lowering exposure risks, as even low levels of Cr(VI) and Ni(II) can cause carcinogenesis and nephrotoxicity. For public health, the ability to remove significant quantities of metal is critical (4,6).

Treating water at these pH values can mitigate public health risks from Ni(II) and Cr(VI) contamination. The best pH settings for Ni(II) and Cr(VI) were pH 5 and pH 7, respectively, for biosorption. Functional group protonation and binding site availability are highly pH-sensitive. Electrostatic interactions between metal ions and functional groups on ATPP are most favorable at these pH levels, leading in efficient metal ion binding and elimination.

In strongly acidic conditions, high concentrations of hydrogen ions (H^+) compete with metal ions for the same active biosorption sites, thereby reducing the efficiency of metal removal. Conversely, at higher pH values, deprotonation of functional groups on the ATPP surface can reduce the positive charge density, leading to decreased binding efficiency and competition between metal ions and hydroxide ions (28,37-40).

The observed differences in pH trends between Cr(VI) and Ni(II) biosorption are due to their distinct ionization states and interactions with the biosorbent. Ni(II), a divalent cation : Ni^{2+}, shows maximum adsorption at acidic pH, where the biosorbent surface favors cation binding. At higher pH levels, Ni(II) produces $Ni(OH)_2$, limiting the concentration of free metal ions available for biosorption, thereby reducing overall removal efficiency. In contrast, Cr(VI) exists as anionic species: CrO_4^{2-} or $HCrO_4^-$, which are efficiently adsorbed at neutral pH due to electrostatic interactions with protonated functional groups on biosorbent (13,38).

The amount of biosorbent used also played a crucial role in the removal efficiency of Ni(II) and Cr(VI). It was found that by increasing the biosorbent dosage, the biosorption of Ni(II) ions was significantly improved. For Ni(II), the increase in biosorbent dosage initially provides more active sites, leading to improved biosorption. However, this effect was not observed for Cr(VI) ions due to particle aggregation and the resulting decrease in effective surface area (38-40). Beyond a certain point, additional biosorbent does not translate to higher removal efficiency. These findings emphasize the importance of optimizing biosorbent dosage to maximize removal efficiency to levels safe for humans, aligning with regulatory standards and public health goals while minimizing material usage (13,16,27).

The removal efficacy of Cr(VI) and Ni(II) using ATPP differed significantly, with Cr(VI) removing 52.28% at pH 7 and Ni(II) removing 18.23% at pH 5 during the same contact time. Cr(VI) has a higher removal rate than Ni(II) with ATPP due to its anionic form, which binds more efficiently to the biosorbent. Ni(II)'s divalent cationic form is sensitive to pH, precipitating as $Ni(OH)_2$ at higher pH, limiting adsorption (41-43).

The Mann Whitney U test confirmed a significant increase in biosorption capacity after acid activation. Both biosorbents effectively removed Ni(II) and Cr(VI), with ATPP showing superior biosorption capabilities outperforming RPP for both environmental cleanup and public health. ATPP's 52.28% removal of Cr(VI) at pH 7 and 18.23% removal of Ni(II) at pH 5 contribute to reducing metal concentrations to meet WHO and EPA water safety standards. Cr(VI), a known carcinogen, poses severe health risks including lung cancer, kidney damage, and respiratory issues, while Ni(II) exposure is linked to kidney dysfunction, dermatitis, and potential carcinogenic effects. By efficiently reducing these toxic metals, ATPP mitigates the risks associated with heavy metal exposure and bioaccumulation, reducing public health hazards. Additionally, ATPP's use as an eco-friendly biosorbent supports SDG 6, SDG 12 and SDG 14, contributing to waste valorization and reducing the environmental footprint of water treatment processes (34).

ACKNOWLEDGMENTS

The authors gratefully acknowledge Universiti Sains Malaysia (USM), Kubang Kerian, Kelantan, Malaysia, for providing essential support and research facilities.

