Combination of Shrimp Chitosan and Moringa oleifera Seed Powder as Natural Bioadsorbents for Reducing Copper (Cu) Concentration

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ARMADA
JURNAL PENELITIAN MULTIDISIPLIN

e-ISSN: 2964-2981

ARMADA : Jurnal Penelitian Multidisiplin

https://ejournal.45mataram.ac.id/index.php/armada

Vol. 04, No. 08 Agustus, 2026

Page: 3926-3936

DOI:
https://doi.org/10.55681/armada.v4i8.3369

Article History:

Received: Juni 21, 2026

Revised: Juli 16, 2026

Accepted: Agustus 19, 2026

Abstract : Copper (Cu) contamination in aquatic environments requires effective control because Cu is essential at low concentrations but toxic at high levels. This study aims to evaluate the effectiveness of a combination of shrimp chitosan and Moringa oleifera seed powder as natural bioadsorbents for reducing Cu concentrations and to determine the most effective composition. The study employed a laboratory experimental method with four treatments and three replications, namely P0 (control), P1 (2 g/L chitosan + 2 g/L M. oleifera), P2 (3 g/L chitosan + 1 g/L M. oleifera), and P3 (1 g/L chitosan + 3 g/L M. oleifera). Cu concentrations were analysed using Atomic Absorption Spectrophotometry (AAS), while the data were analysed using analysis of variance followed by Duncan's test at a 95% confidence level. The results showed that the combination of both bioadsorbents significantly reduced Cu concentrations. The highest Cu concentration was observed in the control (18.57 ± 0.14 mg/L), whereas the lowest was recorded in P3 (3.17 ± 0.07 mg/L). Removal efficiency increased from 58.79 ± 0.40% (P1), 71.63 ± 0.34% (P2), to 82.98 ± 0.34% (P3). Therefore, P3 was the most effective composition.

Keywords : Adsorption ; Bioadsorbent ; Copper ; Moringa Oleifera Seed ; Shrimp Chitosan

Abstrak *: Pencemaran tembaga (Cu) di perairan memerlukan pengendalian efektif karena Cu bersifat esensial pada kadar rendah tetapi toksik pada konsentrasi tinggi. Penelitian ini bertujuan mengevaluasi efektivitas kombinasi kitosan udang dan serbuk biji Moringa oleifera sebagai bioadsorben alami dalam menurunkan kadar Cu serta menentukan komposisi paling efektif. Penelitian menggunakan metode eksperimen laboratorium dengan empat perlakuan dan tiga ulangan, yaitu P0 (kontrol), P1 (2 g/L kitosan + 2 g/L M. oleifera), P2 (3 g/L kitosan + 1 g/L M. oleifera), dan P3 (1 g/L kitosan + 3 g/L M. oleifera). Kadar Cu dianalisis menggunakan Atomic Absorption Spectrophotometry (AAS), sedangkan data dianalisis melalui analisis ragam dan uji Duncan pada taraf kepercayaan 95%. Hasil menunjukkan bahwa kombinasi kedua bioadsorben mampu menurunkan kadar Cu secara signifikan. Kadar Cu tertinggi terdapat pada kontrol (18,57 ± 0,14 mg/L), sedangkan terendah pada P3 (3,17 ± 0,07 mg/L). Efisiensi penurunan meningkat dari 58,79 ± 0,40% (P1), 71,63 ± 0,34% (P2),* *hingga 82,98 ± 0,34% (P3). Dengan demikian, P3 merupakan komposisi paling efektif.*

Kata Kunci *: Kitosan Udang, Biji Kelor (Moringa Oleifera), Bioadsorben, Tembaga (Cu), Penurunan Logam Berat.*

INTRODUCTION

Heavy metal pollution in aquatic environments is an ecological issue that requires serious attention because heavy metals are persistent, difficult to degrade, and can remain for long periods in the water column and sediments. Sources of heavy metal pollution may include industrial activities, mining, agriculture, domestic waste, port areas, and fisheries and aquaculture activities that are not supported by adequate waste management. Heavy metal accumulation can reduce water quality, disturb ecosystem balance, and increase the risk of toxic exposure to aquatic organisms and humans through bioaccumulation and biomagnification (Aziz et al., 2023; Saravanan et al., 2024). Studies in coastal waters and pond environments have also shown that heavy metals can be detected in water, sediments, and aquatic organisms; therefore, their control is an important component of aquatic environmental quality management (Juharna et al., 2022; Sasongko et al., 2022).

Copper (Cu) is a heavy metal with a dual character because it is required by organisms in small amounts but can become toxic when its concentration exceeds the tolerance threshold. Cu is involved in enzymatic activity and metabolism, but excessive exposure can cause oxidative stress, tissue damage, osmoregulatory disturbance, growth reduction, and altered organ function in aquatic organisms. Cu sources in aquatic systems may include metal industry effluents, electroplating, mining, pesticides, pipes, antifouling paints, and urban runoff (He et al., 2023; Saravanan et al., 2024). Cu2+ ions can interact with organic matter, minerals, and adsorbent surfaces; therefore, controlling their concentration requires treatment technology that is effective and compatible with the characteristics of the target metal ion (García Ávila et al., 2025; Ma'rifah et al., 2024).

