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Effectiveness of Water Hyacinth (*Eichhornia crassipes*) and Water Lettuce (*Pistia stratiotes*) in Improving Tofu Wastewater Quality through Phytoremediation

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Abstract

Tofu wastewater contains high concentrations of organic matter, suspended solids, and dissolved solids that may deteriorate water quality if discharged directly into the environment. Phytoremediation is an environmentally friendly wastewater treatment method that utilizes aquatic plants to improve water quality. This study aimed to evaluate the effectiveness of water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes) as phytoremediation agents for tofu wastewater treatment. The experiment was conducted using four treatments, namely control (P0), water hyacinth (P1), water hyacinth + water lettuce (P2), and water lettuce (P3). Observations were carried out on days 0, 7, 14, and 21. Water quality parameters analyzed included pH, temperature, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS). The results showed that phytoremediation for 21 days altered the quality of tofu wastewater. The pH values generally increased from acidic conditions toward more neutral conditions, while temperature remained relatively stable throughout the observation period. Water lettuce was more effective in stabilizing pH and reducing TSS, whereas water hyacinth showed better performance in maintaining DO concentrations and controlling TDS accumulation. These findings indicate that both plant species have potential as phytoremediation agents for tofu wastewater treatment, with their effectiveness depending on the targeted water quality parameters.

Keywords Phytoremediation; Tofu Wastewater; Water Hyacinth; Water Lettuce; Water Quality

INTRODUCTION

The tofu industry is one of the agro-industrial sectors that generates wastewater with relatively high organic matter content. This wastewater originates from soybean washing, soaking, grinding, and filtration processes. If discharged directly into the environment without prior treatment, tofu wastewater can degrade water quality due to its high concentrations of organic matter, suspended solids, and dissolved solids (Ningrum et al., 2020).

The high organic matter content in tofu wastewater can reduce dissolved oxygen (DO) levels, increase turbidity, and alter the physical and chemical characteristics of receiving water bodies (Rismawati et al., 2020). In addition, the decomposition of organic matter by microorganisms requires substantial amounts of oxygen, which may further deteriorate water quality when wastewater is discharged directly into the environment (Metcalf & Eddy, 2014). Therefore, an effective, economical, and environmentally friendly treatment method is needed to minimize the environmental impacts of tofu wastewater. One treatment technology that has attracted considerable attention is phytoremediation, which utilizes plants to absorb, accumulate, transform, or degrade pollutants present in contaminated environments. This method is considered environmentally friendly and cost-effective because it relies on natural processes involving plants and microorganisms in the rhizosphere to reduce pollutant concentrations (Vymazal, 2018).

Among aquatic plants commonly used as phytoremediation agents are water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes). Water hyacinth possesses an extensive fibrous root system that provides a large surface area for pollutant absorption and microbial attachment. Ningrum et al. (2020) reported that water hyacinth improved tofu wastewater quality by reducing pollutant concentrations. Similarly, Siswoyo et al. (2020) found that water hyacinth enhanced wastewater treatment performance in a constructed wetland system through pollutant removal. Meanwhile, Rismawati et al. (2020) reported that water lettuce effectively reduced Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels in tofu industry wastewater.

Previous studies have demonstrated the ability of water hyacinth and water lettuce to improve wastewater quality. However, comparative information regarding their effectiveness in improving tofu wastewater quality based on water quality parameters such as pH, temperature, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS) during different phytoremediation periods remains limited. Evaluation of these parameters is important because they provide fundamental information on changes in the physical and chemical characteristics of wastewater during the treatment process. Therefore, this study was conducted to evaluate the effectiveness of water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) in improving tofu wastewater quality through phytoremediation. Specifically, this study aimed to (1) determine the effect of phytoremediation duration on changes in tofu wastewater quality and (2) evaluate the effectiveness of water hyacinth and water lettuce in improving water quality parameters, including pH, temperature, DO, TDS, and TSS.