AUTHORS' CONTRIBUTION

NHMK: Conceptualization, Methodology, Writing - Original draft preparation. NFMS: Supervision, Data curation, Writing- Original draft preparation, Statistical analysis. NAG: Software, Validation. NMS: Writing- Reviewing and Editing.

CONCLUSION

This study revealed the enhancement in biosorption capacity for Ni(II) and Cr(VI) ions by ATTP compared to RPP. Using a constant initial concentration of 10 mg/L in 150 mL solutions, optimized parameters were identified as pH 5, 0.5 g biosorbent dosage, and 120 minutes for Ni(II), and pH 7, 0.2 g biosorbent dosage, and 120 minutes for Cr(VI). Statistical analysis using the Mann Whitney U test showed that ATPP achieved a median removal of 13.72% for Ni(II) ($Z = -2.250$, $p = 0.024$) and 36.96% for Cr(VI) ($Z = -2.892$, $p = 0.004$), both significantly higher than RPP. Characterization through FTIR analysis confirmed that the introduction of –COOH group at peak of 1645 cm^{-1} on the surface of ATPP due to esterification significantly improved its biosorption capacity. Future research should explore further optimization parameters such as temperature and initial metal ion concentrations to enhance the biosorption capacities of ATPP. Alternative activation methods, different potato cultivars, and other agricultural wastes might collaborate to improve biosorption effectiveness under a variety of environmental circumstances. Furthermore, synergistic mixtures of potato peels with other agricultural wastes, as well as modifications with magnetism or polymeric chemicals, have the potential to widen biosorbents' use in environmental remediation. Heavy metal removal must be effective in order to reduce health hazards connected with toxic element exposure, such as respiratory disorders and cancer. By furthering our understanding and application of biosorption, this research contributes to the advancement of sustainable water treatment technologies and supports the larger goal of ensuring access to safe, clean water, thereby lowering the health risks associated with heavy metal contamination.

