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Original Research Article

Efficiency of *Typha angustifolia* in Phytoremediation of Palm Oil Mill Effluent

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Abstract: This study aims to investigate the potential of *Typha angustifolia* as a vegetation or macrophyte for palm oil mill effluent (POME) phytoremediation to reduce the contaminants before being discharged to receiving water bodies. The raw POME was diluted to 25% and 50% to ensure the growth of the plants. The experiments were conducted for 12 days and repeated three times. The 25% diluted POME systems showed the highest removal of chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen, and zinc, with average removal efficiencies of 65.5%, 59.9%, 82.2%, and 67.5%, respectively. Therefore, *T. angustifolia* has demonstrated its viability as a macrophyte for POME phytoremediation. Overall, the phytoremediation system was able to reduce the concentration of the pollutants in POME and safe to discharge following Malaysian POME discharge regulations.

Keywords: Phytoremediation; Palm oil mill effluent, *Typha angustifolia*

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1. Introduction

For the past half-century, technology and product innovation have widely developed worldwide to the extent of the maximum usage of available resources. The industrial evolution unknowingly contributed to uncontrolled waste production and cluttering into the free flow. The sources of environmental pollution are mainly domestic, industrial, and agricultural activities. In the liquid waste category, palm oil mill effluent (POME) generated from crude palm oil extraction and processing threatens and detriments the aquatics stream due to by-product generation and effluent released into the water stream (Malaysian Palm Oil Board, 2018). POME has high organics concentration, acidic, high total suspended solids

(TSS) with dark brownish colour from palm oil extraction process (Zainal *et al*., 2017). It is also associated with significant aquatic environment degradation due to its high levels of fats, oils, and grease Therefore, treated POME need to comply with the Water Quality Standards set by the Malaysian Department of Environment (DOE) before being discharged.

Several treatments were proposed and implemented in treating POME including ponding treatment system, anaerobic and aerobic digestion, membrane bioreactor, electrocoagulation, microalgae cultivation, activated carbon adsorption, membrane process, advanced oxidation process, photocatalytic degradation and artificial neural network (Tan Ai Wei, 2019). Despite all the efforts, the implemented methods were unreliable due to their environmental effects and costs of experimentation compared to phytoremediation. The phytoremediation technique is cost-efficient, environmentally safe, and easy to conduct treatment with simple application. Several plant species have been studied as phytoremediators including water hyacinth, *Scirpus grossus*, *Cyperus alternifolius*, and water spinach (Sa'At *et al*., 2022).

Phytoremediation with the use of green plants employs mechanisms such as phytodegradation, phytovolatilization, rhizofiltration, rhizodegradation, and phytodegradation. (Kafle *et al*., 2022). However, the complex mechanism in pphytoremediation maselect aect allenging to select a suitable phytoremediator in the effluent treatment.

2. Materials and Methods

In this study, a phytoremediation system was constructed in a lab-scale hydroponic system with three different dilutions of POME with three repetitions with the *Typha angustifolia* plant. The system was placed in a controlled environment shaded from direct sunlight due to the hot weather in Perlis, Malaysia. The growth of *T. angustifolia* and pollutant removal efficiencies from the POME were investigated according to the organics, nutrients, and heavy metal removal efficiencies in the POME sample before and after the phytoremediation process. The reduction of chemical oxygen demand (COD) and total suspended solids (TSS) determines the effectiveness of *T. angustifolia* in the treatment process. The plant nutrient and heavy metal analysis in both POME and plant parts was limited to ammoniacal nitrogen, phosphorus, and zinc content. The phytoremediation process was continued for 12 days for significant data collection.

2.1. Experimental Setup

The constructed system was designed as a hydroponic system. Three systems were introduced: tap water, unplanted POME, and planted POME with *T. angustifolia*. Tap water was considered as the control for plant cultivation without any additional nutrients. The unplanted POME resembled the natural degradation of POME without a plant in the system to analyse the nutrient and heavy metal loss naturally by other organic matters. For planted POME, plants were kept in a container with POME as medium with different concentrations as DF 10, DF 25 and DF 50. The experimental setup for the phytoremediation is shown in Figure 1 and Table 1.

