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Effect of the number of *Cyperus rotundus* and medium height on the performance of batch-constructed wetland in treating aquaculture effluent

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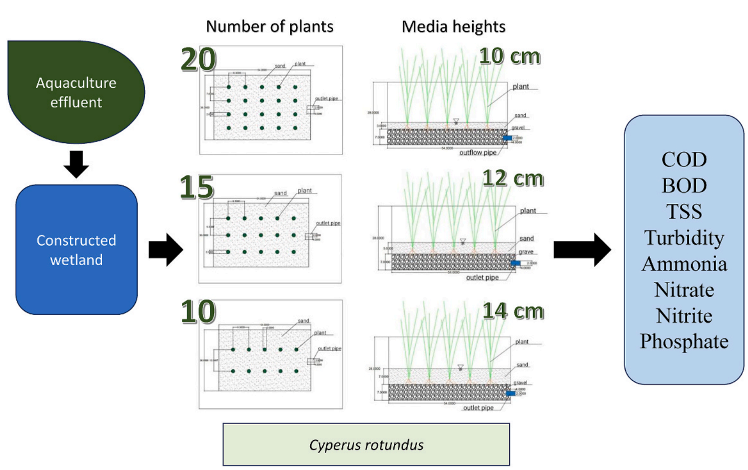
HIGHLIGHTS

- *Cyperus rotundus* can withstand 100% aquaculture concentration.
- The use of *C. rotundus* in CW increased the removal of COD, BOD, TSS, turbidity, and phosphate.
- Number of plants and medium height variation did not affect the pollutants removal.
- The 10 cm media height showed higher RGR as compared to control system.

GRAPHICAL ABSTRACT



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ABSTRACT

Increasing aquaculture cultivation produces large quantities of wastewater. If not handled properly, it can have negative impacts on the environment. Constructed wetlands (CWs) are one of the phytoremediation methods that

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can be applied to treat aquaculture effluent. This research was aimed at determining the performance of *Cyperus rotundus* in removing COD, BOD, TSS, turbidity, ammonia, nitrate, nitrite, and phosphate from the batch CW system. Treatment was carried out for 30 days with variations in the number of plants (10, 15, and 20) and variations in media height (10, 12, and 14 cm). The result showed that aquaculture effluent contains high levels of organic compounds and nutrients, and *C. rotundus* can grow and thrive in 100% of aquaculture effluent. Besides that, the use of *C. rotundus* in CWs with the effect of numbers of plants and media height showed performance of COD, BOD, TSS, turbidity, ammonia, nitrate, nitrite, and phosphate with 70, 79, 90, 96, 64, 82, 92, and 48% of removal efficacy, respectively. There was no negative impact observed on *C. rotundus* growth after exposure to aquaculture effluent, as indicated by the increase in wet weight, dry weight, and growth rate when compared to the control. Thus, adding aquaculture effluent to CWs planted with *C. rotundus* supports the growth and development of plants while also performing phytoremediation.

1. Introduction

The development of the aquaculture sector is expected to lead to an increase in demand for fish as a source of protein for human consumption, amounting to 21.2 tons in 2016 and continuing to increase every decade (FAO, 2018). Increased aquaculture cultivation produces large quantities of aquaculture effluent as by-products (Ahmad et al., 2021; Kurniawan et al., 2021a). If not handled properly, it can cause negative impacts on the environment, such as decreasing the quality of surface water (Ahmed and Turchini, 2021). This is because aquaculture effluent contains high levels of organic compounds and nutrients that come from fish feed waste and excreta (Goddek et al., 2016; Iber and Kasan, 2021; Nzilani Musyoka and Nairuti, 2021). Excessive input of organic compounds and nutrient content can cause eutrophication and anoxic conditions in water bodies, thereby causing the loss of biodiversity and possibly having long-term effects on ecosystem function (Ahmad et al., 2021; Ahmed and Turchini, 2021; Thomsen et al., 2020).

Phytoremediation is a green technology that can be applied to treat aquaculture effluent (Kurniawan et al., 2021b; Ng and Chan, 2021). Several previous researchers reported that phytoremediation has been proven capable of treating domestic wastewater containing high organic content (Almansoory et al., 2021; Imron et al., 2019; Said et al., 2021). is often used to treat wastewater (Al-Ajalin et al., 2020a; Purwanti et al., 2018b; Rana and Maiti, 2020). Constructed wetlands (CWs) are built and designed by utilizing natural processes between plants, media, and associated microbes in treating wastewater (Rana and Maiti, 2020; Thalla et al., 2019). Wastewater treatment using the CWs occurs physically, chemically, and biologically in the plant root zone (Al-Ajalin et al., 2020b; Vymazal, 2018a, 2018b).

