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Application of Mung Bean Biocoagulant for Tofu and Tempeh Wastewater Treatment

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Abstract

Wastewater generated from tofu and tempeh production commonly contains high organic loads and suspended particles, necessitating environmentally sustainable treatment methods. This study investigated the use of mung bean (*Vigna radiata*) as a biocoagulant for reducing chemical oxygen demand (COD) and turbidity and improving the pH of tofu and tempeh wastewater. The study evaluated the effect of extraction with 1 M NaCl on biocoagulant performance, determined the optimum biocoagulant dosage, and assessed the influence of slow-mixing time on treatment effectiveness. Coagulation–flocculation was performed using mung bean biocoagulants before and after NaCl extraction, with dosages ranging from 1 to 5 g per 500 mL of wastewater and slow-mixing times ranging from 15 to 35 minutes. Initial characterization indicated that several wastewater quality parameters exceeded the applicable discharge standards. The NaCl-extracted biocoagulant performed better than the unextracted biocoagulant, achieving COD and turbidity removal efficiencies of 9.95% and 90.98%, respectively, with a final pH of 7.27. Across the dosage variations, the highest COD removal efficiency of 41.45% was obtained at 4 g/500 mL, whereas the highest turbidity removal efficiency of 91.17% was achieved at 2 g/500 mL. The highest final pH of 7.81 was recorded at 5 g/500 mL. The optimum slow-mixing time was 15 minutes, resulting in COD removal of 14.26%, turbidity removal of 87.45%, and a final pH of 7.19. These findings demonstrate that NaCl-extracted mung bean biocoagulant has considerable potential for improving tofu and tempeh wastewater quality, particularly through turbidity removal. The study contributes to the development of plant-based biocoagulants as an environmentally sustainable alternative for wastewater treatment, although optimization remains necessary to improve COD removal efficiency.

Keywords: Biocoagulant; Coagulation–Flocculation; Mung Bean; Tofu and Tempeh Wastewater; Wastewater Treatment

INTRODUCTION

The tofu and tempeh industry is one of Indonesia's major food sectors and generates large volumes of wastewater containing high concentrations of organic matter and suspended solids. Therefore, wastewater must be treated before discharge to comply with the Indonesian wastewater quality standards stipulated in Minister of Environment and Forestry Regulation No. P.5/MENLHK/SETJEN/KUM.1/2/2019. Among the available treatment methods, coagulation–flocculation is widely applied because of its effectiveness in removing suspended and dissolved pollutants. However, its performance depends on several operating parameters, including coagulant dosage and mixing conditions (Mohd et al., 2023)

Natural coagulants have attracted increasing attention as environmentally friendly alternatives to conventional chemical coagulants because they are biodegradable, produce less sludge, exhibit low toxicity, and do not introduce hazardous metals into treated wastewater (Owodunni & Ismail, 2021). Mung beans are a promising natural coagulant due to their high protein content, which acts as a cationic polyelectrolyte capable of neutralizing negatively charged colloidal particles and promoting floc formation (Wintersohle et al., 2023).

The coagulating proteins can be enhanced through extraction using salt solutions, particularly NaCl. Previous studies have shown that NaCl extraction improves the performance of plant-based biocoagulants by increasing the availability of active protein compounds (Kristianto et al., 2019). However, studies on the application of NaCl-extracted mung bean biocoagulants for treating tofu and tempeh wastewater remain limited. Therefore, this study evaluated the performance of 1 M NaCl-extracted mung bean biocoagulant in reducing COD, turbidity, and pH, as well as determining the optimum biocoagulant dosage and slow mixing time.

METHODS

Wastewater Sampling

Tofu and Tempeh Industrial Wastewater was collected directly on-site at the wastewater inlet point. The sampling process began by rinsing the sample container three times. Next, water samples were collected and placed into 5-liter containers. The collected water samples were analyzed to determine the COD, turbidity, and pH of the wastewater.

Mung Bean Preparation

The mung bean biocoagulant was prepared using the following steps: First, the mung beans were oven-dried at 80°C for 6 hours. Second, the mung beans were ground using a blender. Third, the mung bean powder was sieved through a 50-mesh sieve. The mung bean powder was then stored in a tightly closed container.