Water contaminated with heavy metals can be treated through chemical precipitation, membrane filtration, ion exchange, electrocoagulation, coagulation-flocculation, and adsorption. Adsorption technology is widely developed because the process is relatively simple, flexible, compatible with various adsorbents, and allows the use of natural materials as metal-binding media. Adsorption effectiveness is influenced by adsorbent characteristics, surface area, availability of functional groups, pH, contact time, initial metal concentration, adsorbent dose, and the chemical conditions of the solution (García Ávila et al., 2025). Biomaterial-based adsorbents are considered relevant because they are renewable, biodegradable, and can be developed from abundant local resources (Omer et al., 2022; Upadhyay et al., 2021).

Natural-material-based bioadsorbents are an important alternative for heavy metal remediation because they combine pollutant-binding ability with environmental sustainability. Fishery waste, plant biomass, and agricultural by-products can be developed as adsorbents because they contain active functional groups such as amine, hydroxyl, carboxyl, phosphate, and protein groups. These groups can interact with metal ions through complexation, chelation, ion exchange, electrostatic interaction, hydrogen bonding, and surface adsorption (Begum et al., 2021; Rahman et al., 2023). Recent reviews have also emphasized that plant- and biopolymer-based natural materials have strong prospects for water treatment because they are inexpensive, easy to obtain, and can be modified into composites with higher adsorption capacity (Benettayeb et al., 2022; Orisawayi et al., 2026).

Chitosan is a biopolymer obtained from chitin deacetylation and is commonly found in shrimp shells, crab shells, and other crustaceans. Shrimp shell waste has strong potential as a chitosan source because it is abundantly generated by fishery processing activities and is often not optimally utilized. Chitosan derived from shrimp shells is attractive for development because it contains amine (-NH2) and hydroxyl (-OH) groups that can serve as active sites for metal ion binding (Apriliani et al., 2023; Kurniawidi et al., 2022). Chitosan characteristics, such as degree of deacetylation, particle size, porosity, and solubility under weak acidic conditions, determine its adsorption ability toward heavy metals (Pari et al., 2022; Nerdy et al., 2022).

The ability of chitosan to bind heavy metals is related to the presence of amine and hydroxyl groups in its polymer chain. The amine group has lone electron pairs on nitrogen atoms that can form coordination bonds with metal ions, while the hydroxyl group can support complex formation through surface interactions. Chitosan and chitosan-based composites have been widely reported to be effective in removing heavy metals from water and wastewater (Begum et al., 2021; Hemmami et al., 2024). Recent research has shown that chitosan derived from shrimp carapace can remove Cu(II) from wastewater through adsorption and metal-ligand complexation mechanisms (Benazouz et al., 2025). The application of chitosan in water treatment is further supported by studies on shrimp-based and modified chitosan that can adsorb various metal ions from contaminated water (Rahman et al., 2023; Khairi et al., 2025).

Moringa oleifera seeds are biomaterials with potential as natural coagulants and biosorbents in water treatment. These seeds contain cationic proteins, carboxyl, hydroxyl, amine groups, and organic compounds that can contribute to charge neutralization, floc formation, and contaminant binding. Moringa oleifera has been studied as a biosorbent for removing water contaminants, including heavy metals, pesticides, dyes, and pharmaceutical compounds (Gomes et al., 2022; Benettayeb et al., 2022). Moringa seed biomass has also been reported to remove Pb, Cd, and Cu from water through biosorption involving active groups on the biomass surface (Nwagbara et al., 2022). The use of Moringa seeds as a biocoagulant is increasingly relevant because this material is easily obtained, relatively inexpensive, and capable of forming flocs during water treatment (Ambami & Sururi, 2024; Harahap et al., 2023).

The combination of shrimp chitosan and Moringa seed powder may produce complementary mechanisms in reducing Cu concentration. Chitosan functions as an adsorbent with amine and hydroxyl groups that can bind Cu2+ ions, whereas Moringa seeds function as both a biosorbent and biocoagulant that supports floc formation and provides additional active organic groups. Combining these materials is expected to increase the contact probability between Cu2+ ions and adsorbent active sites, strengthen floc formation, and facilitate metal separation from the liquid phase (Hamed & Elbarbary, 2023; Vigneshwaran et al., 2020). Studies on natural coagulants and locally based coagulation-filtration combinations have also shown that natural materials can improve water treatment efficiency and reduce dependence on synthetic coagulants (Octavianka & Purnomo, 2023; Fitrah et al., 2025).

A research gap remains in studies specifically evaluating the effectiveness of shrimp chitosan and Moringa seed powder combinations for Cu reduction using different dose compositions. Many previous studies have discussed chitosan as a single adsorbent or Moringa seeds as a natural coagulant separately, whereas studies on the ratio of these two materials for Cu removal remain limited. The combination ratio is important because different material proportions can affect the number of active sites, surface characteristics, floc-forming ability, and metal ion binding efficiency (García Ávila et al., 2025; Omer et al., 2022). Biomaterial-based adsorbent formulations must be determined appropriately because heavy metal removal performance is influenced not only by total dose but also by the compatibility between adsorbent characteristics and the target metal ion (Begum et al., 2021; Orisawayi et al., 2026).

