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Comparison of the Effectiveness of Phytoremediation of Yellow Velvetleaf (Limnocharis flava) and Water Hyacinth (Eichhornia crassipes) on Reducing BOD and COD of Liquid Waste from Home-Made Tofu Industry in Namorambe District

Nada Amirah[1], Nisma Triana Munthe[2], Sri Sudewi Pratiwi Sitio[3], Lina Febriani Tanjung[4], Rizqi Nanda Putri[5]
[1,2,3]*Public Health Study Program, Faculty of Public Health, Institut Kesehatan Deli Husada Deli Tua*
[4,5]*Hospital Administration Study Program, Faculty of Public Health*, Institut Kesehatan Deli Husada Deli Tua
nadaamirah96@gmail.com, *nismamunthe262@gmail.com*, *dewisitio08@gmail.com*, *linafebrianitanjung@gmail.com*, *rizqinandaputri45@gmail.com*

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Abstract: The household tofu industry produces liquid waste with a high organic load as reflected in the Biochemical Oxygen Demand and Chemical Oxygen Demand values, thus potentially polluting water bodies if discharged without treatment. This study aims to compare the effectiveness of phytoremediation using Yellow Velvetleaf (Limnocharis flava) and Water Hyacinth (Eichhornia crassipes) plants in reducing Biochemical Oxygen Demand and Chemical Oxygen Demand in liquid waste from the home-based tofu industry in Namorambe District, Deli Serdang Regency. The study used a pretest and posttest design with 6 treatment reactors, consisting of 3 Yellow Velvetleaf reactors and 3 water hyacinth reactors, and 2 control reactors without plants. Each reactor contained 5 L of liquid waste and 500 g of fresh plant biomass. Measurements of Biochemical Oxygen Demand and Chemical Oxygen Demand were carried out before treatment and after a retention time of 2, 4, and 6 days. The initial levels of Biochemical Oxygen Demand and Chemical Oxygen Demand were 510 mg/L and 1,560 mg/L, respectively. The results showed that both plants were able to reduce Biochemical Oxygen Demand and Chemical Oxygen Demand levels with different patterns. Water hyacinth showed the highest reduction on day 2, with a decrease in Biochemical Oxygen Demand of 46% and Chemical Oxygen Demand of 44%, while Yellow Velvetleaf reached the optimal reduction on day 4 with a decrease in Biochemical Oxygen Demand of 35% and Chemical Oxygen Demand of 37%. The effectiveness of both plants decreased after day 4, which is thought to be related to pollutant absorption saturation and plant biomass decomposition. In general, water hyacinth was more effective at short residence times, while Yellow Velvetleaf showed more stable performance at medium residence times. Phytoremediation using local aquatic plants has the potential to be a simple and low-cost alternative for treating tofu industrial wastewater, with residence time management being a key factor in success.

1 INTRODUCTION

The tofu industry is a soybean-based agro-industry that is widely developed in Indonesia, both at the household and small-scale industries. Production activities, including soaking, milling, boiling, filtering, and molding, generate large volumes of liquid waste (Zunidra et al., 2024). This waste carries a significant organic pollutant load, consisting of residual protein, dissolved carbohydrates, fat, starch, fine particles of soybean pulp, and residues of coagulating agents such as calcium sulfate or acetic acid dissolved in the process water. The soaking and washing water streams dominate the dissolved organic compound content, while the milling, filtering, and boiling processes contribute suspended particles and dissolved compounds resulting from protein denaturation. The accumulation of these components increases the biochemical oxygen demand and chemical oxygen demand in tofu liquid waste (Hardyanti et al., 2023).

Biochemical oxygen demand reflects the oxygen requirement of microorganisms to decompose organic matter aerobically, while chemical oxygen demand indicates the total oxygen requirement to chemically oxidize organic and inorganic compounds. High BOD and COD values reflect high organic pollutant loads, which can potentially reduce dissolved oxygen, trigger unpleasant odors, and disrupt the balance of aquatic ecosystems (Li et al., 2022; Zhang et al., 2021). At the small-scale industrial level, untreated wastewater discharge increases the risk of degradation of the receiving water body's quality and poses health risks to the surrounding community (Singh et al., 2022).