Mung Bean Extraction with 1 M NaCl

200 grams of mung bean powder was dissolved in 300 mL of 1 M NaCl and stirred using a magnetic stirrer at 150 rpm for 2 hours to extract the active components of the biocoagulant. The solution was then filtered using Whatman No. 42 filter paper using a vacuum filter and then dried in an oven. The resulting filtrate was used as a biocoagulant

Characteristics of Tofu and Tempeh Industrial Wastewater

The following table shows the characteristics of liquid waste from the tofu and tempe wastewater. The COD and pHparameters are controlled under Government Regulation Number 22 of 2021, while turbidity is controlled under Regulation of the Minister of Environment and Forestry Number 5 of 2019.

Table 1. Wastewater Characteristics

Parameters	Quality standards	Concentration	Units
COD	300	4071	mg/L
Turbidity	25	875	NTU
pH	6-9	4,84	-

Processing Using the Coagulation-Flocculation Method Using Mung Bean Extract Biocoagulant

Coagulation–flocculation experiments were conducted using a jar test apparatus with five 500 mL beakers. Biocoagulant dosages of 1–5 g/500 mL and slow mixing times of 15–35 minutes were evaluated. Each test consisted of rapid mixing at 150 rpm for 2 minutes, followed by slow mixing at 40 rpm and 30 minutes of sedimentation. The optimum operating conditions were then used to evaluate the overall treatment performance of the mung bean biocoagulant.

FTIR Analysis

The functional groups of the mung bean biocoagulant were analyzed using Fourier Transform Infrared (FTIR). Three functional groups of the mung bean biocoagulant were analyzed: before extraction, after extraction, and after coagulation and flocculation. The FTIR results were displayed graphically, and the functional groups were then analyzed based on the literature.

RESULTS

Effect of 1 M NaCl Extraction on Mung Bean Biocoagulant Performance

To determine the most effective type of biocoagulant, a comparison was made between wastewater treatment results using biocoagulant before and after 1 M NaCl extraction based on COD, turbidity, and pH parameters. The biocoagulant with the better results was then used in the dosage optimization and slow stirring time stages.

Table 2. Comparison of Final Concentration Results Using Biocoagulant Before and After 1 M NaCl Extraction

Parameters	Initial concentration (mg/L)	Final concentration (mg/L)			
		Before extraction	Removal (%)	After extraction	Removal (%)
COD	4071	4314	-5,97%	3666	9,95
Turbidity	875	487	76,67	78,9	90,98
pH	4,84	4,23	-	7,27	-

The initial COD concentration of the wastewater was 4071 mg/L. After treatment with the unextracted biocoagulant, the COD concentration increased to 4314 mg/L, corresponding to a removal efficiency of −5.97%. In contrast, treatment with the 1 M NaCl-extracted biocoagulant reduced the COD concentration to 3666 mg/L, resulting in a removal efficiency of 9.95%.

The unextracted biocoagulant reduced turbidity from 875 NTU to 487 NTU, corresponding to a removal efficiency of 76.67%. After NaCl extraction, the final turbidity decreased further to 78.9 NTU, with a removal efficiency of 90.98%.

The initial wastewater pH was 4.84. Treatment with the unextracted biocoagulant reduced the pH to 4.23, whereas the extracted biocoagulant increased the final pH to 7.27. Overall, the extracted biocoagulant achieved lower final COD and turbidity values and produced a final pH closer to neutral than the unextracted biocoagulant. Therefore, the extracted biocoagulant was selected for the subsequent experiments.

The Effect of Biocoagulant Dose on COD Removal Efficiency

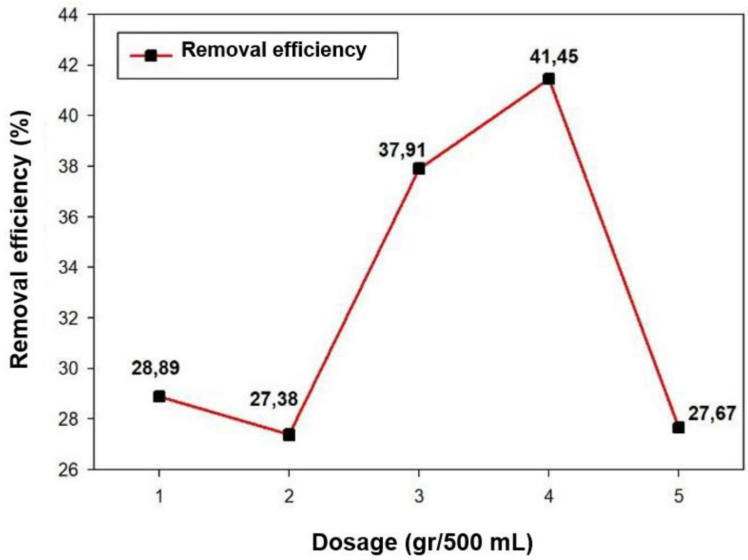

Figure 1. Effect of Biocoagulant Dosage on COD Removal Efficiency

Figure 1 illustrates the effect of biocoagulant dosage on COD removal. The removal efficiency increased as the dosage was raised from 1 to 4 g/500 mL, reaching a maximum value of 41.45% at 4 g/500 mL. However, a further increase in dosage did not improve COD removal, indicating that 4 g/500 mL was the optimum dosage under the experimental conditions.