This study aimed to analyze the effectiveness of a combination of shrimp chitosan and Moringa oleifera seed powder in reducing copper (Cu) concentration at a laboratory scale. This study also aimed to determine the most effective adsorbent composition for reducing Cu concentration compared with a control treatment without adsorbent addition. The results are expected to provide a scientific basis for developing natural bioadsorbents derived from fishery waste and local plants as more environmentally friendly, economical, and sustainable alternatives for treating water contaminated with heavy metals. The use of shrimp waste-derived chitosan and Moringa oleifera as water treatment materials supports circular economy principles and the development of remediation technologies based on local resources (Sulistyowati et al., 2024; Widyastuti, 2023).

RESEARCH METHODS

This laboratory-scale experimental study evaluated the effectiveness of shrimp chitosan and *Moringa oleifera* seed powder in reducing Cu concentration in a test solution. The experiment applied controlled adsorbent compositions and measured Cu concentrations before and after treatment. The study was conducted from February to March 2026, with Cu analysis performed at the Chemistry Laboratory of Institut Teknologi Surabaya using Atomic Absorption Spectrophotometry (AAS). Equipment included a grinder, sieve, oven, autoclave, measuring cylinder, beakers, Erlenmeyer flasks, pipettes, analytical balance, pH meter, stirrer, stopwatch, filter paper, funnel, sample bottles, and AAS. Materials consisted of shrimp chitosan, *M. oleifera* seed powder, Cu solution, distilled/deionised water, HCl, NaOH, and 1% acetic acid. Chitosan was selected for its amine and hydroxyl groups, which support metal binding through complexation, ion exchange, and electrostatic interactions, while *Moringa* seeds function as biosorbent and biocoagulant through their proteins and functional groups that facilitate adsorption and floc formation (Begum et al., 2021; Upadhyay et al., 2021; Gomes et al., 2022; Vigneshwaran et al., 2020).

The treatment design comprised P0 (control without adsorbent), P1 (2 g/L chitosan + 2 g/L *Moringa*), P2 (3 g/L chitosan + 1 g/L *Moringa*), and P3 (1 g/L chitosan + 3 g/L *Moringa*). These ratios were used to determine the most effective composition, as adsorbent dose and composition influence active sites, surface characteristics, floc formation, and metal–adsorbent contact (Omer et al., 2022; Nwagbara et al., 2022). *Moringa* seeds were ground and sieved to standardise particle size, while chitosan was dissolved in 1% acetic acid to improve dispersion through protonation of its amine groups. The adsorbents were added to the Cu solution according to treatment, stirred for the predetermined contact time, filtered, and analysed using AAS. Cu removal involved adsorption, complexation, ion exchange, electrostatic interaction, and floc formation (Begum et al., 2021; Hamed & Elbarbary, 2023). The main parameters were Cu concentration (mg/L) and removal efficiency, calculated as: Removal efficiency (%) = $[(C_0 - C_1)/C_0] \times 100$. Supporting parameters included pH, adsorbent dose, and contact time. Results were expressed as mean ± standard deviation and analysed using ANOVA, followed by Duncan's multiple range test at a 95% confidence level ($P < 0.05$) when significant differences were detected. This analysis determined differences among treatments and identified the most effective adsorbent composition (Lusiana & Mahmudi, 2023).

RESULTS AND DISCUSSION

Copper (Cu) Concentration after Treatment with Shrimp Chitosan and Moringa Seed Powder Combination

The results showed that the application of shrimp chitosan and Moringa oleifera seed powder reduced copper (Cu) concentration in the test solution. The control treatment without adsorbent addition (P0) produced the highest Cu concentration, namely 18.57 ± 0.14 mg/L. Cu concentration decreased to 7.68 ± 0.08 mg/L in P1, 5.29 ± 0.07 mg/L in P2, and reached the lowest concentration of 3.17 ± 0.07 mg/L in P3. Duncan's post hoc test showed that each treatment had different superscript notation; therefore, Cu concentrations differed significantly among treatments at $P<0.05$. This pattern indicates that different compositions of shrimp chitosan and Moringa seed powder produced different responses in final Cu concentration in the test solution.

Table 1. Cu concentration after treatment with shrimp chitosan and Moringa seed powder combination

Treatment	Treatment Composition	Cu Concentration (mg/L) Mean ± SD
P0	Cu solution without adsorbent	$18.57^{d} \pm 0.14$
P1	Cu + 2 g/L shrimp chitosan + 2 g/L Moringa seed powder	$7.68^{c} \pm 0.08$
P2	Cu + 3 g/L shrimp chitosan + 1 g/L Moringa seed powder	$5.29^{b} \pm 0.07$
P3	Cu + 1 g/L shrimp chitosan + 3 g/L Moringa seed powder	$3.17^{a} \pm 0.07$

Note: Different superscript letters in the same column indicate significant differences among treatments based on Duncan's test at the 5% level

The high Cu concentration in P0 occurred because no adsorbent was available to bind Cu2+ ions from the solution phase. Heavy metals such as Cu are persistent in aquatic environments and cannot be biologically degraded; therefore, their reduction requires transfer from the dissolved phase to a solid phase or floc. Heavy metal pollution in water is a major issue because metals can persist in the water column, accumulate in sediments, and cause toxic risks to aquatic organisms (Aziz et al., 2023). Cu is essential at low concentrations but can cause toxic effects at high concentrations by inducing physiological disturbance, oxidative stress, and tissue damage in aquatic organisms (Saravanan et al., 2024).