Plant type is one of the factors that influences the performance of CWs (Al-Baldawi et al., 2021; Arliyani et al., 2023; Said et al., 2021). Plants that can be used in CWs are those that have the characteristics of hyperaccumulators and hypertolerance to what will be processed (Adeyemi et al., 2021; Kurniawan et al., 2022b). Some plants that can be used are *Typha angustifolia, Pandanus amaryllifolius, Azolla microphilla, and Cyperus rotundus* (Muda et al., 2020; Pradesh et al., 1991; Purwanti et al., 2018a, 2020). *C. rotundus* is one of the plants that is reported to be able to treat high concentrations of organic contents in wastewater (Cao et al., 2012; Purwanti et al., 2018a; Thalla et al., 2019). Based on previous research by Erwin et al. (2017), *C. rotundus* reduced phosphate levels and chemical oxygen demand (COD) in laundry wastewater by 82% and 95% within a contact time of four days. Similar to Purwanti et al. (2018a), the use of *C. rotundus* under the subsurface flow CWs can reduce the concentration of biological oxygen demand (BOD), COD, and total suspended solids (TSS) in tempe processing wastewater by 81%, 69%, and 47%, respectively. Amalia et al. (2014) also reported that *C. rotundus* can also reduce BOD and COD in leachate, with respective efficiencies ranging from 44.95 to 82.65% and 53.90–73.38%.

Apart from that, the number of plants used and the height of the media on CWs are also some of the factors that improve the performance of CWs. Ahmed et al. (2021) mentioned that the use of 8 plants of *Eichornia crassipes* was enough to provide good BOD, COD, nitrogen (N), and phosphate (P) removal, while the addition of the number of plants did not significantly improve the pollutant removal performances. Previous research has also stated that the type of media and media height influenced the wastewater treatment process with CWs (Erwin et al., 2017). Based on Al-Ajalin et al. (2020a), it was reported that variations in media and free surface height in CWs also have a significant effect on removing pollutants from wastewater due to the different contact of wastewater with the medium.

Although it has been reported that *C. rotundus* is used to treat various types of wastewater, there is little literature that reports the use of *C. rotundus* to treat aquaculture effluent under the influence of the number of plants and variations in media height. Therefore, to fill this gap, the general aim of this research was to analyze the capability of *C. rotundus* to treat aquaculture effluent. This research also focused on the influence of the number of plants and variations in media height on the performance of pollutant removal in aquaculture effluent. It is expected that the results of this research can be a reference for the implementation of CWs for aquaculture effluent treatment and also for the performance of C. rotundus as a potential plant for phytoremediation.

2. Materials and methods

2.1. Source and characteristization of aquaculture effluent

The effluent sample used in this research was taken from aquaculture ponds located in Pasuruan Regency, Indonesia (7°34′47"S 112°45′20.7"E). Samples were taken and stored using HDPE tank with a size of 200 L. The initial characteristics of effluent were analyzed directly after sampling including the BOD, COD, TSS, total nitrogen (TN), total phosphate (TP), ammonia, nitrate, nitrite, turbidity, temperature, dissolved oxygen (DO), and pH parameters. All parameters were measured using applicable standard methods (APHA, AWWA, 2012).

2.2. Source of plants and propagation

The motherplants of *C. rotundus* was taken from the Campus-C area of Airlangga University, Surabaya, Indonesia. *C. rotundus* was then propagated to produce a sufficient number of individuals for research under the greenhouse at Airlangga University, Surabaya, Indonesia (Said et al., 2021). Plant propagation was carried out in 45-liter containers containing soil media and watered every day. The second generations of *C. rotundus* with the characteristics of fresh green plants and a height of 20–30 cm were then acclimatized in a 45-liter container containing sand (3 cm), gravel (7 cm), and 6 L of tap water for 7 days before using in the main research (Purwanti et al., 2018a).

2.3. Range finding test (RFT)

The RFT test was carried out to determine the ability of *C. rotundus* to survive under aquaculture effluent exposure (Imron et al., 2023; Purwanti et al., 2019). The RFT test was carried out by adding aquaculture effluent with varying concentrations of 0%, 10%, 20%, 30%, 50%, 75%,