The Effect of Biocoagulant Dose on Turbidity Removal Efficiency

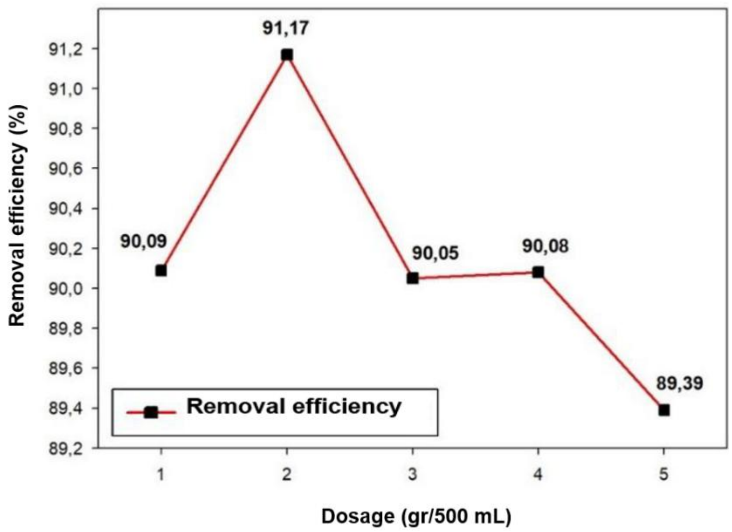

Figure 2. Effect of Biocoagulant Dose on Turbidity Removal Efficiency

Figure 2 illustrates the effect of biocoagulant dosage on turbidity removal efficiency. Turbidity removal increased with increasing biocoagulant dosage and reached the highest removal efficiency of 91.17% at a dosage of 2 g/500 mL. Beyond this dosage, the removal efficiency gradually decreased, indicating that 2 g/500 mL was the optimum dosage for turbidity removal under the experimental conditions.

3.4 The Effect of Biocoagulant Dose on final pH

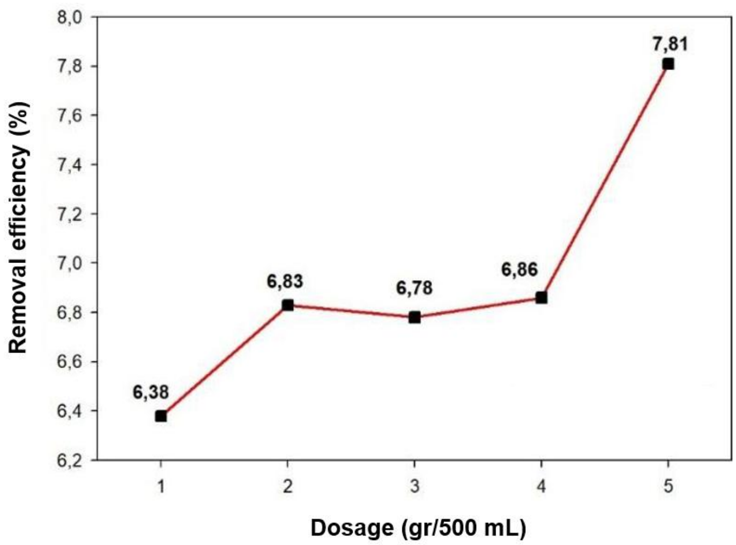

Figure 3. Effect of Biocoagulant Dose on final pH

Figure 3 shows the effect of biocoagulant dosage on the final pH of the treated wastewater. In general, the final pH increased with increasing biocoagulant dosage, although a slight decrease was observed at 3 g/500 mL. The highest final pH (7.81) was obtained at a dosage of 5 g/500 mL.