The decrease in Cu concentration in P1, P2, and P3 indicates that the combination of shrimp chitosan and Moringa seed powder has potential as a natural bioadsorbent. Heavy metal reduction by adsorbents is generally influenced by adsorbent surface characteristics, availability of functional groups, solution pH, contact time, initial metal concentration, and adsorbent dose (García Ávila et al., 2025). Biomaterial-based adsorbents are widely developed because they contain natural active groups, are biodegradable, are relatively easy to obtain, and can serve as more environmentally friendly alternatives to synthetic materials (Omer et al., 2022).

Shrimp chitosan played an important role in Cu reduction because it contains amine (-NH2) and hydroxyl (-OH) groups that can interact with metal ions. The amine group in chitosan has lone electron pairs on nitrogen atoms that can form coordination bonds with Cu2+ ions, while the hydroxyl group supports surface interactions and metal complex formation. Chitosan and chitosan-based composites have been widely reported to be effective heavy metal adsorbents because their functional groups can bind metal cations through complexation, ion exchange, and electrostatic interaction (Begum et al., 2021). The development of chitosan-based adsorbents is also relevant because chitosan can be modified to improve adsorption capacity, stability, and selectivity toward specific metal ions (Upadhyay et al., 2021).

Treatment P1, which used 2 g/L shrimp chitosan and 2 g/L Moringa seed powder, reduced Cu concentration to 7.68 ± 0.08 mg/L. This reduction indicates that the balanced combination of the two materials already provided active sites for binding most Cu2+ ions in the solution. Chitosan in P1 provided amine and hydroxyl groups, whereas Moringa seed powder provided active organic groups and proteins that supported biosorption. Nano-chitosan has also been reported to adsorb several metal ions, including Cu2+, Pb2+, Zn2+, and Cr6+, from aqueous solutions, strengthening the potential of chitosan as a heavy metal adsorbent platform (He et al., 2023). Chitosan has good metal-binding capacity because of its hydroxyl and amine groups, although its performance remains affected by pH, structural stability, and physical material properties (Zhang et al., 2021).

Treatment P2 produced a lower Cu concentration than P1, namely 5.29 ± 0.07 mg/L. This condition indicates that increasing the chitosan proportion to 3 g/L can increase the number of active sites available for binding Cu2+ ions. A higher chitosan dose may increase the contact probability between Cu2+ and amine groups in the chitosan polymer chain. Chitosan-based adsorbents have been reported to be effective for heavy metal removal because they can work individually or as composites through complexation and surface interaction mechanisms (Ashraf et al., 2024). Chitosan nanocomposites are also widely developed because material integration can improve surface area and porosity, thereby increasing heavy metal adsorption ability (Rostami et al., 2024).

The effectiveness of P2 is also consistent with studies showing that shrimp shell-derived chitosan can reduce Cu(II) from wastewater. Chitosan derived from shrimp carapace has potential as an adsorbent because shrimp waste contains chitin that can be converted into chitosan through deacetylation. Shrimp waste-derived chitosan has been reported to remove Cu(II) through adsorption mechanisms influenced by interactions between Cu2+ ions and chitosan active groups (Benazouz et al., 2025). The use of shrimp shell-derived chitosan also has ecological value because it converts fishery waste into functional material for the treatment of heavy metal-contaminated water (Khairi et al., 2025).

Treatment P3 produced the lowest Cu concentration, namely 3.17 ± 0.07 mg/L. The P3 composition consisted of 1 g/L shrimp chitosan and 3 g/L Moringa seed powder, meaning that the proportion of Moringa seed powder was higher than in the other treatments. This result indicates that Moringa seeds contributed substantially to Cu reduction under the conditions of this study. Moringa oleifera seeds contain cationic proteins, hydroxyl, carboxyl, amine groups, and organic compounds that can contribute to metal binding and floc formation (Gomes et al., 2022). Moringa seed biomass has also been reported to remove Cu from water through biosorption involving active groups on the biomass surface (Nwagbara et al., 2022).

The role of Moringa seeds in P3 can be explained by their ability to act as both a biosorbent and a natural biocoagulant. Cationic proteins in Moringa seeds can assist the neutralization of particle charges in water so that particles, colloids, or metal complexes can more easily aggregate into flocs. The flocs formed can then carry metal ions out of the solution phase through filtration. Reviews on Moringa oleifera in water treatment show that its seeds have potential as biosorbents for various contaminants because they contain active biomolecules and functional groups capable of interacting with pollutants (Benettayeb et al., 2022). The use of Moringa seeds as natural coagulants also supports sustainable water treatment because it can reduce dependence on synthetic chemical coagulants (Vigneshwaran et al., 2020).

The differences in Cu concentration among P1, P2, and P3 show that Cu reduction effectiveness was not determined only by the total adsorbent dose. All three treatments used a total adsorbent dose of 4 g/L but produced different final Cu concentrations. P1 produced a final concentration of 7.68 mg/L, P2 produced 5.29 mg/L, and P3 produced 3.17 mg/L. These differences indicate that the ratio between shrimp chitosan and Moringa seed powder influenced the number of active groups, surface characteristics, floc-forming probability, and interactions between Cu2+ ions and adsorbent surfaces. Heavy metal adsorption by biomaterials depends strongly on the compatibility between metal ion type, adsorbent surface charge, and solution chemistry (García Ávila et al., 2025).

