# Assessment of *Canna indica, Hymenachne amplexicaulis and Rynchospora corymbosa* Potential for Aquaculture Effluent Treatment Under Different Hydraulic Retention Times in a



Batch-Flow Constructed Wetland



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*ABSTRACT:* Constructed wetlands (CW) offer an eco-friendly solution for treating aquaculture effluent using macrophytes. The effectiveness of different plant species in phytoremediation and optimal hydraulic retention time (HRT) for pollutant removal remain unclear. This study compared the phytoremediation potential of *Canna indica* (Ci), *Hymenachne amplexicaulis* (Ha), and *Rynchospora corymbosa* (Rc) in aquaculture effluent treatment under 3-, 4-, and 5-day HRT in a batch-flow CW. Twelve pilot-scale horizontal sub-surface flow CWs were set up, receiving 0.04 m<sup>3</sup>/day effluent. Effluent samples were analyzed for physicochemical parameters such as pH, Total Dissolved Solids TDS, Biological Oxygen Demand BOD<sub>5</sub>, Chemical Oxygen Demand COD, Total Nitrogen TN, Total Phosphorus TP, Lead Pb, Zinc Zn, and data were processed using two-way ANOVA (α0.05). Ha and Rc showed high removal efficiency (RE) for COD (75.9–97.8%), BOD (43.1–81.1%), and TP (79.6–81.3%) at HRT5. Rc significantly removed pH, BOD, TP, and Zn. CW efficiency improved with plant root development of macrophyte, requiring extended retention for optimal treatment.

KEYWORDS: Aquaculture Effluent, Constructed Wetlands, Hydraulic Retention time, Macrophyte, Removal Efficiency, Phytoremediation.

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# I INTRODUCTION

Many developing countries lack access to the conventional wastewater treatment techniques utilized in the majority of industrialized countries to safeguard the environment and the public at large due to insufficient infrastructure, funding and planning (Bikejar et al, 2022). Recently, a study described the removal of heavy metals such as iron, cadmium, lead, copper, manganese, arsenic, mercury, silver and zinc from domestic wastewater using different treatment methods (Ogundipe et al, 2023). Constructed wetland (CW) applications for recovered water end-user applications and wastewater treatment have been encouraged (de Castro et al, 2024). The CW treatment system combines the physical, chemical and biological processes through the microbial assemblages, wetland plants, and soil activities that occur naturally as a good performing techniques in the removal of pollutants from different wastewater and storm water (Biswal and Balasubramanian, 2022). They are made to benefit from many of the wetlands' natural processes, but they do so in a more controlled setting. Deteriorating water quality is a factor in disease spikes and contamination of aquaculture products, which has a significant negative economic impact on the industry's current operations. When the effluents from these systems are released into receiving water bodies as organic matter, aquaculture wastewater harms the ecosystem (Halifu and Ahaneku, 2010). Wetland plants possess various properties that are crucial to the treatment process, making them key components in the design of constructed wetlands (CWs). Despite their importance, only a limited number of plant species have been commonly utilized in these systems (Akinbile and Yusoff, 2012). Macrophytes are aquatic plants that grow in or near water. They can be grouped as emergent, submergent, or floating plants depending on their life and structure (Hamid *et al*, 2021). Although more than 150 Macrophytes species have been used in CWs globally, only a limited number of these plant species are very often planted in CWs in reality (Karki, 2024). Plant roots provide surface area for the attachment of microbes that degrade the wastewater pollutants in CWs (Kafle *et al*, 2022).

The result obtained indicates that several macrophytes are capable of removing varying concentrations of heavy metals (Singh et al., 2024; Olawale et al., 2021). However, a knowledge gap exists in understanding the specific mechanisms and efficiency of different macrophyte species in diverse environmental conditions. Due to its affordability, friendliness, environmental and sustainability, phytoremediation is being investigated as an alternative to other traditional physiochemical and biological approaches to wastewater treatment (Ting et al, 2018). An appropriate phytoremediation technique was developed by Saha et al (2017) for the efficient removal of harmful hexavalent chromium from mine effluent. Eichhornia crassipes was chosen as the water hyacinth species to address the issue of hexavalent chromium  $Cr_2O\tau^{2-}$  pollution from wastewater. Plants were reported to be able to extract 99.5%  $Cr_2O\tau^{2-}$  from the wastewater treated from the Sukinda chromite mines in 15 days. This aquatic plant was able to lower TDS, BOD, COD, and other water-related components in addition to removing heavy metals. Ewemoje and Sangodoyin (2011) in a study on the treatment of primary lagoon effluents in a pilot scale HssFCW, investigated the effect of HRT<sub>3,5 and 7</sub> and hydraulic loading rate (HLR) with *Coix lacryma* plant for the removal of organics and nutrients in CW system. It was found that Job Tears was capable of removing pollutants at about HRT<sub>7</sub>.