The Effect of Slow Mixing Time on COD Removal Efficiency

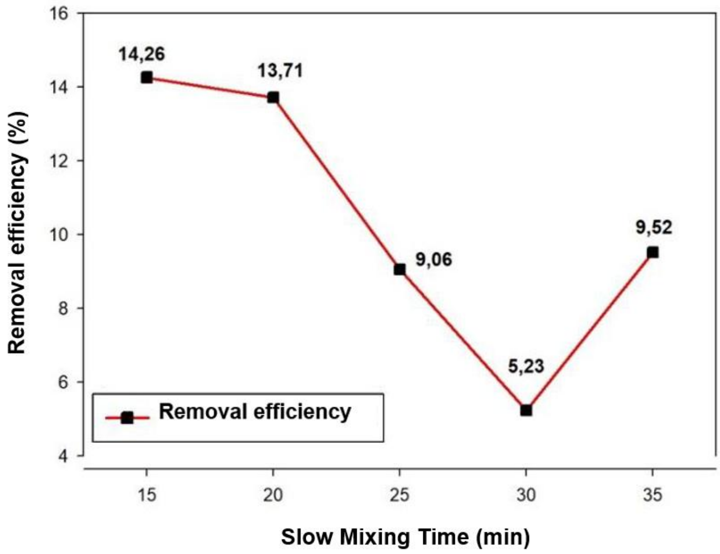

Figure 4. Effect of Slow Mixing Time on COD Removal Efficiency

Figure 4 illustrates the effect of slow mixing time on COD removal efficiency. The highest removal efficiency (14.26%) was obtained at a mixing time of 15 minutes. As the mixing time increased, COD removal efficiency generally decreased, reaching its lowest value at 30 minutes, before increasing slightly to 9.52% at 35 minutes.

3.6 The Effect of Slow Mixing Time on Turbidity Removal Efficiency

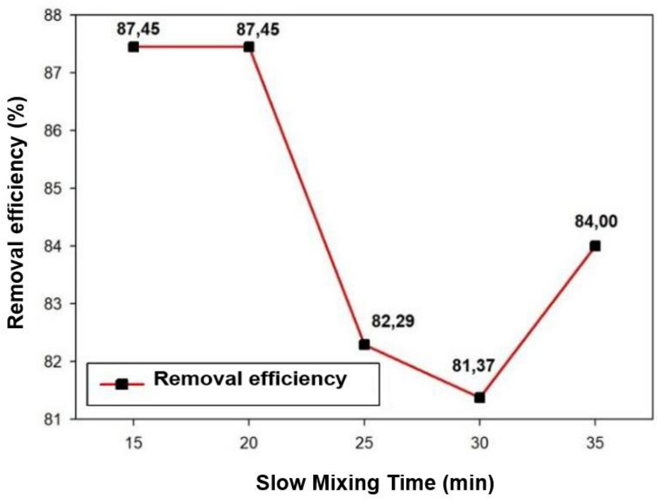

Figure 5. Effect of Slow Mixing Time on Turbidity Removal Efficiency

Figure 5 presents the effect of slow mixing time on turbidity removal efficiency. The highest removal efficiency (87.45%) was achieved at mixing times of 15 and 20 minutes. As the mixing time increased to 25 and 30 minutes, turbidity removal efficiency decreased to 82.29% and 81.37%, respectively, before increasing slightly to 84.00% at 35 minutes.

FTIR Result

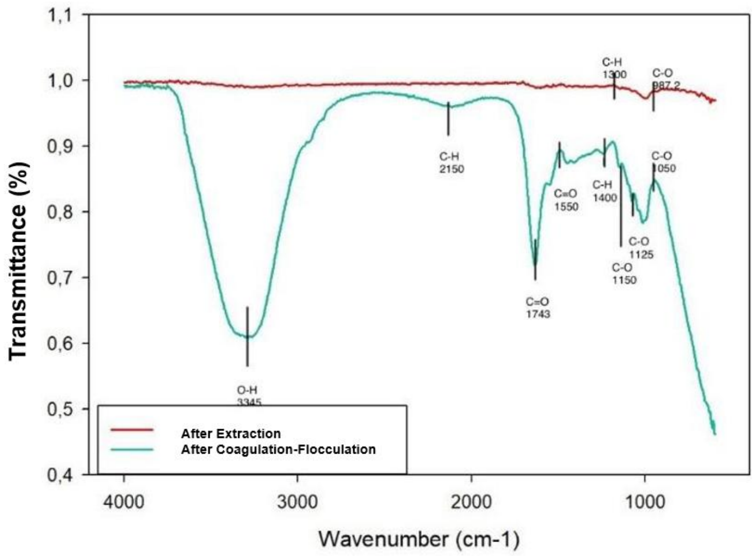

Figure 6. FTIR result

Figure 6 presents the FTIR spectra of the mung bean biocoagulant before and after the coagulation–flocculation process. Several changes in the absorption bands were observed after treatment. The broad O–H absorption band remained around 3400 cm⁻¹, while the C=O absorption band shifted from 1650 to 1743 cm⁻¹. In addition, the absorption bands assigned to C=C (1650–1550 cm⁻¹), C–H (approximately 2150 cm⁻¹), and C–O (1150–1050 cm⁻¹) were no longer detected after the coagulation–flocculation process. A new absorption band was also observed at approximately 2150 cm⁻¹ after treatment.