REFERENCES

1. Handayani CO, Martono E, Harini R. Health Risk Assessment of Heavy Metals in Shallot, Bantul Regency. *Jurnal Kesehatan Lingkungan*. 2022;14(2):82-89. https://e-journal.unair.ac.id/JKL/article/view/32031
2. Rizky HE, Mukono J. Levels of Chromium in Air with Chromium in the Blood of Workers Electroplating in Purbalingga. *Jurnal Kesehatan Lingkungan*. 2018; 9(2): 172–180. https://doi.org/10.20473/jkl.v9i2.2017.172-180
3. Puspitasari M. The Effect of Kupang Seafood's Mercury Level on Consumers' Blood Mercury Level at Bursa Kupang Sidoarjo. *Jurnal Kesehatan Lingkungan*. 2019;11(3):208-214. https://e-journal.unair.ac.id/JKL/article/view/11719
4. Dwipayanti NMU, Dewi IGAKSP, Palgunadi NPGS, Rofida M, Sutiari NK, Purnama IGH. Health Risks Assessment of Heavy Metal from Consumption of Oreochromis Mossambicus and Oreochromis Niloticus in Denpasar, Bali. *Jurnal Kesehatan Lingkungan.* 2021;13(4):250-258. https://doi.org/10.20473/jkl.v13i4.2021.250-258
5. Wiradana NPA, Sandhika NIMGS, Sudaryatma NPE, Widhiantara NIG, Nyandra NM, Oktariani NAF, et al. Occurrence and Consumer Health Risk Assessment of Heavy Metals in Frozen Demersal Fish and Cephalopod Products from Benoa Port, Bali Province. *Jurnal Kesehatan Lingkungan.* 2024;16(1):41–50. https://doi.org/10.20473/jkl.v16i1.2024.41-50.
6. Mulyati TA, Pujiono FE, Indah I. The Exposure of Pb to Hair and Nails in Children Around "X" Coal Mines Using Atomic Absorption Spectroscopy (AAS) Method. *Jurnal Kesehatan Lingkungan*. 2021;13(3):174-179. https://doi.org/10.20473/jkl.v13i3.2021.174-179
7. Nurika G, Indrayani R, Syamila AI, & Adi DI. Management Of Pesticide Contamination in The Environment and Agricultural Products: A Literature Review. *Jurnal Kesehatan Lingkungan*. 2022; *14*(4), 265–281. https://doi.org/10.20473/jkl.v14i4.2022.265-281
8. Lazim ZM, Salmiati, Hadibarata T, Yusop Z, Nazifa TH, Abdullah NH, et al. Bisphenol A Removal by Adsorption Using Waste Biomass: Isotherm and Kinetic Studies. *Biointerface Research in Applied Chemistry.* 2020;11(1):8467–8481. https://doi.org/10.33263/briac111.84678481
9. Ibrahim TNBT, Jesi NAA, Feisal NNAS, Windusari NY, Samat NNA, Kamaludin NNH, et al. Klang River Water Quality Assessment and Its Effects on Human Health Using Chemometric Analysis. *Jurnal Kesehatan Lingkungan*. 2024;16(2) :125–136. https://doi.org/10.20473/jkl.v16i2.2024.125-136
10. Dass MV. Sungai Kim Kim, 3 Lagi Tercemar di Pasir Gudang. Pasir Gudang: Harian Metro; 2024. https://www.hmetro.com.my/mutakhir/2024/02/1064742/sungai-kim-kim-3-lagi-tercemar-di-pasir-gudang
11. Dass MV. 14 Sungai di Johor Dikategorikan Paling Tercemar. Johor Bahru: Harian Metro; 2023. https://www.hmetro.com.my/mutakhir/2023/10/1024676/14-sungai-di-johor-dikategorikan-paling-tercemar
12. Ibrahim MI. 25 Sungai di Malaysia Tercemar Kelas 3 dan 4. Putrajaya: Berita Harian; 2024. https://www.bharian.com.my/berita/nasional/2024/06/1255563/25-sungai-di-malaysia-tercemar-kelas-3-dan-4
13. Imron MF, Setiawan W, Putranto TWC, Abdullah SRS, Kurniawan SB. Biosorption of Chromium by Live and Dead Cells of Bacillus Nitratireducens Isolated from Textile Effluent. *Chemosphere*. 2024;359(1):142389. https://doi.org/10.1016/j.chemosphere.2024.142389
14. Al-Ajalin FA, Idris M, Abdullah SRS, Kurniawan SB, Imron MF. Biosorption of Lead and Copper by Epiphytic Rhizobacterial Species Isolated from *Lepironia articulata* and *Scirpus grossus*. *Journal of Ecological Engineering*. 2024;25(2):44–61. https://doi.org/10.12911/22998993/176144
15. World Health Organization. Guidelines for Drinking-Water Quality: Fourth Edition Incorporating The First and Second Addenda 2022. Geneva: World Health Organization; 2022 https://www.who.int/publications/i/item/9789240045064
16. US EPA. National Primary Drinking Water Regulations. Washington: U.S. Enviromental Protection Agency; 2024. https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations.
17. Ravsanjanie MM, Pawitra AS, Diyanah KC, Zakaria ZA, Marmaya NHB. Utilization of Clean Water, Personal Hygiene of Toddler Caregivers, and Smoking Behavior of Family Members as Risk Factors for Cases of Stunting Toddlers. *Jurnal Kesehatan Lingkungan.* 2021;13(1):48-56. https://doi.org/10.20473/jkl.v13i1.2021.48-56
18. Azteria V, Rosya E. Drinking Water Quality of Water Refill Station in Gebang Raya Tanggerang. *Jurnal Kesehatan Lingkungan*. 2023;15(2):120-126. https://e-journal.unair.ac.id/JKL/article/view/42203
19. Santiyo Wibowo, Syafii, W., Gustan Pari, & Elis Nina Herliyana. Utilization of Lignocellulosic Waste as a Source of Liquid Smoke: A Literature Review, Lampung, Indonesia. *Jurnal Kesehatan Lingkungan*. 2023; 15(3); 196–216. https://doi.org/10.20473/jkl.v15i3.2023.196-216
20. Elgarahy AM, Elwakeel KZ, Mohammad SH, Elshoubaky GA. A Critical Review of Biosorption of Dyes, Heavy Metals and Metalloids From Wastewater As An Efficient and Green Process. *Cleaner Engineering and Technology.* 2021;4(1):1-15. https://doi.org/10.1016/j.clet.2021.100209
21. Pramudinta NK, Sulistyorini L, Iva Rustanti Eri W. Adsorption Kinetics of Banana Stem Activated Carbon in Reducing Phosphate Levels. *Jurnal*