Several plant species, including Canna indica, Hymenachne amplexicaulis, Rynchospora corymbosa, water hyacinth (Eichhornia crassipes), water lettuce (Pistia stratiotes), feathered mosquito fern (Azolla pinnata), duckweed (Lemna perpusilla), bulrush (Typha latifolia), vetiver grass (Chrysopogon zizanioides), and common reed (Phragmites australis), have been studied for their potential in wastewater treatment. However, these studies often focus on individual species and do not compare their pollutant removal efficiency under the same wastewater conditions and varying hydraulic retention times (HRTs). For example, research by Borgulat et al (2022) and Zhang et al (2022) demonstrated the effectiveness of Eichhornia crassipes and Typha latifolia in heavy metal removal, but such studies are usually speciesspecific and do not provide comparative analysis under controlled settings. Additionally, there is limited research on the use of these plants for treating fish pond spent water, a common challenge in the study area.

Canna indica commonly known as Indian shot is a perennial growing to between 0.5 m and 2.5 m, depending on the variety. It is hardy with hermaphrodite flowers. Ci has been used for the treatment of industrial wastewater through constructed wetlands. It is effective for the removal of high organic load, Heavy metal and chlorinated organic compounds from paper mill wastewater (Raphael *et al*, 2023). Gunarathan *et al* (2016), in a study, concluded that the *Ci* plant can be used as a phytoremediation agent to mitigate higher pollution concentrations of reverse osmosis (RO) concentrate. *Ci* was also recommended for nitrogen bioremediation in domestic wastewater.

Hymenachne amplexicaulis also known as (Rudge) Nees or simply Hymenachne grass is of the family of Poaceae. Its common name is water straw grass or bamboo grass. A robust perennial, suppressive, invasive and stoloniferous with erect column growing up to 1-2.5 m high and seasonally found in marshland or flooded environments. Hymenachne grass has a prostate stem with a developed adventitious root. Their stems have special spongy pith with aerenchyma tissue for high absorbent, capable of filtering and act as a good fodder (De, 2016), to help the stems float and aid in flood tolerability. It grows in a fertile inundated clay and can be used as dry season forage. It can be propagated from seeds or vegetatively. Its major challenge is that it has the tendency to spread in a semi natural pastures and less isolated in wetlands when connected to overland and ditch networks (Bouchard et al, 2020) but few information on Ha usage in CW for aquaculture effluent is scanty.

*Rhynchospora corymbosa* is a tropical plant and a species in the family of *Cyperaceae* also known as Golden Beak Sedge. Both annual and perennial species are represented in the genus, most of which have upright, 3-sided stems with threeranked leaves. Rhynchospora can be found on nearly every continent. It occurs most often in sunny environments with moist, acidic soils. Rhynchospora may be the predominant type of flora in savannas and wetlands. (Ewemoje *et al*, 2023) The inflorescences (spikelet) are sometimes subtended by bracts which can be leaf-like or showy. Plate 1 shows the pictures of *Ci, Ha* grass and *Rc* used in the study in (a), (b), and (c) respectively.

Several studies have shown the importance of HRT on the performance of CWs (Ewemoje et al, 2015; Rabello et al, 2019; Zhang et al, 2021; IIyas et al, 2021). HRT is an important CW design and operation parameter and a predictor of its performance. It is the duration of wastewater within the wetland system. A significant effect of HRT and other design factors was reported in a study on the removal of common pharmaceuticals and other pollutants. It has also been reported that both BOD and COD removal were affected by longer HRT. A longer HRT allows an extensive interaction between the pollutants and the components of the CW systems (Shruthi and Shivashankara, 2022). Previous studies did not investigate the effect of HRT on the Ci, Ha grass and Rc in the study area. There are also limited studies on the interaction between plant diversity and HRT in the study area. This study aims to evaluate the performance of Ci, Ha grass and Rc under different HRTs of 3, 4, and 5 days in the treatment of aquaculture effluent.