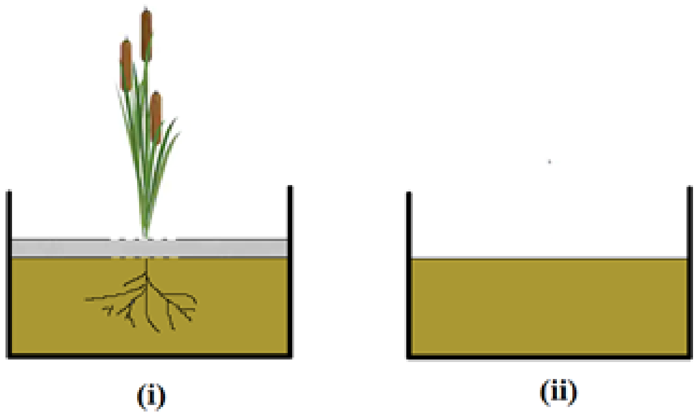

Figure 1. The hydroponic system set-up of (i) planted system of POME sample, (ii) unplanted system of POME sample

Table 1. The concentration and POME: Tap water Ratio

Systems	POME Ratio: Tap Water
DF10	10:90
DF25	25: 75
DF50	50:50

2.2. Sampling and Analysis

POME was collected from Malpom Oil Palm Mill, Nibong Tebal, Penang from the polishing treatment pond specifically before final discharge. After collection, the sample was sealed and stored at 4℃ in the cold room to prevent any biological degradation that could affect the analytical measurement of the experiment (Zainal *et al.*, 2017). Samples of 500 mL were collected from each container and analysed for their physicochemical properties including COD, TSS, ammoniacal nitrogen (NH_3-N), phosphorus (P), and zinc (Zn). The methods and equipment used are summarised in Table 2.

The *T. angustifolia* plants were collected from a nearby paddy field at Kangar, Perlis, Malaysia. The plant was selected with almost the same size and height. The plants were directly washed and grown for 2 weeks for acclimatisation in tap water before being employed in the treatment systems. The plant height was recorded at the initial (day 0) and every week until the harvesting on day 12. In each set, 3 plant rhizomes were planted in the pot. A gravel was used as media for plant support. The performance of phytoremediation in COD, TSS, ammonia, phosphorus and zinc was based on the removal efficiencies. The removal efficiencies were calculated as in Equation (1).

$$RE\ (\%) = (C_t - C_o)/Co \times 100 \quad (1)$$

where RE is the removal efficiencies, C_t is the concentration at days and C_o is the concentration at the initial day.

Table 2. Water Quality Analysis Method

Parameter	Method	Unit	Equipment
COD	Chemical Reactor Digestion Method	mg/L	HACH DR2800 Spectrophotometer
TSS	Filtration method	mg/L	Vacuum Filtration Set
NH_3-N	Nessler Method	mg/L	HACH DR2800 Spectrophotometer
P	PhosVer 3 with Acid Persulfate Digestion Method	mg/L	HACH DR2800 Spectrophotometer
Zinc	Zincover	mg/L	HACH DR2800 Spectrophotometer

Statistical analysis of sample data was performed using MS Excel using two-way ANOVA for the plant with control which unplanted systems. The physical properties of the plant were determined by analysing the plant's dry weight and maximum height at the initial and end of the experiment. The growth of plants will indicate the tolerance of *T. angustifolia* towards POME and the plant’s adaptability.

3. Results and Discussions

3.1. Physicochemical Properties of POME Samples

Table 3 lists the physicochemical characteristics of polishing pond POME concerning the Environmental Quality (Prescribe Premise) (Crude Palm-Oil) (CPO) Regulation discharge standard (Department of Environment, 2010). The COD of raw POME was 2090 mg/L, considered higher than palm oil mill secondary effluent (POMSE) with a COD of 1600 mg/L (Fadzil *et al*., 2013). The nitrogen content of raw POME was twice higher than the discharge POME standard and the pH indicated higher alkalinity of POME which results from microbial activities. The measured colour of raw POME was high. The high turbidity of 2699 NTU is evidence of high particles or pollutants content in the sample direct to high TSS and total dissolved solids of 1867 mg/L and 4800 mg/L, respectively. At the same time, the phosphorus content of raw POME was 75 mg/L. Naturally, phosphorus promotes the growth of plants by regulating protein synthesis for the formation of biomolecules, new cell and cell divisions, and the formation of biomolecules (Razaq *et al*., 2017). Besides, zinc is considered slightly higher than discharge POME. Zinc toxicity ends in stunted plant growth due to disturbances in plant physiological processes (Mirshek Ali *et al*., 2012).

Table 3. Physicochemical properties of polishing pond POME

Parameter	Unit	Final Discharge POME	CPO Discharge limits
pH	-	8.11	5-9
COD	mg/L	2090	1000
TSS	mg/L	1866.67	400
Total Dissolved solid	mg/L	4800	-
Colour	Pt/Co	11280	-
Conductivity	mS/cm	7.5	-
Turbidity	NTU	2699	-
Total Ammonia	mg/L-N	166	-
Total Nitrogen	mg/L	45.3	200
Ammoniacal nitrogen	mg/L	269.8	100
Phosphorus	mg/L	75	-
Zinc	mg/L	5.7	-

The final discharge of pond POME's average pH and total nitrogen concentration were still within the permitted range of the discharge regulation. However, ammoniacal nitrogen (NH_3-N), TSS, and COD do not follow the standard. Therefore, the polishing pond POME in this study still needs further treatment to conform to the standard. Furthermore, POME has a significant value of nutrients that can promote the plants' growth and may be used as wastewater in phytoremediation treatment.