Kesehatan Lingkungan. 2024;16(1):51-58. https://doi.org/10.20473/jkl.v16i1.2024.51-58

22. Yaashikaa PR, Palanivelu J, Hemavathy RV. Sustainable Approaches for Removing Toxic Heavy Metal From Contaminated Water: A Comprehensive Review of Bioremediation and Biosorption Techniques. *Chemosphere*. 2024;357(1):141933. https://doi.org/10.1016/j.chemosphere.2024.141933
23. Chong ZT, Soh LS, Yong WF. Valorization of Agriculture Wastes as Biosorbents for Adsorption of Emerging Pollutants: Modification, Remediation and Industry Application. *Results in Engineering*. 2023;17(1):1-20. https://doi.org/10.1016/j.rineng.2023.100960
24. Zhang Z, Chen Y, Wang D, Yu D, Wu C. Lignin-Based Adsorbents for Heavy Metals. *Industrial Crops and Products*. 2023;193(1):116119. https://doi.org/10.1016/j.indcrop.2022.116119
25. Li W, Chai L, Du B, Chen X, Sun RC. Full-Lignin-Based Adsorbent for Removal of Cr(VI) From Waste Water. *Separation and Purification Technology*. 2023;306(A):122644. https://doi.org/10.1016/j.seppur.2022.122644
26. Dey S, Veerendra GTN, Padavala SSAB, Manoj AVP. Evaluate The Use of Flower Waste Biosorbents for Treatment of Contaminated Water. *Water-Energy Nexus*. 2023;6(1):187–230. https://doi.org/10.1016/j.wen.2023.11.001
27. Muhamad II, Pa'e N, Yusof AHM. Bacterial Nanocellulose and Its Application in Wastewater Treatment. *Elsevier eBooks*. 2020;14(1):299–314. https://doi.org/10.1016/b978-0-12-816789-2.00014-6.
28. Randa D, Eri IR, Marlik M, Hermiyanti P. Effect of Adding "Raja" Banana Peel Bioactivator (Musa Textilia) on Tempeh Liquid Waste in Making Organic Liquid Fertilizer. *Jurnal Kesehatan Lingkungan*. 2023;15(2): 127–133. https://doi.org/10.20473/jkl.v15i2.2023.127-133
29. Jena PS, Pradhan A, Nanda SP, Dash AK, Naik B. Biosorption of Heavy Metals from Wastewater Using Saccharomyces Cerevisiae as A Biosorbent: A Mini Review. *Materials Today: Proceedings*. 2022;67(8):1140–1146. https://doi.org/10.1016/j.matpr.2022.07.306
30. Masuku M, Nure JF, Atagana HI, Hlongwa N, Nkambule TTI. Advancing The Development of Nanocomposite Adsorbent Through Zinc-Doped Nickel Ferrite-Pinecone Biochar for Removal Of Chromium (VI) from Wastewater. *Science of The Total Environment*. 2024;908(1):1-16. https://doi.org/10.1016/j.scitotenv.2023.168136
31. Marpongahtun, Andriayani, Muis Y, Gea S, Amaturrahim SA, Attaurrazaq B, et al. Biomass-derived N-doped Carbon Dots/TiO2 for Visible-Light-Induced Degradation of Methyl Orange in Wastewater. *Chemistry Africa.* 2024;7(1):3319-3328. https://doi.org/10.1007/s42250-024-00970-x
32. Rai R, Aryal RL, Paudyal H, Gautam SK, Ghimire KN, Pokhrel MR, et al. Acid-Treated Pomegranate Peel; An Efficient Biosorbent for The Excision of Hexavalent Chromium from Wastewater. *Heliyon*. 2023;9(5):1-17. https://doi.org/10.1016/j.heliyon.2023.e15698