METHODS

This study was conducted at the Air Quality and Weather Laboratory, Environmental Management Study Program, Department of Environment and Forestry, Samarinda State Agricultural Polytechnic. The research was carried out from March to April 2026 over a period of two months. The phytoremediation process was performed for 21 days, with observations conducted on days 0, 7, 14, and 21. Research activities included wastewater preparation, implementation of phytoremediation treatments, water quality measurements, and data analysis. The equipment utilized in this study consisted of a pH meter, dissolved oxygen (DO) meter, total dissolved solids (TDS) meter, analytical balance, drying oven, Buchner funnel, vacuum pump, filter paper, measuring cylinder, and 16-L styrofoam containers. Materials used included tofu wastewater obtained from a local tofu-processing industry, water hyacinth (Eichhornia crassipes), water lettuce (Pistia stratiotes), tap water, and distilled water.

Tofu wastewater was diluted to a concentration of 15% prior to its use as the experimental medium. Dilution was achieved by mixing 750 mL of tofu wastewater with 4.25 L of water to produce a total volume of 5 L for each treatment container. The experiment employed four treatment variations consisting of a control without plants (P0), 200 g of water hyacinth (P1), a combination of 200 g of water hyacinth and 200 g of water lettuce (P2), and 200 g of water lettuce (P3). Each treatment was conducted in duplicate, and the average values obtained from the two replicates were used for subsequent analyses. A volume of 5 L of diluted tofu wastewater was placed into each treatment container, followed by the introduction of phytoremediation plants according to the designated treatment composition. The phytoremediation process proceeded for 21 days without the addition of any external substances. Observations were conducted periodically on days 0, 7, 14, and 21 to evaluate changes in wastewater quality during the treatment period.

Water quality assessment focused on pH, temperature, dissolved oxygen (DO), total dissolved solids (TDS), and total suspended solids (TSS). Measurements of pH were performed using a pH meter, whereas temperature and DO were measured using a DO meter. TDS concentrations were determined using a TDS meter. All measurements were conducted at each observation interval for every treatment. Total suspended solids (TSS) were analyzed using the gravimetric method following APHA (2017) procedures. Wastewater samples were filtered through pre-weighed filter paper and subsequently dried in an oven at 103–105°C until a constant weight was obtained. The dried filter paper was then reweighed, and TSS concentration was calculated using the following equation:

$$TSS\ (mg/L) = ((A - B) \times 1000) / V$$

where TSS represents Total Suspended Solids (mg/L), A is the weight of filter paper plus residue after drying (mg), B is the initial weight of the filter paper (mg), and V is the volume of the filtered sample (mL). The collected data were analyzed descriptively using the mean values obtained from the duplicate treatments. Results were presented in tables and graphical forms to illustrate changes in wastewater quality throughout the phytoremediation period. Treatment effectiveness was evaluated based on the percentage reduction of TDS and TSS concentrations, the percentage increase in dissolved oxygen, and changes in pH values between the initial and final observation periods. Percentage reduction of TDS and TSS was calculated using the equation $[(C_0 - C_t)/C_0] \times 100$, where C_0 represents the initial parameter value and C_t represents the value at a given observation time. The percentage increase in dissolved oxygen was calculated using $[(D_t - D_0)/D_0] \times 100$, where D_0 is the initial dissolved oxygen concentration and D_t is the concentration at the observation time. Changes in pH were determined using the equation $\Delta pH = pH_t - pH_0$, where pH_0 represents the initial pH value and pH_t represents the pH value at a specific observation time. Treatments exhibiting the greatest reductions in TDS and TSS, the highest increase in dissolved oxygen, and pH values approaching neutrality were considered to demonstrate superior phytoremediation performance.

FINDINGS AND DISCUSSION

Effect of Phytoremediation Duration on Tofu Wastewater Quality

Potential of Hydrogen (pH)

Changes in the pH of tofu wastewater during the phytoremediation process are presented in Table 1.

Table 1. Changes in pH of tofu wastewater during phytoremediation

Treatment	Day 0	Day 7	Day 14	Day 21
P0	4.50	8.72	10.20	9.02
P1	4.54	8.71	9.79	9.00
P2	4.50	8.74	9.35	8.65
P3	5.21	9.06	9.62	7.80

Based on Table 1, the pH of tofu wastewater increased in all treatments during the 21-day phytoremediation period. On day 0, the wastewater was acidic, with pH values ranging from 4.50 to 5.21. After seven days of treatment, the pH increased to 8.71–9.06 and remained relatively high until the end of the observation period. The increase in pH indicates an improvement in the chemical condition of the wastewater during phytoremediation.