(c)

Plate 1: Pictures of the studied macrophytes (a) *Hymenachne amplexicaulis* (b) *Canna indica* (c) *Rhynchospora corymbosa* 

For optimal fish growth in a pond, the water quality must be maintained at suitable levels to support the health and development of aquatic organisms (Diana et al, 2017). A lot of spent water in aquaculture is discharged into waterways without adequate treatment thereby polluting the water bodies nearby (Ahmad et al, 2021). This often leads to eutrophication and algae booming which results in an unconducive environment for the aquatic life downstream. Therefore, the construction of a wetland with the appropriate aquatic plants (macrophytes) will enhance the treatment of aquaculture (fish pond) wastewater for sustaining the treatment system. The construction of a wetland with appropriate aquatic plants (macrophytes) can significantly improve the treatment of aquaculture wastewater in Nigeria, where the aquaculture industry has seen rapid growth in recent years. This approach will not only enhance wastewater treatment efficiency but also help sustain the treatment system over time. Similar to the extensive documentation of environmental effects in Southeast Asia and Latin America (Liu et al, 2021), the rapid expansion of fish farming in Nigeria has raised concerns about water quality and environmental sustainability. Studies in Nigeria, such as by Adabembe et al (2022), highlight the growing

environmental challenges posed by untreated fish pond wastewater, including eutrophication and biodiversity loss. Additionally, the social impacts of aquaculture operations, such as displacement of local communities and conflicts over water resources, have been noted in several studies (Ahmad et al, 2022). The integration of constructed wetlands could help mitigate these negative impacts by improving water quality and promoting sustainable fish farming practices in the region. The primary components of fish farm effluents include solid matter, primarily a mixture of uneaten feed, faeces, phytoplankton colonization microorganisms, and dissolved matter such as ammonia, urea, carbon dioxides, and phosphorus. (Liu et al, 2021; Ahmad et al, 2022). It is necessary to develop more environmentally friendly aquaculture production technologies to increase fish production. Reusing fish pond effluent from wetlands (CWs) following proper treatment could be one approach, leading to systems with nearly zero discharge. (Suantika et al, 2020). Constructed wetlands (CWs) have great potential for the treatment of fishpond wastewater in recirculating aquaculture systems, according to a study that was conducted to evaluate the suitability of using them for the task. This is because the discharge of contaminated water and the associated environmental impact can be significantly reduced (Pulkkinen et al, 2021).

## II. MATERIALS AND METHODS

#### *A.* The study area

The experimental and sampling sites were within the Aquaculture and Fisheries Farm, Landmark University ( $8^{\circ}12'-8^{\circ}13'N$ ,  $5^{\circ}08'-5^{\circ}09'E$ ), located in the forest-grassland transition zone, with water supply relying on groundwater, surface water, and a campus dam.



Figure 1: Sourced from Elemile et al. 2019

#### B. Wastewater sampling and analysis

The experiment was conducted during the rainy season (July–September), during the rainy season, the increased rainfall leads to higher water flow and dilution of pollutants, which can affect the concentration of contaminants in the fishpond effluent. This provides an opportunity to evaluate the effectiveness of the wetland system in treating water under conditions that may represent the natural variability of the aquatic environment. In contrast, the dry season often results in more concentrated effluents due to reduced rainfall and water flow, which could alter the dynamics of pollutant removal. By conducting the experiment during the rainv season, the study captures a more representative scenario of the fluctuating environmental conditions, providing a comprehensive understanding of the wetland's performance across different seasonal contexts. involved collecting fish pond effluent samples in two 2-litre sealed plastic containers at 4°C for laboratory analysis of contaminants, following APHA (2005) water sampling methods; pH and turbidity were measured per the 21st edition of APHA's Standard Methods, with sampling done before and after feeding the effluent into a constructed wetland planted with three study plants, covering three HRTs.