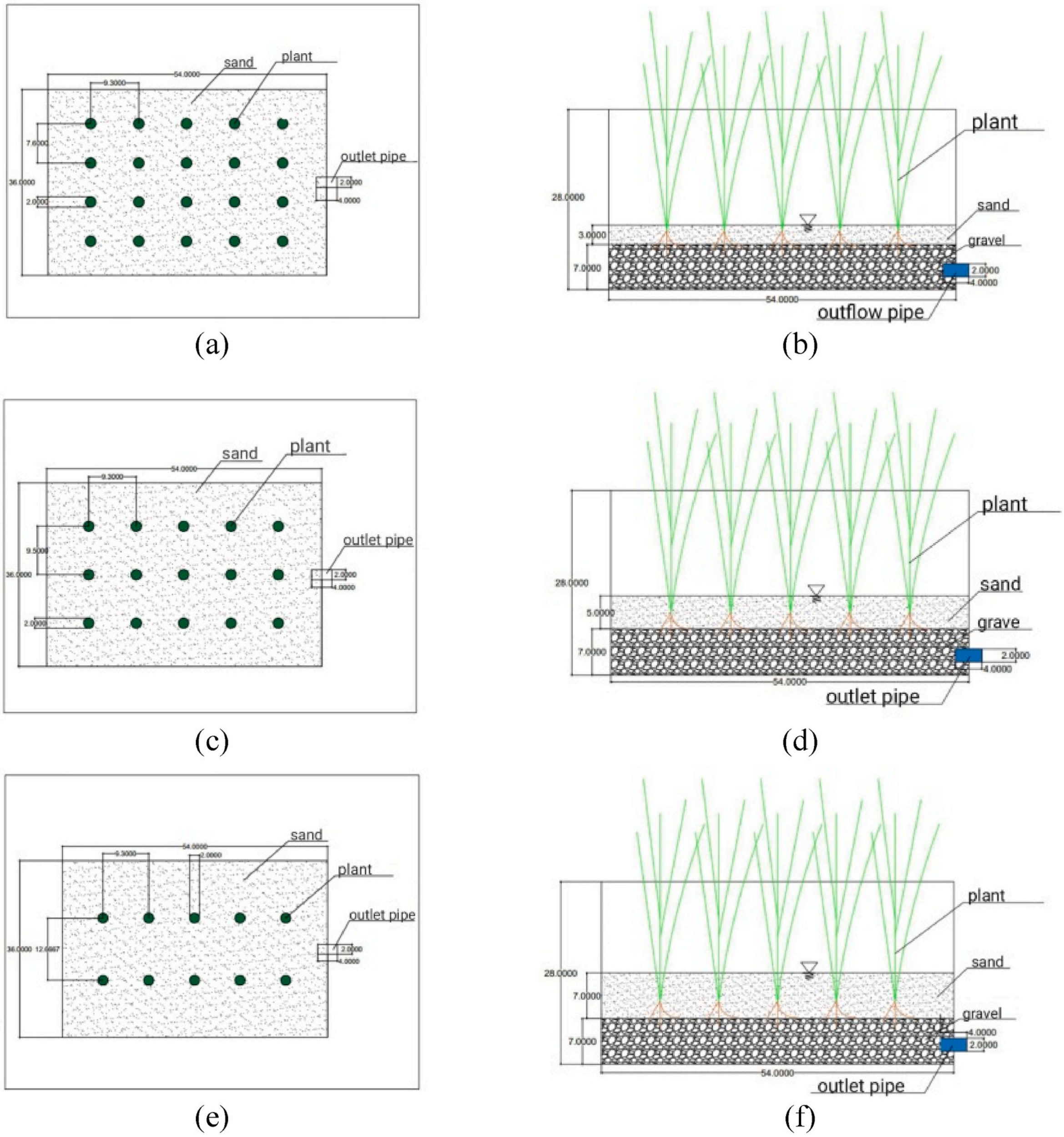

Fig. 1. Reactor Design for (a) 20 plants, (c) 15 plants, (e) 10 plants with different media height of (b) 10 cm, (d) 12 cm, and (f) 14 cm.

Table 1
Initial characteristics of aquaculture effluent.

Parameter	Unit	Value#	Standard*
BOD	mg/L	66±23	50
COD	mg/L	139±9.7	100
TSS	mg/L	91±27	200
DO	mg/L	0	-
pH	-	7.2+0.1	6-9
Temperature	°C	31	Max 38
Turbidity	NTU	151±13	-
Color	Unit PtCo	113.85	-
Nitrite	mg/L NO_2-N	0.00	1
Nitrate	mg/L NO_3-N	0.91±0.67	20
Ammonia	mg/L NH_3-N	92.83±24	5
Total Nitrogen	mg/L NH_3-N	94.43±24	30
Phosphate	mg/L PO_4-P	9.19±1.12	-

*Indonesian national standard for unclassified industrial effluent No. 5, 2014
#Highlighted cells exceeding the national standard

and 100% (diluting with tap water). There were 10 plants used in each reactor [plastic container size 54 × 36 × 28 cm containing gravel (7 cm) and sand (3 cm) media with sizes of 10–15 mm and 3–5 mm, respectively]. The RFT test was carried out for 7 days, with the volume of aquaculture effluent being 6 L with a subsurface flow system (Purwanti et al., 2018a). The parameters observed for this test are the morphology of the *C. rotundus*, which consists of leaf color, plant condition (withered or fresh), and new individuals.

2.4. Experimental set-up

The main research was carried out using a batch reactor under a subsurface flow-constructed wetland system (Chen et al., 2021; Hu et al., 2020) with variations in media height and number of *C. rotundus* plants to treat aquaculture effluent. Variations in the height of the medium used were 10, 12, and 14 cm, while variations in number of plants were 0, 10, 15, and 20 plants. In this research, two types of reactors were used (control and the treated reactors). The two control reactors used

Table 2
RFT results of *C. rotundus* exposed to aquaculture effluent.