Efforts to reduce biochemical oxygen demand (BOD) and chemical oxygen demand (COD) require an environmentally friendly and economical approach for implementation at the household level. Phytoremediation is a biologically based wastewater treatment method that utilizes aquatic plants to absorb, stabilize, and accelerate the degradation of pollutants through interactions between plant roots and rhizosphere microorganisms. This method is considered economical and applicable for household-scale wastewater treatment because it does not require complex technology and has low energy requirements (Rezania et al., 2016; Vymazal, 2020). Various aquatic plants have been reported to be effective in reducing the organic load of wastewater, particularly water hyacinth (Eichhornia crassipes), which has a dense root system and rapid biomass growth, increasing the contact area with the wastewater medium (Rezania et al., 2015; Osemwegie et al., 2020).

Yellow velvetleaf has been reported to reduce various pollutant parameters, including Biochemical Oxygen Demand, Chemical Oxygen Demand, total suspended solids, sulfate, phosphate, and heavy metals through root absorption and microbial activity around the roots (Bahute et al., 2024; Lidiana, 2022). The reduction in Biochemical Oxygen Demand is also related to increased dissolved oxygen levels due to plant photosynthesis and degradation processes by microorganisms (Zahra, 2022). Water hyacinth has a dense root system, increasing the contact area with wastewater and accelerating the pollutant absorption process. This plant has been proven effective in reducing Biochemical Oxygen Demand (BOD) and suspended particles, as well as accumulating various heavy metals (De Laet et al., 2021; Lestari et al., 2021; Rahman et al., 2020).

Field observations at the Putri Deli home-based tofu industry indicate that production is carried out daily, requiring approximately 2,250 kilograms of soybeans per day and employing approximately 10 workers. Process water usage is significant, including soaking, washing, grinding, and boiling. Liquid waste is piped directly into the sewer without any pre-treatment unit. Physically, the waste in the production area is whitish-yellow, while the wastewater in the front ditch appears gray, with foam on the surface and a pungent odor. This waste flow during production hours increases the daily organic pollutant load to receiving water bodies. This situation underscores the urgency of implementing simple waste treatment technologies based on local plants. Based on availability, ease of propagation, and resistance to polluted water, yellow velvetleaf and water hyacinth were selected to be studied as phytoremediation agents in reducing Biochemical Oxygen Demand and Chemical Oxygen Demand in liquid waste from home-made tofu industry.

2 METHOD

This study used a quantitative descriptive design with a pretest and posttest to evaluate changes in Biochemical Oxygen Demand and Chemical Oxygen Demand levels in liquid waste from a home-based tofu industry after phytoremediation using yellow velvetleaf and water hyacinth plants at the Putri Deli tofu industry in Namorambe District, Deli Serdang Regency, from January to July 2025. Initial values were obtained from measurements of Biochemical Oxygen Demand and Chemical Oxygen Demand levels before treatment, while final values were obtained after phytoremediation treatment at varying residence times on days 2, 4, and 6.

The study population consisted of all liquid waste produced by the Putri Deli tofu industry. Samples were collected using the grab sampling method. A sample volume of 35 L was divided into six treatment reactors of 5 L each: three reactors with yellow velvetleaf and three reactors with water hyacinth, and a 5 L sample for initial measurements. Additionally, two control reactors without plants were used to compare the natural changes in Biochemical Oxygen Demand and Chemical Oxygen Demand parameters without phytoremediation treatment.