Sample dilution is important to allow plants to survive without any root damage or plant diseases. A preliminary assessment was carried out using undiluted (raw) POME and 50% diluted POME samples collected from a polishing pond. After a week of observation, the plants in the system of undiluted POME completely dried and the roots started to decay in the sample. The high concentration of ammoniacal nitrogen, phosphorus, zinc, and solid content has disrupted the nutrient and water uptake by roots. The plants in the system of 50% diluted POME showed some newly grown small shoots at the end of 21 days. The small shoots are 5–15 cm in height. At the same time, as a trial,10% and 20% diluted POME hydroponic systems with a single plant in each system were set up. After monitoring for a week, the plants showed newly grown shoots with rapid growth. The newly grown leaves are approximately 10–20 cm green leaves. Therefore, the study was further carried out using hydroponic systems of 10%, 25% and 50% of diluted POME. The duration of the study was fixed for 15 days.

3.2. POME Removal Efficiencies

The phytoremediation treatment for COD, TSS, ammonia, phosphorus and zinc removal efficiencies performance in planted and unplanted (control) systems is shown in Figure 2. The removal performance shows higher performance using *T. angustifolia* than control (unplanted) systems in all parameters for all systems. The performance of phytoremediation systems for pollution removal is significantly influenced by vegetation and concentration of effluent.

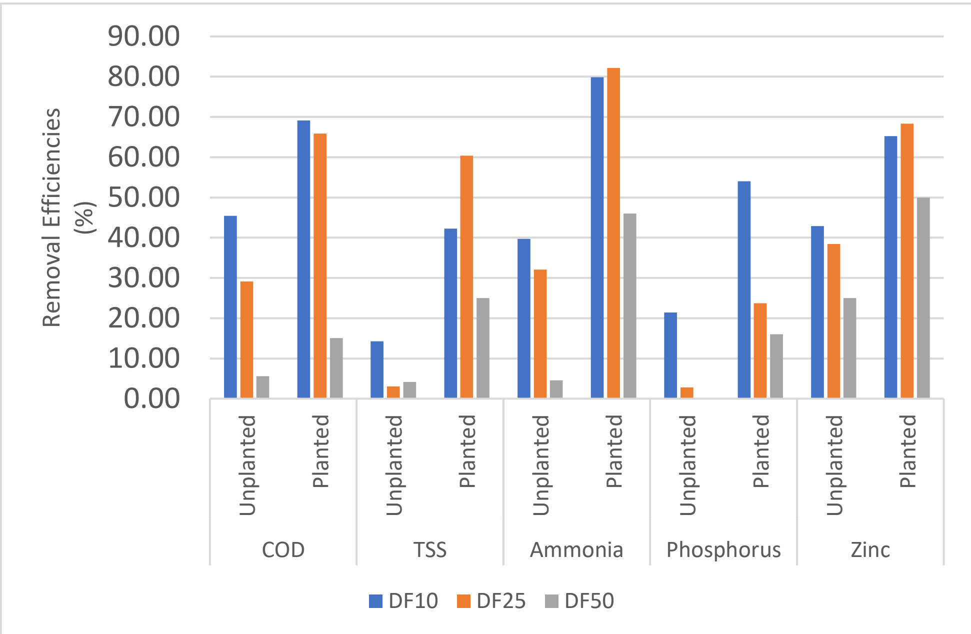

Figure 2. Effect of *T. angustifolia* (planted system) vs control (unplanted) vs concentration on pollutant removal efficiencies

For COD removal efficiencies, the POME concentration of DF10 shows the highest removal efficiencies with 69.1% in planted systems compared to 65.9% in DF25 and 15.1% in DF50 systems. The statistical analysis shows a $P<0.05$ with a significant difference. The

COD reduction occurred due to the organic compound degradation of carbon-to-carbon dioxide and water (Ng & Chan, 2017) in both DF10 and DF25 systems. In DF50 with *T. angustifolia*, the organic materials in the form of suspended solids, are attached to plant roots and reduce the efficiency of the extracting and digesting process via rhizofiltration mechanism (Kafle *et al.*, 2022).

For the TSS removal efficiencies, the planted system showed a high removal of solids from the POME sample. Between the planted systems, DF10 and DF25, the diluted POME systems indicated a logarithmic increase in removal properties. After 12 days, the systems were still capable of removing the solids particles from POME. The planted DF50 system started to rapidly remove solid particles with only 23%. The high vegetative density and vegetative length of *T. angustifolia* increased the removal of solid particles trapped through roots and translocated to the stem (Farraji *et al*., 2017). While an unplanted system for all dilution showed a slight decrease in the removal of TSS. The POME concentration in DF50 is higher and has a high particle content. The variances between the POME dilution showed higher variability and increased from 10% to 50% POME dilution. At the same time, between the treatment periods, the variation was almost the same. The p-value was less than 0.05, demonstrating that the interaction effect was statistically significant as the concentration and treatment period had an adverse effect on the results.