Day	Concentration						
	0%	10%	20%	30%	50%	75%	100%
0	10 fresh plants						
7	10 fresh plants with addition of plant height and 4 new shoots	10 fresh plants with addition of plant height and 19 new shoots	10 fresh plants with addition of plant height and 6 new shoots	10 fresh plants with addition of plant height and 7 new shoots	10 fresh plants with addition of plant height and 9 new shoots	10 fresh plants with addition of plant height and 5 new shoots	10 fresh plants with addition of plant height and 9 new shoots

contained (i) media + aquaculture effluent and (ii) media + plants. Meanwhile, the treated reactor contains media, effluent, and plants. The amount of effluent used was 6 L for each reactor. This research was conducted for 30 days, with sampling times at the beginning and end of the research. Measured parameters consisted of BOD, COD, TSS, phosphate, ammonia, nitrate, nitrite, and turbidity. This research was conducted in triplicates. The number of reactors used was 33, consisting of 27 treated reactors, 3 control reactors (i), and 3 control reactors (ii). The details of the reactor used in this research can be seen in Fig. 1.

2.5. Plant growth analysis

Plant growth analysis was carried out to determine that the addition of aquaculture waste in the wetland affect the plant life or not (Almaamary et al., 2022). Plant growth analysis was carried out by counting the number of individuals at the beginning and end of the study. In addition, plant growth analysis was carried out by measuring the plant's wet weight and dry weight. Measurement of wet and dry weights of plants was carried out using analytical scales. Wet weight was counted by measuring the weight of 3 plant samples in each reactor and averaging it for each reactor. Plant dry weight measurements were also obtained from the average of 3 plants after drying in oven for 24 h at a temperature of 105 °C. The growth rate was calculated using equation (1) (Ahmed et al., 2021; Allamin et al., 2021; Paolacci et al., 2016).

$$RGR(/day) = \left(\frac{\ln(FW_t) - \ln(FW_0)}{t}\right) \qquad \text{Eq. (1)}$$

where, FW_0 and FW_t describe the initial and the final wet weight (g), respectively, t represents the exposure period (day).

2.6. Statistical analysis

Statistical analysis in this research was carried out using SPSS software version 16.0 (Kurniawan and Imron, 2019a, 2019b). Data processing was carried out using a two-way ANOVA to determine the significant correlation between factors (height of sand media and number of plants) and the response (decrease or increase in tested parameters). Further statistical analysis to determine significant differences between results was carried out using the Tukey HSD test as a post-hoc test. The p-value <0.05 in the Tukey HSD test showed that there were significant differences between the obtained results.

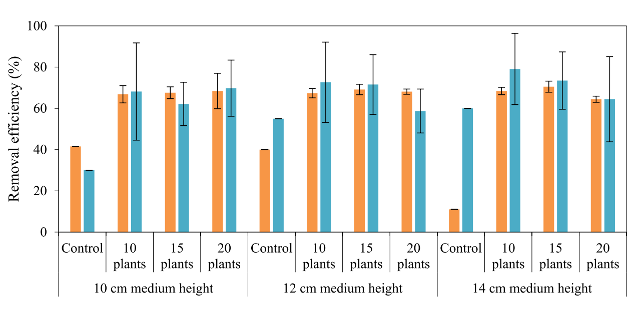

Fig. 2. Removal of COD and BOD in aquaculture effluent by *C. rotundus.* Data are shown as mean ± SD ($n = 3$).

3. Results and discussions

3.1. Initial characteristics of aquaculture effluent

The initial characteristics of aquaculture effluent can be seen in

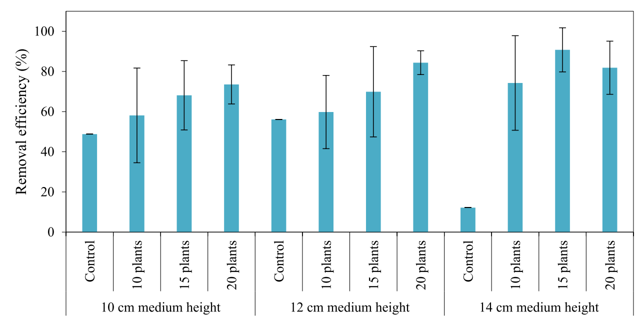

Fig. 3. Removal of TSS in aquaculture effluent by *C. rotundus.* Data are shown as mean ± SD ($n = 3$).

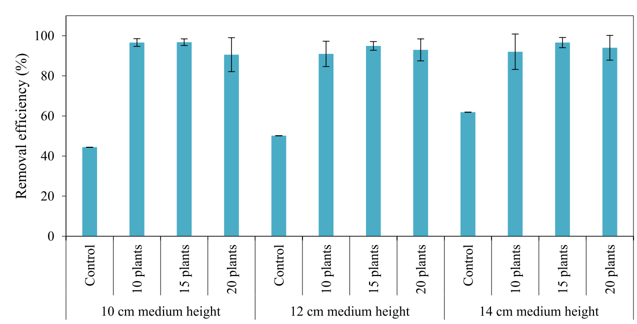

Fig. 4. Removal of turbidity in aquaculture effluent by *C. rotundus.* Data are shown as mean ± SD ($n = 3$).