The test plants, yellow velvetleaf and water hyacinth, were obtained from a swamp in Lau Mulgap Village, Namorambe District, Deli Serdang Regency. Plants were selected for their health and relatively uniform size. Yellow velvetleaf has single leaves arranged in a root rosette, a square-shaped stalk, 15 to 25 cm long, oval leaflets with a pointed tip and a blunt base, smooth edges, and a green color. Yellow velvetleaf stems are triangular in cross-section and 5 to 75 cm long. Water hyacinth is 0.4 to 0.8 m tall, has short-segmented stems with a diameter of 1 to 2.5 cm and a length of up to 30 cm, single oval leaves with a smooth green surface, and a swollen leaf stalk base. Before use, the plants were cleaned of dirt adhering to the roots using running water, then acclimatized in a tub filled with clean water for 7 days. After acclimatization, 500 g of wet plant biomass was weighed for each treatment reactor. Wastewater samples were taken from the tofu industry's drainage system using clean, closed jerry cans, then homogenized before being introduced into the reactor. Each reactor was filled with 5 L of wastewater. The treatment reactor was planted with yellow velvetleaf or water hyacinth plants, depending on the treatment group, while the control reactor was unplanted. All reactors were placed in locations with natural lighting and protected from direct rain. During the treatment period, the wastewater was not replaced and no chemicals were added.

Sampling was carried out three times: on days 2, 4, and 6. Samples were collected using sterile bottles and immediately sent to the Medan BTKLPP laboratory for analysis of biochemical oxygen demand and chemical oxygen demand levels using standard methods. The results of the measurements were recorded before and after treatment. The reduction effectiveness was calculated based on the difference and percentage reduction in biochemical oxygen demand and chemical oxygen demand levels for each residence time variation, which were then analyzed descriptively and quantitatively.

3 RESULTS AND DISCUSSION

This study covers the characteristics of liquid waste for the Tofu Industry such as BOD and COD. Tofu water sampling uses a combined time sampling method based on applicable procedures, namely the Indonesian National Standard (SNI), the results of wastewater quality analysis will refer to the Regulation of the Minister of Environment No. 5 of 2014 concerning Wastewater Quality Standards for the Tofu Industry.

3.1 Analysis of Physical Water Quality

Based on the researchers' observations using their five senses, changes in the physical quality of the tofu liquid waste were observed, including odor and color. After undergoing a phytoremediation process using yellow velvetleaf and water hyacinth plants, the water color changed.

Table 1: Physical Water Quality Analysis

Day	Yellow Velvetleaf	Water Hyacinth
2	Brownish yellow	Grayish white
4	Light yellow to gray	Light yellow to gray
6	Dark black	Dark black

Visual observations revealed changes in the physical quality of tofu wastewater during the phytoremediation process using yellow velvetleaf and water hyacinth. On day 2, the wastewater from the yellow velvetleaf treatment was yellow-brown, while from the water hyacinth treatment it appeared grayish-white. On day 4, the water color in both treatments changed from light yellow to grayish, indicating ongoing turbidity reduction and organic matter degradation. However, on day 6, the water in both treatments turned dark black, indicating reaccumulation of dissolved organic matter and possible anaerobic processes due to saturation of plant absorption and biomass decomposition (Astuti and Rosemalia, 2022; Bahute et al., 2024).

Tofu wastewater originates from the soaking and washing of soybeans, milling, boiling, filtering, and coagulation processes, and is discharged without pretreatment due to the lack of a wastewater treatment plant. This wastewater is generally turbid due to high suspended solids and organic matter content, as reflected in the Biochemical Oxygen Demand and Chemical Oxygen Demand parameters. The organic matter composition of tofu liquid waste is dominated by protein, carbohydrates, and fat, which contribute to color and odor changes (Zunidra et al., 2024; Hardyanti et al., 2023).

Color changes during the phytoremediation process can be used as an early indicator of changes in physical water quality related to turbidity and organic compound content. Water hyacinth showed a faster decrease in turbidity in the initial phase than yellow velvetleaf , but residence times exceeding 4 days tended to further degrade the water's physical quality. This emphasizes the importance of regulating residence time and managing plant biomass for effective phytoremediation (De Laet et al., 2019; Astuti and Rosemalia, 2022).