The combination of 1 g/L shrimp chitosan and 3 g/L Moringa seed powder in P3 produced a more complementary adsorption system than the other treatments. Chitosan still provided amine and hydroxyl groups as Cu2+ binding sites, whereas the higher proportion of Moringa seeds supplied cationic proteins and active organic groups that strengthened biosorption and coagulation-flocculation. The combination of chitosan and Moringa oleifera seeds has been reported to help control heavy metal residues in water and fish tissues, supporting the scientific basis of this combined approach for metal contamination treatment (Hamed & Elbarbary, 2023). Moringa seeds have also been used in heavy metal removal systems for Cd, Cr, and Pb, indicating that their potential as metal-adsorbing materials is not limited to Cu (Ravikumar & Udayakumar, 2020).

Percentage Reduction of Copper (Cu) after Treatment

The Cu reduction percentage showed a pattern consistent with the final Cu concentration. Treatment P0 showed no reduction because no adsorbent was added, resulting in a reduction percentage of 0.00 ± 0.00%. Treatment P1 produced a Cu reduction of 58.79 ± 0.40%, P2 produced 71.63 ± 0.34%, and P3 produced the highest reduction of 82.98 ± 0.34%. Duncan's post hoc test showed that each treatment had different superscript notation; therefore, all treatments differed significantly at $P<0.05$. These data indicate that the combination of shrimp chitosan and Moringa seed powder significantly increased Cu reduction compared with the control.

Tabel 3. Persentase penurunan kadar Cu setelah perlakuan

Treatment	Initial Cu (mg/L	Final Cu (mg/L)	Cu Reduction (%) Mean ± SD
P0	18,57	18.57	$0.00^{a} \pm 0.00$
P1		7.68	$58.79^{b} \pm 0.40$
P2		5.29	$71.63^{c} \pm 0.34$
P3		3.17	$82.98^{d} \pm 0.34$

Note: Different superscript letters in the same column indicate significant differences among treatments based on Duncan's test at the 5% level

The 58.79% reduction in P1 indicates that the balanced combination of shrimp chitosan and Moringa seed powder was able to bind more than half of the Cu concentration in the solution. This ability indicates that active groups from both materials contributed to reducing dissolved Cu2+ ions. The -NH2 and -OH groups in chitosan can form complexes with metal ions, while the carboxyl, hydroxyl, amine, and protein groups in Moringa seeds can support contaminant binding through biosorption (Begum et al., 2021). Shrimp waste-derived chitosan has also been used to reduce heavy metals such as Cu, Fe, and Pb; therefore, it is relevant as a bioadsorbent in water treatment systems (Lestari et al., 2024).

The reduction percentage in P2 increased to 71.63%. This increase indicates that a higher chitosan proportion can enhance Cu binding effectiveness compared with the balanced combination in P1. Chitosan can bind Cu2+ ions through complexation, ion exchange, electrostatic interaction, and surface adsorption. Reviews of chitosan-based adsorbents state that modifying chitosan form and composition can improve heavy metal removal performance by increasing active-site availability and material stability (Omer et al., 2022). Chitosan derived from shrimp and crab shells has also been shown to act as a natural adsorbent for heavy metals and dyes, supporting the use of crustacean waste in bioresource-based water treatment approaches (Nerdy et al., 2022).

The highest reduction percentage in P3, 82.98%, indicates that the combination with a higher proportion of Moringa seed powder produced the greatest effectiveness under the conditions of this study. The role of Moringa seeds in P3 was related to the presence of cationic proteins that can assist charge neutralization and floc formation, allowing Cu that has interacted with biomaterials to be more easily separated from the solution phase. The use of Moringa seeds as natural coagulants has been widely reported to reduce water contaminants through charge neutralization and floc formation mechanisms (Harahap et al., 2023). Moringa seeds also have adsorbent potential because their functional groups can bind metal ions through surface interaction and complexation (Sharah, 2023).

The Cu reduction mechanism in P3 can be explained by the combined action of chitosan and Moringa seeds. Chitosan contributed to Cu2+ complexation through amine and hydroxyl groups, whereas Moringa seeds supported biosorption and coagulation-flocculation through cationic proteins and active organic groups. Positively charged Cu2+ ions can interact with carboxylate or negatively charged groups on organic material surfaces, while flocs can help carry metal ions out of the solution. Heavy metal adsorption on biomaterials generally occurs through combined mechanisms such as surface adsorption, ion exchange, complexation, hydrogen bonding, and electrostatic interaction (Aziz et al., 2023). These multiple interactions explain why the two-biomaterial combination produced higher Cu reduction than the control without adsorbent.

The results also show that natural bioadsorbents have potential to support more sustainable treatment of heavy metal-contaminated water. Chitosan derived from shrimp waste can reduce fishery waste burdens while producing functional material for environmental remediation. The valorization of crustacean waste into chitosan is aligned with waste valorization principles because low-value waste can be converted into useful adsorbent material (Sulistyowati et al., 2024). The development of shrimp waste-derived chitosan has also been reported to support pollutant removal from water because its chemical characteristics are rich in active groups and can be readily combined with other materials (Kurniawidi et al., 2022).