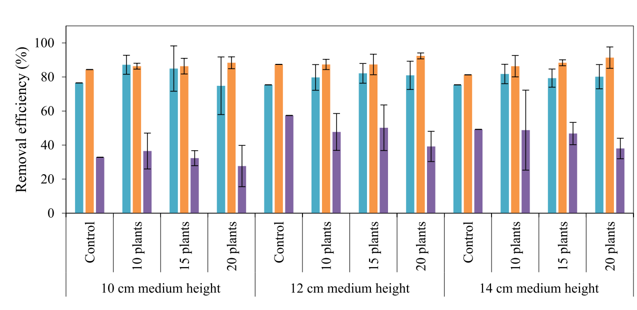

Fig. 5. Removal of ammonia, nitrate, and nitrite in aquaculture effluent by *C. rotundus.* Data are shown as mean ± SD ($n = 3$).

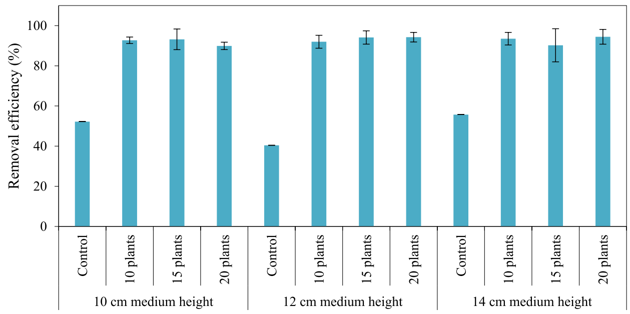

Fig. 6. Removal of phosphate in aquaculture effluent by *C. rotundus*. Data are shown as mean ± SD ($n = 3$).

Table 1. Based on Table 1, the used aquaculture effluent contains high levels of organic compounds and nutrients. Organic and nutrient compounds in aquaculture effluent originated from fish feces and excess fish food (Brod and Øgaard, 2021; Goddek et al., 2016; Iber and Kasan, 2021). Apart from that, the high levels of ammonia and phosphate in aquaculture effluent were also caused by the addition of fertilizer to the pond (Iber and Kasan, 2021; Kurniawan et al., 2022a). Fertilizer was used to regulate the growth of algae in fishponds providing some additional food for fish (Green, 2015; Iber and Kasan, 2021). Heiderscheidt et al. (2020) stated that aquaculture effluent in Finland contains very high levels of COD, total nitrogen, and phosphate, reaching 76, 8.6, and 7.6 mg/L, respectively. Nasir et al. (2023) also stated that the nutrient concentration (N and P) in aquaculture effluent. High levels of organic compounds in aquaculture effluent can reduce dissolved oxygen, which can cause anaerobic conditions in the water (Fyson et al., 2006). Continuous disposal of aquaculture effluent without proper treatment can have a negative impact on the environment, especially euthorphication due to the high nutrient contents.

3.2. Range finding test result

The results of the RFT for *C. rotundus* after being exposed to aquaculture effluent for 7 days can be seen in Table 2 (detailed pictures are provided in Table S1). Based on Table 2, *C. rotundus* could grow and live well at all concentrations, as indicated by the growth of new shoots in the reactor. At a concentration of 100% aquaculture effluent, *C. rotundus* has fresh plant morphology, green leaf color, and has nine new shoots. Purwanti et al. (2018a) reported that *C. rotundus* can live well in wastewater that has a high organic and nutrient contents. Thalla et al. (2019) also reported that *C. rotundus* can also live well in the concentration of 100 mg/L BOD in municipal wastewater. It can be concluded that *C. rotundus* was able to grow well in 100% aquaculture effluent, therefore, the concentration used in subsequent research was 100%.

3.3. Effect of the number of plants and media height on aquaculture effluent treatment

3.3.1. COD and BOD removal

The ability of *C. rotundus* to reduce COD and BOD concentrations in aquaculture effluent under the variation of the number of plants and media height after 30 days of treatment can be seen in Fig. 2. Based on Fig. 2, *C. rotundus* removed COD and BOD with a range of 64–70% and 64–79%, respectively, with final concentrations of 41–49 mg/L and 20–30 mg/L, respectively. The highest COD removal efficiency, 70.51 ± 2.69%, occurred under 15 plant numbers and the media height of 14 cm. Meanwhile for BOD, the highest removal efficiency (79.09 ± 17.26%) was obtained under 10 plant numbers and the media height of 14 cm. In contrast, the control reactor only showed COD and BOD removal of 11–41% and 30–60%, respectively. Removal of COD and BOD in the control reactor occurred due to the organic degradation process by microorganisms (Al-Ajalin et al., 2020b; Imron et al., 2023). Apart from that, the media in CWs also functions as a filtration medium for wastewater (AL Falahi et al., 2021). Theoritically, the higher the number of plants in CWs, the higher the COD and BOD removal efficiency (Ahmed et al., 2021). The more plants, the greater the surface area of the plants for contact with wastewater performing the phytoremediation mechanisms (Kurniawan et al., 2022b). Apart from that, the pollutant load will be smaller because the same concentration with different numbers of plants will produce different pollutant loads for the plants (Ahmed et al., 2021). However, the variations of the number of plants in this research did not gave significant influence on COD and BOD removals ($p > 0.05$).