3.2 Changes in Biochemical Oxygen Demand Levels

Biochemical Oxygen Demand (BOD) measurements on Putri Deli's home-based tofu industry wastewater were conducted at the Medan BTKLPP Laboratory after phytoremediation with yellow velvetleaf and water hyacinth plants at varying retention times of 2, 4, and 6 days. Initial results showed a BOD level of 510 mg/L.

Table 2: Changes In BOD Levels after Treatment with The Phytoremediation using Yellow Velvetleaf and Water Hyacinth

Variable	Plants	Before (mg/L)	Plant residence time	After (mg/L)	Reduction (%)
BOD Level	Yellow Velvetleaf	510	Day 2	415	18
			Day 4	315	35
			Day 6	380	25
	Water Hyacinth	510	Day 2	275	46
			Day 4	375	26
			Day 6	380	25

The data showed that both plants were effective in reducing BOD, but with different patterns. Yellow velvetleaf achieved the highest reduction on day 4, at 35%, from 510 mg/L to 315 mg/L. On days 2 and 6, the reductions were 18% (415 mg/L) and 25% (380 mg/L), respectively. Conversely, water hyacinth showed the most significant BOD reduction on day 2, at 46% (275 mg/L), then decreased on day 4 (26%, 375 mg/L), and remained relatively stable on day 6 (25%, 380 mg/L).

These differences in response may be attributed to the morphological and physiological characteristics of the plants, which influence their mechanisms of organic matter uptake and degradation. The high initial response of water hyacinth is likely due to its dense root system and intense rhizosphere microbial activity in the early phase, accelerating the organic matter removal process (Ali et al., 2020; Yan et al., 2021). Similar findings have reported that water hyacinth can significantly reduce BOD in various types of waste through efficient biological mechanisms, particularly in the early phase of phytoremediation (Rezania et al., 2015; Osemwegie et al., 2020).

The decline in effectiveness of both plants after day 4 is likely related to pollutant adsorption saturation and decreased plant physiological activity, including the potential for biomass decomposition that can release organic matter back into the wastewater medium (Nadhifah et al., 2024; Vymazal & Kröpfelová, 2015; Wang et al., 2021). Thus, the optimal residence time of plants in phytoremediation for BOD reduction is in the range of 2–4 days, where water hyacinth is superior in the initial phase and yellow velvetleaf shows more stable effectiveness in the middle of the residence time.

3.3 Changes in Chemical Oxygen Demand Levels

Chemical oxygen demand measurements were conducted at the Medan BTKLPP Laboratory on Putri Deli tofu industry wastewater after phytoremediation using yellow velvetleaf and water hyacinth with retention times of 2, 4, and 6 days. The initial chemical oxygen demand level was 1560 mg/L..

Table 3: Changes in COD Levels after Treatment with Phytoremediation using Yellow Velvetleaf and Water Hyacinth

Variable	Plants	Before (mg/L)	Plant residence time	After (mg/L)	Reduction (%)
COD Level	Yellow velvetleaf	1560	Day 2	1280	17
			Day 4	980	37
			Day 6	1070	31
	Water Hyacinth	1560	Day 2	870	44
			Day 4	1160	25
			Day 6	1160	25

Chemical Oxygen Demand (COD) measurements of Putri Deli's home-made tofu wastewater were conducted at the Medan BTKLPP Laboratory after phytoremediation with yellow velvetleaf and water hyacinth plants at retention times of 2, 4, and 6 days. The initial COD level was recorded at 1,560 mg/L.

The results showed that both plants were able to reduce COD, but with different patterns. In the yellow velvetleaf treatment, the highest reduction occurred on day 4, at 37% to 980 mg/L, while on days 2 and 6, the reductions were 17% (1,280 mg/L) and 31% (1,070 mg/L), respectively. Water hyacinth showed the highest COD reduction on day 2, at 44% to 870 mg/L, while on days 4 and 6, the reduction stabilized at 25% to 1,160 mg/L. These data indicate that water hyacinth is more effective at reducing COD at short residence times, while yellow velvetleaf is relevant for effectiveness at the intermediate phase of the residence time.