#### 1) Constructed wetland setup

Three sets of four plastic constructed wetland cells (56  $cm \times 41 cm \times 36 cm$ ) were set up with perforated PVC pipes for water level monitoring and effluent distribution. A storage tank with gravel and sand pre-treated the influent, and a hydro test checked for leaks. The CWs were filled with gravel and sand substrates, and young Ci, Ha, and Rc plants, identified at the University of Ibadan Botany Department, were transplanted into CW1, CW2, and CW3, while CW4 served as a control. Two additional replicas of CW1-CW4 were established. Macrophytes acclimated in fresh water before fish pond wastewater was introduced, with sampling starting after six weeks. Wastewater flow was manually controlled at the inlet and regulated by gravity, while PVC pipes facilitated effluent distribution and collection. Plate 2 shows the constructed wetland experimental set-up, the Influent tank, constructed wetland cell and all the other units as shown from (a) to (h).



Plate 2: Constructed wetland experimental set-up: (a) Influent tank (b) Constructed Wetland cell (c) control setup unplanted (d) cell planted with *Rhynchospora corymbosa* (e) cell planted with *Hymenachne amplexicaulis* (f) cell planted

with *Canna indica (g)* Standing perforated PVC pipe (h) Control valve.

#### *2) The substrate*

The substrate bed depth, as shown in Figure 1, consisted of a 100 mm lower layer of 12–15 mm granite aggregates covering the outlet drain pipe, a 180 mm middle layer of 1–2 mm coarse sand where macrophytes were planted, and an 80 mm freeboard to prevent overflow; sand medium porosity was determined in the lab, flow rate was computed using the bucket method, young plants were acclimated before introducing fish pond wastewater, and the CW cells were maintained outdoors without shade for optimal sunlight exposure.



**Figure 2.** Schematic diagram of the cross-section of the substrate arrangement in the CW setup

The aquaculture spent water was allowed to stay within the CW for 3,4 and 5 days corresponding to  $HRT_3$ ,  $HRT_4$  and  $HRT_5$  respectively before sampling and testing were done to determine the pollutant removal efficiency of the CWs with different macrophytes

#### 3) Wastewater characterization

The fish pond effluent was characterized before and after the introduction into the CWs by analyzing physicochemical parameters, including pH, TDS, BOD5, COD, TN, TP, and heavy metals (Pb and Zn), using standard APHA (2005) procedures; pH was measured with a calibrated Hanna pH meter, TDS via the gravimetric method, BOD<sub>5</sub> by determining DO before and after five days of dark incubation at 20°C, COD using the closed reflux titrimetric method, TN and TP via the Palintest Photometer 7100 colorimetric technique, and heavy metals pre-concentrated before analysis with Atomic Absorption Spectrophotometry (AAS SearchTech, AA320N, UK).

#### 4) Pollutant removal efficiency calculation

The per cent removal (removal efficiency) was calculated as follows (Abdelhakeem *et al*, 2016):

$$\frac{Percentage removal efficiency =}{\frac{Concentration in - concentratio out}{concentration in}} \times 100$$
 (1)

Where *Concentration in* and *Concentration out* are the inflow concentration and outflow concentration of measured parameters respectively (mg/L). Where inflow and outflow

concentrations of measured parameters (mg/L) were used; data analysis was performed using Microsoft Excel for descriptive statistics, and ANOVA at  $\alpha = 0.05$  was conducted in SPSS 23.0 to compare effluent characteristics and removal efficiencies across different macrophytes before and after treatment.

## III. RESULTS AND DISCUSSION

#### A. Characterization of raw and treated effluent

Eight physico-chemical parameters were tested for the Fish Pond Wastewater (FPW) and Fresh Water Source (FWS) each time the treatment was carried out. The mean values of the parameters for the fish pond wastewater (FPW) were calculated. As presented in Figure 3, the mean concentrations of the FPW for the measured parameters were higher than those of the fish pond sediment (FWS), with the exception of the pH value. The FPW mean values of TDS, COD, BOD, TN, TP, Pb and Zn as shown in Figure 2 in mg/L are  $889.7 \pm 53.1$ ,  $224.2 \pm 14.8$ ,  $69.9 \pm 17.5$ ,  $5.7 \pm 0.3$ ,  $6.4 \pm 0.4$ ,  $0.02 \pm 0.0$  and  $0.4 \pm 0.0$  respectively which are greater than the corresponding values for FWS which are 418.3, 69.2, 33.5, 1.6, 1.6, 0.02 and 0.2 respectively. Also, from the Table, the mean value of pH for the FPW is  $7.6 \pm 0.3$  which is different from that of FWS which is 8.1 in the alkaline region also. The findings clearly indicate that fish farming has a negative impact on the quality of the fish pond sediment (FWS), underscoring the necessity for treatment before the fish pond wastewater (FPW) can be reused, recycled, discharged into rivers, or used for groundwater recharge. The concentrations of contaminants in the FPW exceed the recommended limits set by the WHO and FAO, particularly for zinc (Zn), which, despite being a beneficial micronutrient in fish feed for growth and reproduction, is present at levels that may pose environmental risks. (WHO, 2006; Dawood et al, 2021).