Similarly, the media height should affect the performance of CW, the higher the media (more volume), the higher the removal efficiency due to the lower pollutant load per medium volume (Al-Ajalin et al., 2020a). However, in this study, the removal efficiency for variations in media height did not show a significant difference ($p > 0.05$). The use of plants (*C. rotundus*) showed significant improvement to the COD and BOD removals, suggesting that interactions between plants root system, medium, and bacteria in CW giving positive impact to the elimination of the organic matter. The obtained result was in accordance with Ahmet et al. (Ahmed et al., 2021) which stated that the addition of the number of plants did not guarantee the improvements of organic compounds removal due to the fact that organic (BOD and COD) removals was done by the microbial communities in the medium. In addition, it is suggested that there might be no significant difference in microbial communities between varied medium heights, which results in the non-significant value of organic removals. Additional analysis of microbial communities and number of bacterial colonies can enrich the results, and give an additional view on how the media height might affect the organic matter removal (Arliyani et al., 2023).

3.3.2. TSS removal

Fig. 3 shows the efficiency of TSS removal on CWs by *C. rotundus* after 30 days of treatment. Based on Fig. 3, CWs filled with *C. rotundus* removed TSS ranging from 60 to 90%. The highest TSS removal occurred in 15 plants and 14 cm media height with 90.7%, while the control only showed 12.2% removal. The media in the CWs help with the filtration and sedimentation of solids in wastewater (AL Falahi et al., 2021; Purwanti et al., 2018b), while microorganisms help decompose organic compounds, which also contributed to the TSS (Malakootian et al., 2021; Parde et al., 2020; Wdowczyk and Szymańska-Pulikowska, 2021), so that the TSS value also decreases. The results also showed that the use of *C. rotundus* in the CWs system significantly increases the TSS removal when compared to the control reactor, indicating that the plants root also played a role in the process of TSS removal. The increasing number of plants showed an increase in TSS removal but was not significant ($p > 0.05$). Similarly, the increase in medium height also showed a slight increase in TSS removal. These results suggested that the increase in free-surface water level did not affect TSS removal significantly. Further research can accommodate the variations in sand medium height rather than the free-surface water level to observe its effect on TSS removal.

3.3.3. Turbidity removal

The results in Fig. 4 showed that the control reactor was able to set aside a turbidity value of 44.43% for a media height of 10 cm, 50.19% for a media height of 12 cm, and 61.92% for a media height of 14 cm after 30 days of treatment. These results represent the ability of the used media (gravel and sand) to reduce turbidity through filtration, either by sand media or biofilms found on the surface of the media. The decrease in turbidity values was proportional to the TSS removal (Koskiaho and Puustinen, 2019). The turbidity value is influenced by the solids content in aquaculture effluent, namely colloidal and discrete particles.

Fig. 4 also shows that the addition of *C. rotundus* in the CWs system causes a significant increase in the turbidity removal efficiency for all treatment reactors, suggesting that the plants root system played a role in the removal of turbidty via various mechanisms (filtration,