DISCUSSION

This explanation for the Effect of 1 M NaCl Extraction on Mung Bean Biocoagulant Performance shows that the increased removal efficiency after extraction suggests that soluble organic compounds released from the untreated mung bean powder, including starch, crude proteins, amino acids, tannins, and phenolic compounds, contributed additional organic matter to the wastewater (Ndubuisi et al., 2025). In contrast, the improved performance of the extracted biocoagulant can be attributed to the extraction process, which enriched active coagulating components, particularly proteins and charged polysaccharides, that promoted the aggregation and settling of organic particles (Badawi & Salama, 2023).

The higher turbidity removal efficiency obtained after NaCl extraction is likely due to the increased availability of positively charged proteins and peptides. These compounds facilitate charge neutralization and particle bridging, allowing suspended particles to aggregate into larger and denser flocs that settle more readily (Benalia et al., 2024). Similar findings were reported by Owodunni & Ismail, 2024, who attributed the high flocculation activity of mung bean extract to its cationic protein content.

The increase in pH after NaCl extraction is associated with proteins containing basic amino groups that can neutralize hydrogen ions while interacting with negatively charged organic compounds (Long et al., 2025). Proteins in plant-based coagulants can regulate pH through natural acid–base interactions without requiring additional chemical reagents (Kotb & Moaz, 2025).

The results showed that the biocoagulant extracted with 1 M NaCl showed better performance than the unextracted biocoagulant, resulting in lower final COD and turbidity values while maintaining a more favorable pH. Based on these results, the extracted biocoagulant was used in the subsequent experiments.

The lower COD removal observed at smaller biocoagulant dosages can be attributed to the limited amount of active coagulating compounds available to destabilize colloidal particles and initiate floc formation (Kristianto et al., 2019). As the dosage increased, more active sites became available for charge neutralization and particle bridging, promoting the formation of larger and more stable flocs that enhanced the removal of organic matter (Khan et al., 2023).

As for the effect of biocoagulant dose on COD removal efficiency, however, increasing the dosage beyond the optimum level did not improve COD removal. Excessive biocoagulant addition may introduce additional organic compounds into the wastewater or interfere with the coagulation process by oversaturating the available binding sites (Eamrat et al., 2024). Consequently, the efficiency of pollutant removal decreases despite the higher coagulant dosage. Similar observations were reported by Mohd et al., 2023, who noted that an appropriate coagulant dosage is essential for effective floc formation and stable coagulation performance.

As for the effect of biocoagulant dose on turbidity removal efficiency, the improved turbidity removal observed at the optimum dosage indicates that sufficient active coagulating compounds were available to destabilize suspended particles and promote effective floc formation (Hosein et al., 2026). However, increasing the biocoagulant dosage beyond the optimum level resulted in lower removal efficiency, a phenomenon commonly associated with coagulant overdosing. Excess coagulant can induce charge reversal and restabilization of colloidal particles, thereby reducing the effectiveness of the coagulation process (Gerais et al., 2024). Consequently, the flocs become less stable and may partially disintegrate, allowing fine suspended particles to remain in the treated wastewater.

Furthermore, once the available colloidal particles have been neutralized, additional biocoagulant contributes little to further particle aggregation and may even hinder floc growth by disrupting the balance of the coagulation process (Machado & Farias, 2025). These findings highlight the importance of selecting an appropriate biocoagulant dosage to achieve maximum turbidity removal while maintaining stable floc formation.

As for the effect of biocoagulant dose on final pH, the increase in final pH with increasing biocoagulant dosage suggests that a greater amount of active coagulating compounds was available to participate in acid–base reactions (Kurniawan et al., 2020). At lower dosages, the quantity of these compounds was insufficient to effectively neutralize hydrogen ions (H^+), causing the treated wastewater to remain slightly acidic. As the dosage increased, more amino-containing functional groups became available, gradually shifting the pH toward neutral conditions (Maher et al., 2026).