Figure 3. Fish pond wastewater characterization

All units are in mg/L except for pH; FAO: Food and Agriculture Organization, FPW- Fish Pond Wastewater, FWS-Fresh Water Source.

#### B. Removal efficiency with different HRTs

The values of the parameters obtained after the treatment of the FPW after 3 days of Hydraulic Retention Time (HRT<sub>3</sub>) are shown in Figure 4. The three macrophytes (Ci, Ha and Rc) reduced the physico-chemical parameters of the FPW except for the values of lead (Pb) which remained constant. This shows that the macrophytes are efficient in removing the pollutants in the FPW. However, the Removal Efficiency (RE) of the pollutants differs for the three different macrophytes used. The RE of Ci for all the parameters is less than the RE of Ha and Rc. Ha shows the best RE for nutrient removal due to its invasive nature wherever it is found making it a high nutrient removal (Clarkson et al, 2011), whereas Rc did better. The RE of pH, BOD, TN and TP by the control system are lower compared to the three macrophytes. However, the RE of Pb and Zn for the control system is higher than those of the three macrophytes and the reason can be attributed to the exposure of the control system to the atmosphere which facilitated cation and anion exchange, oxidation and reduction and complexion (Yalcuk and Ugurlu, 2009).



**Figure 4.** Influent and effluent concentrations and RE values for  $CW_1$ ,  $CW_2$ ,  $CW_3$  and  $CW_4$  at HRT<sub>3</sub> All units are in mg/L except for pH;  $CW_1 = Canna$  indica planted CW;  $CW_2 = Hymenachne$  amplexicaulis planted CW;  $CW_3 = Rhynchospora$  corymbosa planted CW and  $CW_4 =$ 

Control unplanted CW.

The values of physico-chemical parameters obtained after treating FPW at HRT<sub>4</sub> are shown in Figure 4 in comparison with Figure 3, it was observed that the RE of *Ci* followed the same trend where its RE for all the parameters are lower than the RE of *Ha* and *Rc* except for TN where the RE of *Ci* and *Rc* were the same (71.9%). This implies that as HRT increases, the RE of the three macrophytes also increases. The results of Ewemoje *et al* (2015) on the impact of hydraulic retention time on pollutant removal in CWs are similar to these findings. For TDS and COD, the RE of *Ha* is better than the RE of *Rc* in all the parameters analyzed. For pH and Zn, their RE (of 5.1% and 50% respectively) for *Ha* and *Rc* were the same. The RE of the control system in removing BOD, TN, TP and pH were less when compared to the RE of these parameters by the three macrophytes. This was also observed in Figure 3.





All units are in mg/L except for pH;  $CW_1 = Canna$  indica planted CW;  $CW_2 = Hymenachne$  amplexicaulis planted CW;  $CW_3 = Rhynchospora$  corymbosa planted CW and  $CW_4 =$ Control unplanted CW.

Figure 5 shows the final RE results obtained at HRT<sub>5</sub> for the treatment of FPW. It was observed that the RE of the control system for pH is less than the RE obtained by the three macrophytes for the same parameter. It was also observed that there was no difference in pH removal by the control system at HRT<sub>4</sub> and HRT<sub>5</sub>. This could be because a day difference in HRT is not enough for a significant change to occur in the pH of the control system. However, it was noticed that the RE of HRT<sub>3</sub> and HRT<sub>5</sub> were not the same (2-day difference). This same trend was observed for the RE of pH by *Ci* as the only difference recorded was on the HRT<sub>3</sub> and HRT<sub>5</sub>.