The increase in pH may be associated with plant photosynthetic activity, which utilizes dissolved carbon dioxide and consequently reduces the formation of carbonic acid in the water. In addition, microbial activity in the rhizosphere can transform complex organic compounds into simpler substances and influence the ionic balance of the wastewater medium (Dhir, 2013; Vymazal, 2018). The water lettuce treatment (P3) produced the final pH value closest to neutral (7.80), indicating its potential to stabilize the chemical conditions of the aquatic environment.

Temperature

Changes in the temperature of tofu wastewater during phytoremediation are presented in Table 2.

Table 2. Changes in tofu wastewater temperature (°C) during phytoremediation

Treatment	Day 0	Day 7	Day 14	Day 21
P0	27.3	26.7	26.8	26.6
P1	27.1	27.3	27.4	26.6
P2	27.3	27.4	26.7	26.4
P3	27.5	27.4	26.7	26.4

Based on Table 2, the temperature of tofu wastewater remained relatively stable throughout the study, ranging from 26.4 to 27.5°C. The results indicate that no substantial temperature differences occurred among treatments or observation periods. This suggests that the phytoremediation process had little influence on the temperature parameter. Temperature is an environmental factor that is strongly influenced by weather conditions and solar radiation intensity. The temperature range observed during the study remained within the optimum range for microbial activity and the growth of aquatic plants involved in the phytoremediation process (APHA, 2017). According to Metcalf and Eddy (2014), stable temperatures can support the biodegradation of organic matter and nutrient uptake by plants.

Dissolved Oxygen (DO)

Changes in dissolved oxygen (DO) concentrations during the phytoremediation process are presented in Table 3.

Table 3. Changes in dissolved oxygen concentration of tofu wastewater (mg/L) during phytoremediation

Treatment	Day 0	Day 7	Day 14	Day 21
P0	4.78	2.59	6.00	6.75
P1	5.62	4.14	5.45	5.62
P2	4.58	3.93	4.99	3.85
P3	4.58	5.08	6.03	2.66

The DO values showed different patterns among treatments. Some treatments experienced a decrease during the initial observation period, followed by an increase on day 14. These results indicate that the phytoremediation process involves complex interactions among plants, microorganisms, and organic matter present in the wastewater. The decrease in DO during the early stages of the experiment was likely caused by microbial activity utilizing oxygen to decompose the organic matter contained in tofu wastewater. Over time, plant photosynthesis contributed to an increase in dissolved oxygen concentrations in the water (Truu et al., 2009). However, several treatments exhibited a decline in DO on day 21, which may be attributed to increased oxygen demand for plant respiration and the continued decomposition processes occurring within the treatment system.

Total Dissolved Solids (TDS)

Changes in Total Dissolved Solids (TDS) during the phytoremediation process are presented in Table 4.

Table 4. Changes in TDS concentration of tofu wastewater (mg/L) during phytoremediation

Treatment	Day 0	Day 7	Day 14	Day 21
P0	276.5	302.0	317.5	418.0
P1	300.0	297.0	398.0	452.0
P2	29.5	292.5	430.0	708.5
P3	258.5	341.0	420.0	639.5

Based on Table 4, TDS values generally increased in all treatments throughout the phytoremediation period. The highest increase was observed in the combined treatment of water hyacinth and water lettuce (P2), while the lowest increase occurred in the control treatment (P0). The increase in TDS indicates a greater concentration of dissolved substances in the wastewater medium. This condition may result from the mineralization of organic matter, which produces simple ions and soluble compounds, as well as the release of dissolved substances from plant tissues during the phytoremediation process. According to Rezania et al. (2015), the decomposition of organic matter and plant biomass can contribute to increased concentrations of dissolved solids in aquatic systems. Therefore, an increase in TDS does not necessarily indicate a failure of the phytoremediation process; rather, it may reflect the transformation and breakdown of organic matter within the wastewater medium.

Total Suspended Solids (TSS)

Changes in Total Suspended Solids (TSS) during the phytoremediation process are presented in Table 5.