The effectiveness of water hyacinth in reducing COD at short residence times demonstrates the important role of root structure in expanding the contact area between roots, microorganisms, and

organic pollutants. Plant roots function as a microbial substrate that accelerates the oxidation of complex organic compounds into simpler ones (Ali et al., 2020; Yan et al., 2021). However, decreasing effectiveness at longer residence times indicates saturation of the phytoremediation system, either due to limited plant adsorption capacity or decreased microbial activity due to metabolite accumulation (Rezania et al., 2016; Wang et al., 2021).

The decrease in effectiveness after day 4 for both plants is likely due to pollutant saturation in the media and decreased plant physiological activity, including the potential for plant biomass decomposition, which begins to release organic matter back into the wastewater (Nadhifah et al., 2024). Thus, the optimal residence time in phytoremediation for COD reduction is in the range of 2–4 days, where water hyacinth is superior in the early phase and yellow velvetleaf shows more stable effectiveness in the intermediate phase of contact.

3.4 Comparison of Average Decrease in Biochemical Oxygen Demand and Chemical Oxygen Demand Levels

Comparison of the average BOD and COD levels showed that water hyacinth (Eichhornia crassipes) was more effective in reducing the organic load of liquid waste than yellow velvetleaf (Limnocharis flava). Water hyacinth produced an average BOD after treatment of 343.3 mg/L, lower than yellow velvetleaf at 360 mg/L. The lowest minimum BOD value was also achieved by water hyacinth (275 mg/L) compared to yellow velvetleaf (315 mg/L), although the variation in water hyacinth results was higher.

Table 4: Comparison of Average BOD and COD Reduction

Variable	Plants	Min.	Max.	Mean	Std. deviation
BOD Level	Yellow Velvetleaf	315	415	360	50,744
	Water Hyacinth	275	380	343.3	59,231
COD Level	Yellow Velvetleaf	980	1.280	1.110	153,948
	Water Hyacinth	870	1.160	1.063	167,432

For COD, water hyacinth also showed a lower average (1,063 mg/L) than yellow velvetleaf (1,110 mg/L), with the lowest minimum value in water hyacinth (870 mg/L), while yellow velvetleaf had 980 mg/L. The COD data variation in water hyacinth remained greater, indicating a diverse plant response to wastewater conditions.

The superiority of water hyacinth over yellow velvetleaf in reducing BOD and COD is related to its higher biomass growth rate and root system density, which enhances interactions between roots, pollutants, and microorganisms. Aquatic plants with complex root morphologies tend to be more effective in phytoremediation systems for organic wastewater than plants with simpler root structures (Vymazal, 2020; Rezania et al., 2015). These findings reinforce the importance of plant species selection and residence time management as key factors in optimizing phytoremediation performance for domestic industrial wastewater.

Research on various wastes shows that water hyacinth is effective in reducing organic parameters in wastewater in the early phase of phytoremediation, both from domestic and industrial waste, although its effectiveness is influenced by residence time, plant mass, and waste characteristics (Basransyah et al., 2024). This combination of characteristics makes water hyacinth a more potential plant for phytoremediation applications in liquid waste compared to yellow velvetleaf, especially for household-scale treatment that requires a rapid response to organic pollutant loads.

4 CONCLUSION

Water hyacinth was proven to be more effective than yellow velvetleaf in reducing BOD and COD levels, especially at a retention time of 2–4 days, so it has the potential to be used as a phytoremediation plant for household-scale tofu industrial wastewater. Yellow velvetleaf plants showed optimal performance on the 4th day with a BOD reduction of 35%, but its effectiveness decreased on the 6th day (25%) and the 2nd day (18%), while the best COD reduction occurred on the 2nd day (44%). Meanwhile, water hyacinth was most effective on the 2nd day with a BOD reduction of 46% and COD of 42%, but its effectiveness decreased on the 4th day (26%) and the 6th day (25%).

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