A slight decrease in pH at 3 g/500 mL may be attributed to the complex interactions between acidic and basic compounds within the biocoagulant and the wastewater matrix, which can temporarily influence the balance of hydrogen ions in solution (Kurniawan et al., 2020). Nevertheless, increasing the dosage to 4 and 5 g/500 mL restored the upward trend, with the highest pH recorded at 5 g/500 mL.

The higher pH values obtained at larger dosages indicate that neutralization reactions became more effective as additional active compounds were introduced into the treatment system. Moreover, the formation of larger and more stable flocs may have facilitated the removal of acidic constituents from the wastewater (Iloamaeke et al., 2025). Similar findings were reported by Ravele et al., 2025, who noted that an appropriate coagulant dosage can increase pH through enhanced neutralization reactions and interactions between biocoagulant functional groups and pollutant particles.

For the effect of slow mixing time on COD removal efficiency, the highest COD removal efficiency observed at a slow mixing time of 15 minutes suggests that this duration provided sufficient contact between the biocoagulant and suspended organic particles to promote effective floc formation. Appropriate slow mixing enhances particle collisions and encourages the formation of larger, more stable flocs, thereby improving the removal of organic contaminants (Li et al., 2025).

The gradual decline in COD removal efficiency with longer mixing times is likely caused by excessive shear forces generated during prolonged agitation. These forces can weaken or fragment the flocs, releasing previously trapped organic matter back into the wastewater and reducing overall treatment efficiency (Faiqun et al., 2007). Furthermore, extended slow mixing can destabilize flocs and impair the coagulation–flocculation process.

The slight increase in COD removal efficiency observed at 35 minutes may be attributed to reflocculation, in which fragmented particles collide and reaggregate to form new flocs under favorable mixing conditions. Reflocculation may occur when suitable coagulant dosage and mixing conditions continue to support particle aggregation (Afolabi et al., 2020).

For the effect of slow mixing time on turbidity removal efficiency, the highest turbidity removal efficiency observed at 15 and 20 minutes indicates that these mixing durations provided sufficient time for particle collisions and the formation of large, stable flocs. Under these conditions, suspended particles were effectively destabilized and incorporated into the floc structure, resulting in efficient turbidity removal (Pradiko et al., 2018).

The decline in turbidity removal efficiency at 25 and 30 minutes is likely associated with prolonged exposure to shear forces, which can weaken or fragment the flocs and allow suspended particles to remain dispersed in the treated wastewater. Excessive mixing reduces floc stability and consequently decreases coagulation performance (Stone & Krishnappan, 2023)S.

The slight improvement in turbidity removal efficiency at 35 minutes may be explained by reflocculation, where fragmented particles collide and reaggregate into new flocs under favorable mixing conditions. According to Afolabi et al., 2020, reflocculation can occur when adequate contact time and appropriate mixing conditions continue to support particle aggregation.

Based on the FTIR result, the changes observed in the FTIR spectra indicate that several functional groups of the mung bean biocoagulant participated in the coagulation–

flocculation process. The disappearance and shifting of absorption bands suggest that these functional groups interacted with pollutants in the wastewater, leading to changes in their chemical environment. In particular, the shift of the C=O absorption band from 1650 to 1743 cm^{-1} indicates the involvement of carbonyl-containing compounds during the coagulation process (Herold et al., 2021).

The appearance of a new absorption band near 2150 cm^{-1} further suggests the formation of new chemical interactions following treatment. Absorption in the 2900–2000 cm^{-1} region has been associated with C–H functional groups in alkene compounds. Overall, the observed changes in the FTIR spectra support the occurrence of interactions between the positively charged active sites of the biocoagulant and negatively charged colloidal particles in the wastewater (Bayu et al., 2019). Similar findings have been reported by Gan et al., 2023, who attributed the appearance, disappearance, and shifting of FTIR absorption bands to adsorption and coagulation mechanisms occurring during wastewater treatment.

CONCLUSION

The 1 M NaCl-extracted mung bean biocoagulant outperformed the unextracted biocoagulant in treating tofu and tempeh wastewater, achieving 9.95% COD removal, 90.98% turbidity removal, and a final pH of 7.27. The optimum dosage was 4 g/500 mL for COD removal (41.45%), while the highest turbidity removal (91.17%) and final pH (7.81) were obtained at 2 and 5 g/500 mL, respectively. The optimum slow mixing time was 15 minutes, resulting in COD and turbidity removal efficiencies of 14.26% and 87.45%. FTIR analysis revealed changes in the biocoagulant functional groups after NaCl extraction and coagulation–flocculation, indicating interactions between the biocoagulant and pollutant particles during treatment.