**Figure 6.** Influent and effluent concentrations and RE values for  $CW_1$ ,  $CW_2$ ,  $CW_3$  and  $CW_4$  at  $HRT_5$ All units are in mg/L except for pH;  $CW_1 = Canna$  indica

planted CW;  $CW_2 = Hymenachne amplexicaulis planted CW;$ 

 $CW_3 = Rhynchospora \ corymbosa \ planted \ CW \ and \ CW_4 = Control unplanted CW.$ 

The *Rc*-planted CW had better RE than *Ha* and *Ca* for pH, TDS, COD and BOD as shown in Figure 6. This was also observed in Figure 5 for only TDS and COD and in Figure 3 for only TDS, COD and BOD. This shows that *Rc* performance in removing TDS and COD in FPW is better than *Ha* and *Ci* as the HRT increases. However, *Ha* shows the best RE for TN and TP throughout the considered HRT (3, 4 and 5 days). The accumulation of TN and TP by *Ha* can be responsible for the rapid increase noticed in CW biomass.

# *C.* Comparison of the removal efficiency with HRT for pollutants

#### 1) Removal efficiency of pH versus HRT

Figure 7 shows the trends in the RE of pH by the three macrophytes and control (P1, P2, P3 and C) against HRT. From the results presented, it can be inferred that the removal efficiency (RE) of pH in the constructed wetlands (CWs) varied with hydraulic retention time (HRT) and plant species. The RE for pH increased steadily with HRT, reaching its highest value at HRT5 for the three macrophytes (P1, P2, and P3), with P3 showing the highest pH removal at 8.9%. The control (unplanted CW) showed a rapid increase in RE between HRT3 and HRT4, but the efficiency remained constant afterward. Additionally, the statistical analysis (p<0.05) confirmed that the RE values for the different CW treatments were significantly different. The results implied that the presence of macrophytes enhances pH removal efficiency, particularly at higher HRT, with each plant species exhibiting varying patterns of improvement over time. Optimizing HRT can bring about more efficient pH removal, with certain macrophytes providing sua significant performance.



**Figure 7.** Removal efficiency of pH against HRT (days)  $(P_1 = Canna indica; P_2 = Hymenachne amplexicaulis; P_3 = Rhynchospora corymbosa and <math>C = Control unplanted CW$ ).

# 2) Removal efficiency of total dissolved solids (TDS) versus HRT

The variations in the RE of TDS by the macrophytes and the control concerning the HRT are shown in Figure 8. The RE of the three macrophytes and the control has almost similar trends but there was a slight deviation in the Rc trend. The RE of all increased with an increase in the retention time which implies that the higher the retention time, the higher the removal efficiency. Moreover, it can be seen from the figure that the control has the highest removal efficiency. Thus, RE for control > Rc > for Ha > for Ci. TDS removal in CWs has been attributed more to the property of the substrate which must have influenced the filtration ability of the control setup (Sandoval-Herazo et al, 2018) without root growth disturbance. The significant value of 0.443 which is > 0.05indicated that there was no significant difference in RE when different plant treatments were adopted. TDS does not increase significantly with HRTs. For the HRT effects of P=0.08, RE was not significantly different with the highest values obtained at day 5 for P3 and P2.



**Figure 8.** Removal efficiency of TDS against HRT (days); ( $P_1 = Canna indica$ ;  $P_2 = Hymenachne amplexicaulis; P_3 = Rhynchospora corymbosa and C = Control unplanted CW).$ 

# *3)* Removal efficiency of total nitrogen (TN) and total phosphorus (TP) versus HRT

The trends of RE for TN and TP by the three macrophytes and unplanted control are depicted in Figures 8 and 9. From the plots, the RE trends for TN and TP are similar. The trends of the control, *Ci* and *Rc* increased as the HRT increased, in addition, their RE increased more rapidly from HRT<sub>3</sub> to HRT<sub>4</sub> and at a slower rate from HRT<sub>4</sub> to HRT<sub>5</sub>. There was a very slight increase in the RE of *Ha* for both TN and TP as the HRT increased. This agreed with Gupta *et al* (2016) in which Nitrogen removal was said to be inform of nitrates whose removal is majorly due to denitrification, particularly in influent with high nitrate loading like aquaculture effluent. This process is done by microbes which are supported by high temperatures in the study area. The activities of this microbe on the organic content of the wastewater also increase with the

time of exposure of the wastewater to the microbes. The Nitrogen removal by different plants was not significantly different at P $\leq$ 0.05. The HRT effect was also not significantly different. The highest value was however obtained for the unplanted system followed by P3 and P2. The RE for TP was significant for different plants and HRT. The RE was generally high at HRT<sub>5</sub> emphasizing the time-based precipitation that plays out in phosphorus removal in CWs. The highest RE was recorded for P3 at HRT<sub>5</sub> whereas the control unplanted also performed well in terms of RE of TP for HRT<sub>3</sub> and 4.