Table 5. Changes in TSS concentration of tofu wastewater (mg/L) during phytoremediation

Treatment	Day 0	Day 7	Day 14	Day 21
P0	0.7225	0.3228	0.3219	0.3230
P1	0.3309	0.3327	0.3186	0.3372
P2	0.3331	0.3333	0.3451	0.3416
P3	0.7781	0.3274	0.3244	0.3715

Based on Table 5, TSS values generally decreased during the phytoremediation process, particularly in treatments P0 and P3. The most substantial reduction occurred during the first week of observation, after which TSS values remained relatively stable until the end of the study. The reduction in TSS indicates a decrease in suspended particles within the tofu wastewater. This condition may be attributed to natural sedimentation processes as well as the ability of plant roots to trap suspended particles in the water. According to Sooknah and Wilkie (2004), the root systems of aquatic plants can function as natural filters that enhance particle settling and improve water clarity. Therefore, longer phytoremediation periods provide greater opportunities for the removal of suspended solids from the wastewater medium.

Overall, the 21-day phytoremediation period influenced changes in tofu wastewater quality, as indicated by increased pH values, fluctuations in dissolved oxygen concentrations, increased TDS levels, and reduced TSS concentrations in several treatments. In contrast, temperature remained relatively stable throughout the observation period. These findings suggest that the duration of contact between plants and wastewater plays an important role in the improvement of water quality during the phytoremediation process.

Effectiveness of Phytoremediation Plants in Improving Tofu Wastewater Quality

Effectiveness of Treatments on Potential of Hydrogen (pH)

Changes in the pH of tofu wastewater during the phytoremediation process are presented in Table 6.

Table 6. Changes in pH of tofu wastewater during phytoremediation

Treatment	Day 0	Day 21	Δ pH
P0	4.50	9.02	4.52
P1	4.54	9.00	4.46
P2	4.50	8.65	4.15
P3	5.21	7.80	2.59

Based on Table 6, all treatments showed an increase in pH compared to the initial condition. The tofu wastewater, which was initially acidic, gradually shifted toward a more neutral condition during the phytoremediation process. The water lettuce treatment (P3) produced the final pH value closest to neutral (7.80) compared with the other treatments. The increase in pH was likely associated with a reduction in dissolved carbon dioxide concentration due to plant photosynthetic activity and the decomposition of organic matter during the study period. According to Kadlec and Wallace (2009), aquatic plants can influence the chemical balance of water through nutrient uptake and interactions with microorganisms in the rhizosphere. A pH value closer to neutrality indicates environmental conditions that are more favorable for biological activity and natural wastewater treatment processes (Tchobanoglous et al., 2014). These results suggest that water lettuce was more effective in stabilizing the acidity level of tofu wastewater than the other phytoremediation treatments.

Effectiveness of Treatments on Dissolved Oxygen (DO)

Changes in Dissolved Oxygen (DO) concentrations during the study are presented in Table 7.

Table 7. Changes in DO concentration of tofu wastewater (mg/L)

Treatment	Day 0	Day 21	Change (%)
P0	4.78	6.75	41.21
P1	5.62	5.62	0.00
P2	4.58	3.85	-15.94
P3	4.58	2.66	-41.92

Based on Table 7, DO concentrations responded differently among treatments. The control treatment showed an increase of 41.21%, while the water hyacinth treatment (P1) maintained a relatively stable DO concentration throughout the observation period. In contrast, the combined treatment (P2) and water lettuce treatment (P3) experienced decreases in DO concentration. Changes in DO concentration are influenced by the balance between photosynthesis, plant respiration, and microbial activity involved in the degradation of organic matter. The decline in DO observed in some treatments may have resulted from increased oxygen consumption during microbial biodegradation processes (Reddy & DeLaune, 2008). Conversely, the ability of water hyacinth to maintain DO levels may be attributed to continuous photosynthetic activity, which contributed oxygen to the wastewater medium. Similar findings were reported by Vymazal (2011), who noted that aquatic macrophytes can enhance oxygen transfer and support biological processes within treatment systems. Therefore, among the phytoremediation treatments, water hyacinth demonstrated the greatest effectiveness in maintaining dissolved oxygen levels.

Effectiveness of Treatments on Total Dissolved Solids (TDS)

Changes in Total Dissolved Solids (TDS) concentrations are presented in Table 8.