Moringa seed powder also offers advantages as a local material that is easy to obtain, biodegradable, and potentially applicable as a natural coagulant or biosorbent. Its role in water treatment systems is related not only to metal binding but also to its ability to promote particle settling through floc formation. Research on natural-material-based coagulation indicates that local materials can serve as alternatives in water treatment because they can reduce turbidity and support particle separation from the liquid phase (Fitrah et al., 2025). The use of Moringa seeds as a biocoagulant has also been studied for reducing wastewater pollution parameters, including organic matter and certain inorganic compounds (Hayat & Mu'tamirah, 2019).

The increase in reduction percentage from P1 to P3 indicates that the higher proportion of Moringa seeds provided a major contribution in the combination system. This condition may occur because Moringa seeds supply cationic proteins and active organic groups that support floc formation, while chitosan continues to contribute binding through amine and hydroxyl groups. Combining materials with different mechanisms can improve metal removal effectiveness because adsorption and coagulation can occur simultaneously. Studies on natural coagulant systems show that combining active organic materials can improve aggregation and particle separation from water (Vigneshwaran et al., 2020). Research on Moringa oleifera biosorption also confirms that functional groups on biomass surfaces play an important role in removing metal ions from water (Nwagbara et al., 2022).

The implication of this study is that shrimp chitosan and Moringa seed powder can be considered an initial natural bioadsorbent formulation for reducing Cu concentration at the laboratory scale. The composition of 1 g/L shrimp chitosan and 3 g/L Moringa seed powder produced the lowest final Cu concentration and the highest reduction percentage compared with the other treatments. These results strengthen the potential use of local biomaterials in the treatment of heavy metal-contaminated water. Further development should include testing with actual wastewater, variation in pH and contact time, functional group characterization using FTIR, surface morphology analysis using SEM, and kinetic and isotherm adsorption studies. Strong heavy metal adsorption studies should present not only reduction efficiency but also adsorption capacity, surface mechanisms, and optimum process conditions (García Ávila et al., 2025).

The results should also be interpreted within the limitations of laboratory-scale experiments. The test solution had more controlled conditions than actual wastewater, whereas real wastewater may contain competing ions, dissolved organic matter, suspended solids, pH variations, and other contaminants that can affect adsorbent performance. These factors may alter Cu adsorption ability because active sites on adsorbents may compete with other ions. Studies on heavy metal treatment in water emphasize that adsorption efficiency is strongly influenced by water characteristics, pollutant composition, and operational conditions (Saravanan et al., 2024). Further testing under real conditions is required to evaluate the application feasibility of shrimp chitosan and Moringa seed powder more comprehensively (Benettayeb et al., 2022).

CONCLUSION

The combination of shrimp chitosan and Moringa oleifera seed powder had a significant effect on reducing copper (Cu) concentration at the laboratory scale. The control treatment without adsorbent (P0) produced a Cu concentration of 18.57 ± 0.14 mg/L. Treatment P1, consisting of 2 g/L shrimp chitosan and 2 g/L Moringa seed powder, produced a Cu concentration of 7.68 ± 0.08 mg/L with a reduction percentage of 58.79 ± 0.40%. Treatment P2, consisting of 3 g/L shrimp chitosan and 1 g/L Moringa seed powder, produced a Cu concentration of 5.29 ± 0.07 mg/L with a reduction percentage of 71.63 ± 0.34%. Treatment P3, consisting of 1 g/L shrimp chitosan and 3 g/L Moringa seed powder, produced the lowest Cu concentration of 3.17 ± 0.07 mg/L with the highest reduction percentage of 82.98 ± 0.34%. Based on these results, the combination of 1 g/L shrimp chitosan and 3 g/L Moringa seed powder was the most effective composition for reducing Cu concentration in this study

ACKNOWLEDGMENT

The authors sincerely express their gratitude to the Faculty of Fisheries and Marine, Universitas Airlangga, for providing the facilities, resources, and academic support that made this research possible. Their continuous support is greatly appreciated.

REFERENCES

Ambami, A. R., & Sururi, M. R. (2024). Efektifitas biji kelor sebagai biokoagulan: Studi literatur. FTSP Series: Seminar Nasional dan Diseminasi.

Apriliani, D., Handayani, L., Putri, N., Zuhrayani, R., & Syahputra, F. (2023). Isolasi kitosan dari cangkang udang pisang (Penaeus sp.) sebagai spesies endemik di pantai barat Aceh. Agrointek, 17(3), 599–607.