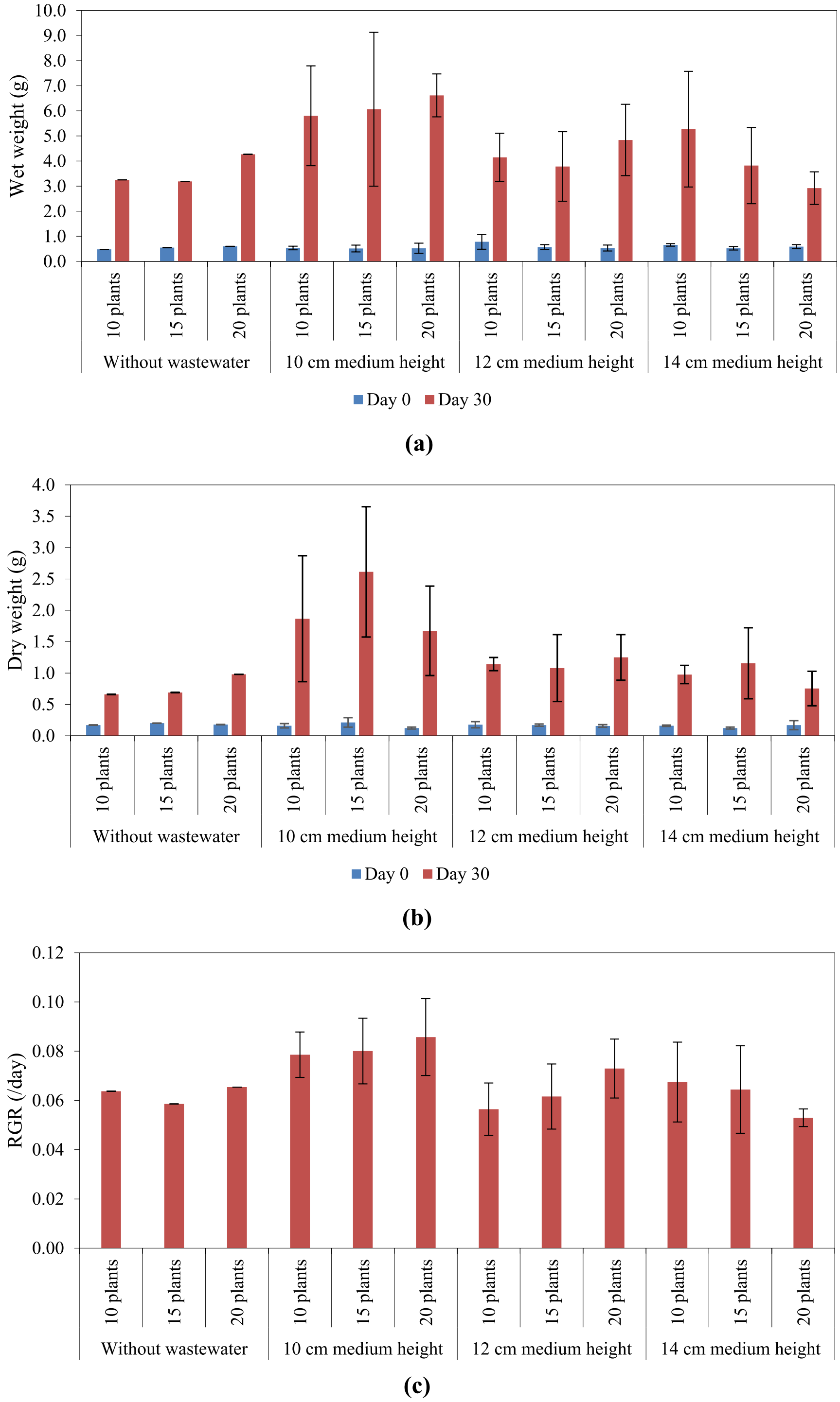

Fig. 7. (a) Wet weight, (b) dry weight of *C. rotundus* before and after being exposed to aquaculture effluent and (c) calculated RGR. Data are shown as mean ± SD (n = 3).

sedimentation, and/or organic degradation) (Khan et al., 2020; Vymazal, 2018a; Zhang et al., 2020). The highest turbidity removal of 96.64% was obtained under 10 plants and 10 cm of medium height, while the control reactor only showed 44.43% of removal. In the case of the number of plants and media height, results showed no significant differences in terms of turbidity removal. Similar to TSS removal, turbidity removal data suggested that both of the used variables were not really affecting the turbidity removal performance.

3.3.4. Ammonia, nitrate, and nitrite removal

Ammonia includes NH_3 and NH_4^+ which are a toxic end product of nitrogen metabolism. The ammonia content in aquaculture effluent generally comes from urine and feces of fish and microbiological oxidation of organic substances (Goddek et al., 2016; Heiderscheidt et al., 2020; Jasmin et al., 2020). The use of *C. rotundus* increased ammonia removal only at a media height variation of 10 cm after 30 days of treatment (Fig. 5). This happens because the ammonia removal process in the CWs system occurs when the oxygen supply is good (Ashkanani et al., 2019; Dodds et al., 2017). CWs with a low media

Table 3
Post-treatment characteristics of aquaculture effluent.

Parameter	Unit	Value	Standard[a]
BOD	mg/L	16.59 ± 10.3	50
COD	mg/L	43.9 ± 4.5	100
TSS	mg/L	37.3 ± 12.3	200
pH	–	7.9	6–9
Temperature	°C	26.8 ± 0.61	Max 38
Turbidity	NTU	7.69 ± 0.98	–
Nitrite	mg/L NO_2–N	0	1
Nitrate	mg/L NO_3–N	0.2 ± 0.02	20
Ammonia	mg/L NH_3–N	0.68 ± 0.25	5
Total Nitrogen	mg/L NH_3–N	0.88 ± 0.25	30
Phosphate	mg/L PO_4–P	0.24 ± 0.05	–

[a] Indonesian national standard for unclassified industrial effluent No. 5, 2014.

height tend to have a better oxygenation system; therefore, there was an increase in removal efficiency using *C. rotundus* at a media height of 10 cm.

Fig. 5 also indicates that both media and plants play a role in the CWs system through their role as facilitators of decomposing microorganisms that remove ammonia. Organic ammonia in CW systems can be reduced by some mechanisms, including adsorption, plant uptake, and volatilization (Vymazal, 2018b). In addition, microorganisms living in CW systems play a role in ammonia decomposition (Palma et al., 2020; Yang et al., 2021). The results of statistical analysis showed that variations in media height and number of plants produce different ammonia removal efficiencies, but the results were not significantly different ($p > 0.05$).