**Figure 9.** Removal efficiency of TN against HRT (days);  $(P_1 = Canna indica; P_2 = Hymenachne amplexicaulis; P_3 = Rhynchospora corymbosa and <math>C = Control unplanted CW$ ).



**Figure 10.** Removal efficiency of TP against HRT (days); ( $P_1 = Canna indica; P_2 = Hymenachne amplexicaulis; P_3 = Rhynchospora corymbosa and <math>C = Control unplanted CW$ ).

4) Removal efficiency of organics (BOD and COD) versus HRT

Figure 11 shows the differences in the RE of COD by the macrophytes and the control systems. The graph shows that the three macrophytes increased simultaneously from HRT<sub>3</sub> to HRT<sub>4</sub> but from HRT<sub>4</sub> to HRT<sub>5</sub>, the *Ci* and *Ha* increased slightly while the *Rc* increased rapidly than from HRT<sub>3</sub> to HRT<sub>4</sub>. The RE of the control was almost constant as the HRT increased. Among the four treatments, the control has the best removal efficiency for COD. This is consistent with the results in the study conducted by Idris *et al* (2012), where the unplanted system produced a quality effluent in terms of BOD removal using a HssFCW. Organics in aquaculture effluents, usually represented with BOD and COD are mostly removed by aerobic and anaerobic degradation (Zhao *et al*, 2020; Deng *et al*, 2021).



**Figure 11.** Removal efficiency of COD against HRT (days); ( $P_1 = Canna indica$ ;  $P_2 = Hymenachne amplexicaulis; <math>P_3 = Rhynchospora corymbosa and C = Control unplanted CW).$ 

This is often done by microbiota found in the substrates. Consequently, plants with rapid growth and well-developed root systems have more pores for oxygen filling into the CW matrix and treatment system. Hence, more oxygen translocation and higher RE under aerobic degradation conditions. Statistically, COD removal was not significant between different plants and HRT. The highest value of RE was obtained for the control experiment (unplanted). This is due to the direct incidence of sun rays and their thermal effect which helps in the breaking down of the pollutants mainly the chemical parts. Figure 12 shows the RE of BOD against the HRT. The RE of Ci as indicated in the graph increased continuously as the HRT increased. The removal efficiency of the control, the Ha and the Rc showed similar variation but Ha and Rc have the best RE efficiency followed by Ci then the control. These two macrophytes have a well-spread root system compared to the thick rhizome in the Ci plant. This also shows that the biological interaction in the study systems became prominent with residence time of the wastewater in the CWs



**Figure 12.** Removal efficiency of BOD against HRT (days);  $P_1 = Canna indica$ ;  $P_2 = Hymenachne amplexicaulis; <math>P_3 = Rhynchospora corymbosa and C = Control unplanted CW).$ 

The RE of BOD was not significantly different between different plants also, but significantly different with different HRT. The HRT<sub>5</sub> gave the highest value of RE for P3 followed by P2. The treatment with the least RE was the control (unplanted) system. This emphasizes the importance of HRT in BOD removal.

#### 5) Removal efficiency of lead (Pb) versus HRT

Figure 13 shows the RE of Pb by the three macrophytes and the control at different HRTs. As indicated in the graph, there was no removal of lead by the three macrophytes throughout the retention days. For the control, the RE was quite higher than the three macrophytes though it remained almost constant as the HRT increased. The reason can be due to the exposure of the control system to the atmosphere which facilitates the cation and anion exchange as well as oxidation and reduction in the control system (Yalcuk and Ugurle, 2009). Also, the mineral composition of the soil used as substrates sometimes affects the dynamic of metals in CW. Whenever there are more clay materials in the substrate, the RE can be affected positively which is the case in the study. The soil in the area was reported by Gbadegeshin and Olabode (2000) to be high in colloidal clay content which has high in soil adsorption properties (Qasaimeh et al, 2015). Lead presence may have been from the pipes used in the conveyance of water in and out of the fish pond especially from old abandoned pipes which were still found to be useful by the owner of the farm to save cost. However, the Pb presence was found to be far below the allowable limit suggested by FAO. The RE of Pb was not significantly affected by HRT. For the studies effluent, the concentration of Pb was very low. This is an indication that there was little or no lead contamination in the effluent treated. The plant-induced RE was also not significant.