Ashraf, A., Dutta, J., Farooq, A., Rafatullah, M., Pal, K., & Kyzas, G. Z. (2024). Chitosan-based materials for heavy metal adsorption: Recent advancements, challenges and limitations. Journal of Molecular Structure, 1309, 138225. https://doi.org/10.1016/j.molstruc.2024.138225

Aziz, K. H. H., Mustafa, F. S., Omer, K. M., Hama, S., Hamarawf, R. F., & Rahman, K. O. (2023). Heavy metal pollution in the aquatic environment: Efficient and low-cost removal approaches to eliminate their toxicity: A review. RSC Advances, 13, 17595–17610. https://doi.org/10.1039/D3RA00723E

Begum, S., Yuhana, N. Y., Saleh, N. M., Kamarudin, N. H. N., & Sulong, A. B. (2021). Review of chitosan composite as a heavy metal adsorbent: Material preparation and properties. Carbohydrate Polymers, 259, 117613. https://doi.org/10.1016/j.carbpol.2021.117613

Benazouz, K., Bouchelkia, N., Moussa, H., Boutheldja, R., Zamouche, M., Amrane, A., Parvathiraja, C., Al-Lohedan, H. A., Bollinger, J.-C., & Mouni, L. (2025). Efficient removal of Cu(II) from wastewater using chitosan derived from shrimp shells: A kinetic, thermodynamic, optimization, and modelling study. Water, 17(6), 851. https://doi.org/10.3390/w17060851

Benettayeb, A., Usman, M., Tinashe, C. C., Adam, T., & Haddou, B. (2022). A critical review with emphasis on recent pieces of evidence of Moringa oleifera biosorption in water and wastewater treatment. Environmental Science and Pollution Research, 29, 48185–48209. https://doi.org/10.1007/s11356-022-19938-w

Fitrah, M. A., Birawida, A. A., Khaer, A., Sedionoto, B., & Budirman. (2025). Kombinasi koagulasi-filtrasi berbahan lokal kepulauan dalam mengurangi kadar kekeruhan pada air sumur gali di Pulau Barrang Caddi, Kota Makassar. Media Kesehatan Politeknik Kesehatan Makassar, 10(1).

García Ávila, F. F., Cabrera Sumba, J. M., Valdez Pilataxi, S. J., Villalta Chungata, J. A., Valdiviezo Gonzales, L. G., & Alegria Arnedo, C. (2025). Removal of heavy metals in industrial wastewater using adsorption technology: Efficiency and influencing factors. Cleaner Engineering and Technology, 24, 100879. https://doi.org/10.1016/j.clet.2024.100879

Gomes, H. de O., Freire, P. de T. C., do Nascimento, R. F., & Pereira Teixeira, R. N. (2022). Removal of contaminants from water using Moringa oleifera Lam. as biosorbent: An overview of the last decade. Journal of Water Process Engineering, 46, 102576. https://doi.org/10.1016/j.jwpe.2022.102576

Hamed, O. E., & Elbarbary, H. K. N. (2023). Chitosan and Moringa oleifera seeds controlling heavy metal residues in water and fish meat. Egyptian Journal of Aquatic Biology & Fisheries, 27(4), 63–75. https://doi.org/10.21608/ejabf.2023.307321

Harahap, L. A., Sirait, R., & Lubis, R. Y. (2023). Efektivitas biji kelor pada proses koagulasi untuk penurunan kekeruhan, logam Fe, dan zat organik KMnO4 pada air. Journal of Physics, 8(2), 66–69.

Hayat, M. F., & Mu'tamirah, S. (2019). Pemanfaatan biji kelor (Moringa oleifera) sebagai koagulan dalam menurunkan kadar fosfat (PO4) dan amoniak (NH3) pada air limbah rumah sakit. Prosiding Seminar Nasional Penelitian dan Pengabdian Kepada Masyarakat.

He, Y., Zhang, P., & Wang, L. (2023). Adsorption and removal of Cr6+, Cu2+, Pb2+, and Zn2+ from aqueous solution by magnetic nano-chitosan. Molecules, 28(6), 2607. https://doi.org/10.3390/molecules28062607

Hemmami, H., Amor, I. B., Amor, A. B., Zeghoud, S., Ahmed, S., & Alhamad, A. A. (2024). Chitosan, its derivatives, sources, preparation methods, and applications: A review. JOTCSA, 11(1), 341–364.

Juharna, F. M., Widowati, I., & Endrawati, H. (2022). Kandungan logam berat timbal (Pb) dan kromium (Cr) pada kerang hijau (Perna viridis) di Perairan Morosari, Sayung, Kabupaten Demak. Buletin Oseanografi Marina, 11(2), 139–148.

Khairi, S., Wijoyo, T. B. R., Radhiansyah, Y. L., Belanisa, T., & Rezeki, S. (2025). Preparasi kitosan dari cangkang udang putih untuk menghilangkan Fe(III) air tanah Kota Pontianak. Stannum: Jurnal Sains dan Terapan Kimia, 7(1), 14–24.

Kurniawidi, D. K., Alaa, S., Nurhaliza, E., Safitri, D. E., Rahayu, S., Ali, M., & Amin, M. (2022). Synthesis and characterization of nano chitosan from vannamei shrimp shell. Jurnal Ilmiah Perikanan dan Kelautan, 14(2), 380–387.

Lestari, D. W., Rodiah, S., & Asnari, M. (2024). Pemanfaatan kitosan sebagai adsorben untuk menurunkan kadar logam tembaga (Cu), besi (Fe), dan timbal (Pb). Phenomenon, 2(1), 61–68.

Lusiana, E. D., & Mahmudi, M. (2023). Anova untuk penelitian eksperimen: Teori dan praktik dengan R. UB Press.

Ma'rifah, A. U., Anggraito, Y. U., & Setiati, N. (2024). Metallothionein sebagai protein pengikat logam untuk bioremediasi logam berat. Jurnal Biologi Pendidikan dan Terapan, 10(2), 186–193.