Future research should evaluate the extracted biocoagulant using real wastewater under pilot-scale conditions and further investigate the coagulation mechanism through analyses such as zeta potential and extraction optimization.

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REFERENCES

Afolabi, M., Onukogu, O. A., Igunma, T. O., Nwokediegwu, Z. Q. S., & Adeleke, A. K. (2020). Systematic review of coagulation-flocculation kinetics and optimization in municipal water purification units. *Iconic Research and Engineering Journals, 3*(8), 259–275. https://www.irejournals.com/paper-details/1708814

Ali, S. K., Abdou, M. M., Emara, M. M., Farag, R. S., & Mubarak, M. F. (2025). Eco-friendly solutions: A comprehensive review of natural coagulants for sustainable water treatment. *Environmental Geochemistry and Health, 47*, Article 535. https://doi.org/10.1007/s10653-025-02803-3

Anyiam, P. N., Phongthai, S., Kingwascharapong, P., Pongsetkul, J., Zhang, W., Jung, Y. H., & Rawdkuen, S. (2025). A comparative review on novel-assisted extraction techniques for retrieving protein from some potential plant sources. *NFS Journal, 40*, Article 100239. https://doi.org/10.1016/j.nfs.2025.100239

Asharuddin, S. M., Othman, N., Al-Maqtari, Q. A., Al-towayti, W. A. H., & Arifin, S. N. H. (2023). The assessment of coagulation and flocculation performance and interpretation of mechanistic behavior of suspended particles aggregation by alum assisted by tapioca peel starch. *Environmental Technology & Innovation, 32*, Article 103414. https://doi.org/10.1016/j.eti.2023.103414

Badawi, A. K., Salama, R. S., & Mostafa, M. M. M. (2023). Natural-based coagulants/flocculants as sustainable market-valued products for industrial wastewater treatment: A review of recent developments. *RSC Advances, 13*(28), 19335–19355. https://doi.org/10.1039/D3RA01999C

Benalia, A., Derbal, K., Amrouci, Z., Baatache, O., Khalfaoui, A., & Pizzi, A. (2024). Application of plant-based coagulants and their mechanisms in water treatment: A review. *Journal of Renewable Materials, 12*(4), 667–698. https://doi.org/10.32604/jrm.2024.048306

da Silva, R. M. P., de Farias, B. S., & Fernandes, S. S. (2025). From natural to industrial: How biocoagulants can revolutionize wastewater treatment. *Processes, 13*(6), Article 1706. https://doi.org/10.3390/pr13061706

de Carvalho Costa, L. R., & Fioravante, I. F. (2024). Evaluation the efficiency of individual organic coagulants and associated with aluminum sulfate in the removal of colloidal substances from Rio Doce, Minas Gerais, Brazil. *Cleaner Chemical Engineering, 10*, Article 100134. https://doi.org/10.1016/j.clce.2024.100134

Eamrat, R., Rujakom, S., Pussayanavin, T., Taweesan, A., Witthayaphirom, C., & Kamei, T. (2024). Optimizing biocoagulant aid from shrimp shells (*Litopenaeus vannamei*) for enhancing microplastics removal from aqueous solutions. *Environmental Technology & Innovation, 33*, Article 103457. https://doi.org/10.1016/j.eti.2023.103457

Gan, F., Wu, K., Ma, F., Wei, C., & Du, C. (2022). In-situ monitoring of nitrate in industrial wastewater using Fourier transform infrared attenuated total reflectance spectroscopy (FTIR-ATR) coupled with chemometrics methods. *Heliyon, 8*(12), Article e12423. https://doi.org/10.1016/j.heliyon.2022.e12423

Herold, F., Leubner, O., Jeschonek, K., Hess, C., Drochner, A., Wei, Q., & Etzold, B. J. M. (2021). Methodology for the identification of carbonyl absorption maxima of carbon surface oxides in DRIFT spectra. *Carbon Trends, 3*, Article 100020. https://doi.org/10.1016/j.cartre.2020.100020

Iloamaeke, I. M. J., Atune, S. I., Onyeije, U. C., & Onuegbu, T. U. (2025). Optimization of coagulation-flocculation process for colour removal in purification of paint industry effluent using novel seed of *Spondias mombin* Linn. *Desalination and Water Treatment, 323*, Article 101284. https://doi.org/10.1016/j.dwt.2025.101284

Kachoue Sefiddashti, M. H., Farhikhte, M., Khorashadi Zadeh, F., & Berahmand, M. (2026). Integrated evaluation of five coagulants and precipitants for fluoride and turbidity removal from steel industry wastewater: Removal performance, sedimentation, and life cycle assessment. *Next Sustainability, 7*, Article 100270. https://doi.org/10.1016/j.nxsust.2026.100270