Table 8. Changes in TDS concentration of tofu wastewater (mg/L)

Treatment	Day 0	Day 21	Change (%)
P0	276.5	418.0	51.18
P1	300.0	452.0	50.67
P2	29.5	708.5	2301.69
P3	258.5	639.5	147.39

Based on Table 8, all treatments showed an increase in TDS concentration during the phytoremediation process. However, the water hyacinth treatment (P1) exhibited the lowest increase among the phytoremediation treatments, indicating a greater ability to control the accumulation of dissolved solids in the wastewater.

The increase in TDS may have resulted from the mineralization of organic matter, which releases simple ions and dissolved compounds into the treatment medium. In addition, nutrients released from decaying plant tissues may contribute to higher dissolved solid concentrations (Irfanullah, 2009). According to Mitsch and Gosselink (2015), decomposition processes in aquatic treatment systems can temporarily increase dissolved substances before stabilization occurs. Therefore, the observed increase in TDS should not be interpreted solely as a reduction in treatment performance, but rather as part of the transformation process of organic matter within the wastewater. Compared with the other phytoremediation treatments, water hyacinth showed better performance in limiting TDS accumulation throughout the treatment period.

Effectiveness of Treatments on Total Suspended Solids (TSS)

Changes in Total Suspended Solids (TSS) concentrations are presented in Table 9.

Table 9. Changes in TSS concentration of tofu wastewater (mg/L)

Treatment	Day 0	Day 21	Reduction (%)
P0	0.7225	0.3230	55.29
P1	0.3309	0.3372	-1.90
P2	0.3331	0.3416	-2.55
P3	0.7781	0.3715	52.26

Based on Table 9, the greatest reduction in TSS was observed in the control treatment (55.29%), followed by the water lettuce treatment (52.26%). These results indicate that the removal of suspended solids was influenced not only by the presence of aquatic plants but also by natural sedimentation processes occurring during the observation period.

Nevertheless, the hanging and dense root system of water lettuce likely contributed to the retention of suspended particles present in the wastewater. According to Brix (1997), aquatic macrophytes can enhance suspended solid removal through filtration, sedimentation, and particle adsorption mechanisms occurring on root surfaces. Similarly, Vymazal (2013) reported that aquatic vegetation plays an important role in improving water clarity by promoting the settling and retention of particulate matter. Therefore, despite the higher reduction observed in the control treatment, water lettuce demonstrated considerable potential as a phytoremediation agent for reducing suspended solids in tofu wastewater.

Overall Effectiveness of Phytoremediation Treatments

Table 10. Summary of phytoremediator effectiveness in improving tofu wastewater quality

Parameter	Treatment showing the best response
pH	P3
DO	P1
TDS	P1
TSS	P3

Overall, the results demonstrated that the effectiveness of phytoremediation plants varied depending on the water quality parameter evaluated. Water lettuce tended to be more effective in improving pH conditions and reducing TSS concentrations, while water hyacinth showed better performance in maintaining dissolved oxygen levels and controlling the accumulation of dissolved solids. These differences are likely related to variations in plant morphology, root structure, nutrient uptake capacity, and interactions with microorganisms in the rhizosphere (Mitsch & Gosselink, 2015).

The findings indicate that both water hyacinth and water lettuce can contribute to the improvement of tofu wastewater quality, although their effectiveness differs according to the parameter being targeted. Consequently, the selection of phytoremediation plants should consider the primary water quality objectives of the treatment system. Water lettuce may be more suitable when pH stabilization and suspended solid reduction are prioritized, whereas water hyacinth may be preferable for maintaining dissolved oxygen concentrations and limiting increases in dissolved solids.

CONCLUSION

The results of this study showed that the 21-day phytoremediation process was able to alter the quality of tofu wastewater, as indicated by changes in pH, temperature, *Dissolved Oxygen* (DO), *Total Dissolved Solids* (TDS), and *Total Suspended Solids* (TSS). The pH values generally increased from acidic conditions toward more neutral conditions, while temperature remained relatively stable throughout the observation period. Changes in DO, TDS, and TSS varied among treatments.

Water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*) exhibited different levels of effectiveness in improving tofu wastewater quality. Water lettuce was more effective in stabilizing pH and reducing TSS, whereas water hyacinth showed greater effectiveness in maintaining DO concentrations and controlling increases in TDS. These findings indicate that both plant species have potential for use as phytoremediation agents in the treatment of tofu wastewater, with the selection of plant species depending on the specific water quality parameters targeted for improvement.

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