**Figure 13.** Removal efficiency of Pb against HRT (days);  $P_1 = Canna indica; P_2 = Hymenachne amplexicaulis; P_3 = Rhynchospora corymbosa and <math>C = Control unplanted CW$ ).

### 6) Removal efficiency of zinc (Zn) versus HRT

The variations of RE of Zn for the three macrophytes and the control are shown in Figure 14. The unplanted system has the best RE which was constant throughout the HRT just like the RE of lead. The same reason given in Pb adsorption as it relates to the presence of colloidal clay material also holds for Zn. The Ha and Rc have the second-best RE which also remained constant throughout the HRT. The RE for the Ci remained constant from HRT<sub>3</sub> to HRT<sub>4</sub> but rapidly increased from HRT<sub>4</sub> to HRT<sub>5</sub>. It also has the least RE. Metal removal in CW is a complex process that combines both biotic and abiotic processes like adsorption, precipitation and ion exchange with some form of oxidation and reduction and plant uptake. Despite that these metals are found in low quantities they cannot be destroyed from studies (Olawale et al, 2021). It should also be noted that Zn removal has also been linked to the pH of the wastewater (Huang et al, 2017), that Zn removal increased initially with HRT until a point where HRT doesn't matter again. Statistically, Zn removal from the treated effluent was significantly different for different plant treatments. The same for the HRT. The highest RE was obtained for unplanted systems in all HRT treatment differences.



#### IV. CONCLUSION

The study shows the capacity and potential of three tropical and indigenous macrophytes in the treatment of aquaculture effluent in a batch-flow HssFCW. The effluent has a significant concentration of nutrients, organics and other physico-chemical pollutants and a mild concentration of heavy metals. The species of plant evaluated performed well in terms of pollutant removal under HRT of 3,4 and 5 days. At the peak HRT of 5 days for all plant species studied. Rc significantly removed pH, BOD<sub>5</sub>, TP and Zn from the aquaculture effluent. The rest plants (Ci and Ha) did not remove all pollutants significantly except for TP. The retention period of aquaculture effluent in the constructed wetland (CW) system is more critical for treatment efficiency than the specific type of macrophyte species studied. Tropical species such as Canna indica (Ci), Hymenachne amplexicaulis (Ha), and Rynchospora corymbosa (Rc) effectively improve spent fish pond water quality prior to discharge or recycling for agricultural use. Therefore, the implementation of full-scale, batch-flow CW systems for aquaculture effluent treatment is a promising and viable approach. Additionally, as plant roots provide oxygen in hydroponic sub-surface flow constructed wetlands (HssFCW), it is crucial to allow adequate root zone development and ensure sufficient hydraulic retention time, as pollutant removal efficiency increases with the age of the macrophytes used.

## AUTHORS CONTRIBUTIONS

**O. D. Raphael:** Conceptualization, Methodology, Software, Validation. **I. Udeoke:** Writing – original draft, Writing – review and editing. **K. Ogedengbe:** Supervision, writing – original draft, **O. I. Adewuyi:** Writing – review and editing. **H. A. Alabi:** Writing – review and editing. **O. M. Abioye:** The final version of the manuscript with analysis.

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**Figure 14.** Removal efficiency of Zn against HRT (days) using aquaculture wastewater under sweet pepper/okra intercrop.  $P_1 = Canna indica; P_2 = Hymenachne amplexicaulis; P_3 \notin ommunications in Soil Science and Plant Analysis, 53(18), pp Rhynchospora corymbosa and C = Control unplanted CW). 2460-2475.$  Ahmad, A.; S.R.S. Abdullah; H.A. Hasan; A.R. Othman and N.I. Ismail. (2021). Aquaculture industry: Supply and demand, best practices, effluent and its current issues and treatment technology. *Journal of Environmental Management*, 287: 112271.

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