The removal efficiency of ammonia for DF10 and DF25 system planted system with *T. angustifolia* was higher as compared to DF50 systems. The earlier adaptation process of *T. angustifolia* caused a slow accumulation of ammoniacal nitrogen from the POME sample. When compared with a highly diluted sample, the water content was higher than the solute content, as more space and energies were available between ammonia and nitrogen that could easily be absorbed by the roots of the plants. This indicates higher removal efficiency at 82.796%, 89.630% for DF10 and DF25, respectively. While for unplanted systems, DF10 and DF25 show slightly higher removal efficiency equal to the planted DF50 system. The removal efficiency of ammoniacal nitrogen removal happened due to natural microbial activities with a lower percentage. Naturally present microorganisms are assumed to carry out natural wastewater utilisation of nutrients for nitrification and denitrification processes (Ng & Chan, 2017). A study supported this fact by explaining the activity of bacteria in converting ammonia into nitrogen through the nitrogen cycle (Ujang *et al*., 2018). Successfully converted nitrates can promote a good increase of plant growth and height as it acts as fertilisers. The unplanted DF50 system shows negative growth due to the possibility of eutrophication and algae growth that is seen on the polystyrene cover after a week. From the statistical analysis of ANOVA, the variances are notable between each POME dilution.

The removal efficiency of zinc by the planted system with three *T. angustifolia* in each system shows significant results compared to the unplanted system with lower removal of zinc. The planted DF25 shows higher removal efficiency than the planted DF10 system. The variability in ANOVA between the POME dilution was nearly the same for DF10 and DF25 systems. Zinc removal in unplanted systems remained constant from day 6 until day 12 with a removal efficiency of 42.9%, 38.5% and 25% for DF10, DF25 and DF50, respectively. The amount of removal through naturally present microorganisms was the same and the reaction became even without any spikes. The unplanted DF50 system shows the lowest removal efficiency, possibly due to high solute concentration compared to other systems. Therefore, there is insufficient evidence to claim the mean values between dilution factors are different. The removal efficiency for all three dilutions was nearly the same, between the range of 50% to 68%, especially for DF10 and DF25 systems. Meanwhile, between the treatment days, the null hypothesis was rejected and concluded as mean values have significant variability with every treatment.

Overall, the planted hydroponic systems had higher removal efficiency of oxygen, solids, nutrients, and heavy metals such as zinc. The *T. angustifolia* has higher feasibility towards the treatment. The application of *T. angustifolia* could increase the removal of various pollutants more easily and rapidly within 12 days of treatment. The system can be suggested as the most convenient and easiest pollutant removal strategy in the palm oil industries due to the high efficiency and feasibility of *T. angustifolia* towards POME nature. At the same time, the low-concentration POME system showed higher removability as the presence of high-water molecules has further increased the energy between the pollutant molecules collision and increased their absorption by plant roots. This is highly significant in both DF10 and DF25 systems samples as compared to DF50 systems.

4. Conclusions

In a nutshell, the study was designed to analyse the feasibility of applying macrophytes, *T. angustifolia,* in the removal of contaminants of POME before final discharge through phytoremediation treatment methods in order to reduce the water pollution of nearby water streams and aquatics environment. The treatment method is biologically acceptable due to zero waste production and no chemical use. Several conclusion and findings are drawn from the research study. Firstly, the initial physicochemical properties of polishing pond

POME were measured and analysed with the Malaysian wastewater discharge limit. The collected POME needed proper treatment for the reduction of the pollutant concentration. Secondly, the removal efficiency for COD, turbidity, colour, TSS, nutrients and heavy metals in planted systems with highly diluted samples of DF10 and DF25 diluted POME was higher compared to DF50 diluted and undiluted POME. As the dilution of the POME was higher, the growth of *T. angustifolia* was more significant and seen through the growth of new shoots and an increase in plant weight. The DF10 diluted POME system showed higher growth, while the DF50 diluted indicated only a small increase in plant weight.

Overall, the pollutants are easily removed from diluted POME with the highest dilution factor. The *T. angustifolia* acts as a good treatment agent in removing the contaminants in POME and the plant has higher adaptability towards the wastewater. The higher removability of contaminants indicated the plants' feasibility as phytoremediation macrophytes. Finally, the treated POME sample was found to have achieved the discharge limit indicating good removability of the system.

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Conflicts of Interest: The authors declare no conflict of interest.

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