Khan, M. T., Ahmad, M., Hossain, M. F., Nawab, A., Ahmad, I., Ahmad, K., & Panyametheekul, S. (2023). Microplastic removal by coagulation: A review of optimizing the reaction conditions and mechanisms. *Water Emerging Contaminants & Nanoplastics, 2*(4), Article 22. https://doi.org/10.20517/wecn.2023.39

Kristianto, H., Prasetyo, S., & Sugih, A. K. (2019). Pemanfaatan Ekstrak Protein dari Kacang-Kacangan sebagai Koagulan Alami: Review. *Jurnal Rekayasa Proses, 13*(2), 65–80. https://doi.org/10.22146/jrekpros.46292

Kurniawan, S. B., Abdullah, S. R. S., Imron, M. F., Said, N. S. M., Ismail, N. 'I., Hasan, H. A., Othman, A. R., & Purwanti, I. F. (2020). Challenges and opportunities of biocoagulant/bioflocculant application for drinking water and wastewater treatment and its potential for sludge recovery. *International Journal of Environmental Research and Public Health, 17*(24), Article 9312. https://doi.org/10.3390/ijerph17249312

Li, Y., Qi, Y., Wei, Q., & Ma, X. (2025). An investigation of the impact of flocculants on process optimization and floc properties in *Chlorella vulgaris* FACHB-15 harvesting. *Water, 17*(7), Article 932. https://doi.org/10.3390/w17070932

Long, R., Huang, Y., Dabbour, M., Mintah, B. K., Pan, J., Wu, M., Zhang, S., Qin, Z., He, R., & Ma, H. (2025). Physical processing-assisted pH shifting for food protein modification: A comprehensive review. *Foods, 14*(13), Article 2360. https://doi.org/10.3390/foods14132360

Maher, W., Salih, S. S., Kadhom, M., Albayati, N., & Ghosh, T. K. (2026). Waste-derived chitosan-functionalized poultry litter biochar as a sustainable adsorbent for Congo red removal from wastewater. *Next Materials, 12*, Article 102166. https://doi.org/10.1016/j.nxmate.2026.102166

Maltauro, R., Stone, M., Collins, A. L., Krishnappan, B. G., & Silins, U. (2023). The effect of shear-dependent flocculation on the multimodality of effective particle size distributions in a gravel-bed river during high flows. *Journal of Soils and Sediments, 23*(10), 3589–3601. https://doi.org/10.1007/s11368-023-03455-5

Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology, 4*(1), 97–118. https://doi.org/10.17509/ijost.v4i1.15806

Ni'am, M. F., Othman, F., Sohaili, J., & Fauzia, Z. (2007). Removal of COD and turbidity to improve wastewater quality using electrocoagulation technique. *The Malaysian Journal* *of Analytical Sciences, 11*(1), 198–205. https://www.ukm.my/mjas/v11_n1/html/11_1_31.html

Owodunni, A. A., & Ismail, S. (2021). Revolutionary technique for sustainable plant-based green coagulants in industrial wastewater treatment—A review. *Journal of Water Process Engineering, 42*, Article 102096. https://doi.org/10.1016/j.jwpe.2021.102096

Owodunni, A. A., Ismail, S., & Ooi, B. S. (2024). Green bean seed coagulant for turbidity removal: Parameter optimization and modelling. *Water Practice & Technology, 19*(5), 1968–1985. https://doi.org/10.2166/wpt.2024.105

Pradiko, H., Afiatun, E., & Fabian, E. (2018). Influence of mixing and detention time in electro coagulation process to treat raw water at Badak Singa Water Treatment Plant. *Indonesian Journal of Urban and Environmental Technology, 1*(2), 137–150. https://doi.org/10.25105/urbanenvirotech.v1i2.2823

Ravele, M. P., Olatunde, O. C., Oyewo, O. A., Makgato, S. S., & Onwudiwe, D. C. (2025). Plant-based coagulants for wastewater treatment: Recent advances and applications. *Cleaner Water, 4*, Article 100147. https://doi.org/10.1016/j.clwat.2025.100147

Wintersohle, C., Kracke, I., Ignatzy, L. M., Etzbach, L., & Schweiggert-Weisz, U. (2023). Physicochemical and chemical properties of mung bean protein isolate affected by the isolation procedure. *Current Research in Food Science, 7*, Article 100582. https://doi.org/10.1016/j.crfs.2023.100582