Nerdy, N., Lestari, P., Simorangkir, D., Aulianshah, V., Yusuf, F., & Bakri, K. T. (2022). Comparison of chitosan from crab shell waste and shrimp shell waste as natural adsorbent against heavy metals and dyes. International Journal of Applied Pharmaceutics, 14(2), 181–185.

Nwagbara, V. U., Chigayo, K., Iyama, W. A., & Kwaambwa, H. M. (2022). Removal of lead, cadmium, and copper from water using Moringa oleifera seed biomass. Journal of Water and Climate Change, 13(7), 2747–2760. https://doi.org/10.2166/wcc.2022.099

Octavianka, H., & Purnomo, A. (2023). Perbandingan kemampuan poly aluminum chloride (PAC) dan biokoagulan dari tepung jagung pada instalasi pengolahan air bersih di PT Semen Indonesia. Jurnal Teknik ITS, 12(2), 6–11.

Omer, A. M., Dey, R., Eltaweil, A. S., Abd El-Monaem, E. M., & Ziora, Z. M. (2022). Insights into recent advances of chitosan-based adsorbents for sustainable removal of heavy metals and anions. Arabian Journal of Chemistry, 15(2), 103543. https://doi.org/10.1016/j.arabjc.2021.103543

Orisawayi, A. O., Koziol, K. K., & Rahatekar, S. S. (2026). Bio-based composites of alginate, cellulose, and Moringa oleifera for heavy metal removal in water purification: A comprehensive and critical review of mechanisms, fabrication, and performance. Environmental Science: Advances, 5, 617–658. https://doi.org/10.1039/D5VA00347D

Pari, R. F., Mayangsari, D., & Hardiningtyas, S. D. (2022). Depolimerisasi kitosan dari cangkang udang dengan enzim papain dan iradiasi sinar ultraviolet. Jurnal Pengolahan Hasil Perikanan Indonesia, 25(1).

Rahman, A., Haque, M. A., Ghosh, S., Shinu, P., Attimarad, M., & Kobayashi, G. (2023). Modified shrimp-based chitosan as an emerging adsorbent removing heavy metals chromium, nickel, arsenic, and cobalt from polluted water. Sustainability, 15(3), 2431.

Ravikumar, K., & Udayakumar, J. (2020). Moringa oleifera seed composite: A novel material for hazardous heavy metals Cd, Cr, and Pb removal from aqueous systems. Journal of Materials and Environmental Sciences, 11(1), 123–138.

Rostami, M. S., & Khodaei, M. M. (2024). Recent advances in chitosan-based nanocomposites for adsorption and removal of heavy metal ions. International Journal of Biological Macromolecules, 270, 132386. https://doi.org/10.1016/j.ijbiomac.2024.132386

Saravanan, P., Saravanan, V., Rajeshkannan, R., Arnica, G., Rajasimman, M., Baskar, G., & Pugazhendhi, A. (2024). Comprehensive review on toxic heavy metals in the aquatic system: Sources, identification, treatment strategies, and health risk assessment. Environmental Research, 258, 119440. https://doi.org/10.1016/j.envres.2024.119440

Sasongko, A. S., Rudi, M., Surya, A. T. J., Aziz, R. M. T., & Pambudi, R. A. (2022). Kandungan logam berat di tambak Gracilaria verrucosa Desa Lontar Kabupaten Serang. Journal of Marine Research, 11(2), 303–308.

Sharah, M. A. (2023). Adsorpsi logam Pb dengan menggunakan biji kelor sebagai adsorben. Jurnal Kridatama Sains dan Teknologi, 5(2).

Sulistyowati, L., Syarif, M., Elvira, M. F., Putrianti, N. P., Krisnawati, E., & Komarudin, M. A. (2024). From waste to wealth: Entrepreneurial ventures in chitosan extraction for environmental sustainability. APTISI Transactions on Technopreneurship, 6(3), 443–457.

Upadhyay, U., Sreedhar, I., Singh, S. A., Patel, C. M., & Anitha, K. L. (2021). Recent advances in heavy metal removal by chitosan based adsorbents. Carbohydrate Polymer Technologies and Applications, 2, 100066. https://doi.org/10.1016/j.carpta.2021.100066

Vigneshwaran, S., Karthikeyan, P., Sirajudheen, P., & Meenakshi, S. (2020). Optimization of sustainable chitosan/Moringa oleifera as coagulant aid for the treatment of synthetic turbid water: A systemic study. Environmental Chemistry and Ecotoxicology, 2, 132–140. https://doi.org/10.1016/j.enceco.2020.08.002

Widyastuti. (2023). Perbandingan karakteristik dan kualitas kitosan dari kulit udang jerbung (Penaeus merguiensis de Man) dan udang windu (Penaeus monodon Fabricius). Jurnal Farmasi Sains dan Obat Tradisional, 2(1).

Zhang, Y., Zhao, M., Cheng, Q., Wang, C., Li, H., Han, X., Fan, Z., Su, G., Pan, D., & Li, Z. (2021). Research progress of adsorption and removal of heavy metals by chitosan and its derivatives: A review. Chemosphere, 279, 130927. https://doi.org/10.1016/j.chemosphere.2021.130927