33. Hidayah N, Putri VD, Elma M, Mahmud N, Syauqiah I, Amenia A, et al. The Functionalization of Pyrolyzed Palm Empty Fruit Bunches-Based Membranes Adsorbent by Fourier-Transform Infrared Spectroscopy. *IOP Conference Series Materials Science and Engineering.* 2022;1212(1):1-10. https://doi.org/10.1088/1757-899x/1212/1/012026.
34. United Nations. THE 17 GOALS | Sustainable Development. New York: United Nations; 2023 https://sdgs.un.org/goals.
35. El-Maghraby LMM. Removal of Copper (II) and Ferric (III) Ions from Aqueous Solutions by Adsorption Using Potato Peel. Assiut *Journal of Agricultural Sciences*. 2019;50(3):98–111. https://doi.org/10.21608/ajas.2019.52737
36. Xia Y, Li Y, Xu Y. Adsorption of Pb(II) and Cr(VI) from Aqueous Solution by Synthetic Allophane Suspension: Isotherm, Kinetics, and Mechanisms. *Toxics*. 2022;10(6):1-14. https://doi.org/10.3390/toxics10060291
37. Aschale M, Tsegaye F, Amde M. Potato Peels as Promising Low-Cost Adsorbent for The Removal of Lead, Cadmium, Chromium and Copper From Wastewater. *Desalination and Water Treatment.* 2021;222(1):405–415. https://doi.org/10.5004/dwt.2021.27108
38. Ramli NN, Kurniawan SB, Ighalo JO, Said NSM, Marsidi N, Buhari J, et al. A Review of The Treatment Technologies for Hexavalent Chromium Contaminated Water. *BioMetals.* 2023;36(6):1189–1219. https://doi.org/10.1007/s10534-023-00512-x
39. Osman AI, El-Monaem EMA, Elgarahy AM, Aniagor CO, Hosny M, Farghali M, et al. Methods to Prepare Biosorbents and Magnetic Sorbents for Water Treatment: A Review. *Environmental Chemistry Letters*. 2023;21(4):2337–2398. https://doi.org/10.1007/s10311-023-01603-4
40. Vasić K, Primožič M, Knez Ž, Leitgeb M. Efficient Removal of Cr(VI) Ions from Aqueous Solutions Using Arabinogalactan Coated Magnetic Nanoparticles. *Chemical Engineering Transactions*. 2023;99(1):205–210. https://doi.org/10.3303/CET2399035
41. Abegunde SM, Idowu KS, Adejuwon OM, Adeyemi-Adejolu T. A Review on The Influence of Chemical Modification on The Performance of Adsorbents. *Resources, Environment and Sustainability*. 2020;1(1):1-9. https://doi.org/10.1016/j.resenv.2020.100001
42. Hussain MK, Khatoon S, Nizami G, Fatma UK, Ali M, Singh B, et al. Unleashing The Power of Bio-Adsorbents: Efficient Heavy Metal Removal for Sustainable Water Purification. *Journal of Water Process Engineering*. 2024;64(1):105705. https://doi.org/10.1016/j.jwpe.2024.105705
43. Yuan X, Li J, Luo L, Zhong Z, Xie X. Advances in Sorptive Removal of Hexavalent Chromium (Cr(VI)) in Aqueous Solutions Using Polymeric Materials. *Polymers*. 2023;15(2):1-34. https://doi.org/10.3390/polym15020388