Fig. 5 shows that in the CWs, nitrate removal can occur, but the use of *C. rotundus* does not increase nitrate removal compared to the control reactor. The use of variations in media height and number of *C. rotundus* plants also did not produce significantly different nitrate removal efficiencies in each treatment. This is in accordance with previous research showing that the removal of ammonia, nitrate, and nitrite is influenced by the work of decomposition microorganisms through the processes of nitrification, and denitrification (Bao et al., 2017; Ngo et al., 2017; Yang et al., 2018). The results show that the media used in the CWs system was able to support the removal of nitrate as a living place for decomposing microorganisms. Similar results were also obtained for nitrite removal in which variation in the use of plants, variations of number of plants, and media height did not significantly affect the overall removal. This result might indicate that only the used media played a role in the mechanisms of nitrite removal and suggesting that the major N removal occurred due to the microbial activities in the medium, while the plant uptake was contributing in a low portion (Bao et al., 2017; Ngo et al., 2017; Yang et al., 2018).

3.3.5. Phosphate removal

In several previous studies, the use of *C. rotundus* in the CWs system showed good phosphate removal performances. For example, Erwin et al. (2017) mentioned the ability of *C. rotundus* to reduce phosphate levels up to 82.24%. Roliya [30] also stated that *C. rotundus* was able to remove 58.60% of phosphate during 8 days of contact time. The results of this study are in accordance with the previous studies and depicted in Fig. 6. The use of *C. rotundus* significantly increased the phosphate removal efficiencies in CWs (reaching the highest of 94.44%) after 30 days of treatment, as compared to control (55.69%). Phosphate is needed by plants as source of nutrient, suggesting that P-uptake might be the major mechanism that occurred inside the CWs (Lima et al., 2018; Shahid et al., 2020). However, the variations of number of plants and media height did not show significant differences to the phosphate removal ($p > 0.05$). This might be occurred due to the amount of bioavailable P was limited, in which maximum P uptake was carried out even by the smallest number of plants (Boström et al., 1988).

3.4. Impact of aquaculture effluent to *C. rotundus* growth

Based on Fig. 7(a), the increase in the wet weight of *C. rotundus* was proportional to the increase in the dry weight, as shown in Fig. 7(b). The results obtained showed a very significant increase in dry weight and wet weight. Before treatment, *C. rotundus* had a wet weight in the range of 0.3–1.2 g, increasing to 2.3–8 g. The dry weight of *C. rotundus* plants before treatment was in the range of 0.1–0.2 g, increasing to 0.5–3 g. Apart from that, *C. rotundus* after treatment experienced a lot of new individual growth, ranging from 30 to 70 new individuals. All relative growth rates (RGR) showed positive values with the highest RGR shown under 20 plants with 10 cm medium height. CW system with 12 and 14 cm medium showed relatively similar RGR with control reactor, suggesting that non-significant growth of *C. rotundus* occurred in those medium height. Only the CW systems with 10 cm medium height showed higher RGR value than control. This result was subjected due to a better microbial community growth on the rizhosphere area in the 10 cm media height, caused by a better oxygenation system (Bolan et al., 2011; Liu et al., 2017; Rehman et al., 2017). The results above confirm that *C. rotundus* plants can grow and reproduce well. Thus, processing aquaculture waste by adding aquaculture waste to CW planted with *C. rotundus* supports the growth and development of plants while also performing phytoremediation.

3.5. Post-treatment water quality

Since the variation of media height and the number of plants did not significantly affect parameter removals, the result of post-treatment water quality was summarized from CW with 10 plants and 10 cm of medium height and tabulated in Table 3. It can be seen that all of the given parameters already met the effluent standard, which indicates that aquaculture effluent treated with CW can be disposed of safely in the water body.

4. Conclusions

The results of this study indicated that the addition of *Cyperus rotundus* in constructed wetland (CW) treating aquaculture effluent was beneficial. Range finding test (RFT) showed that *C. rotundus* can thrive in 100% aquaculture effluent. The use of *C. rotundus* showed significantly higher removal efficency in COD, BOD, TSS, turbidity, and phosphate removals as compared to control. Removal of COD, BOD, TSS, turbidity, ammonia, nitrate, nitrite, and phosphate reaching 70, 79, 90, 96, 64, 82, 92, and 48%, respectively. This study also suggests that aquaculture effluent gave beneficial effect to *C. rotundus* as shown by positive relative growth rates (RGR), especially with 10 cm medium height with values higher than control (without effluent).

CRediT authorship contribution statement

Muhammad Fauzul Imron: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Wa Ode Ayu Hestianingsi:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Trisnadi Widyaleksono Catur Putranto:** Supervision, Funding acquisition. **Nita Citrasari:** Supervision, Funding acquisition. **Siti Rozaimah Sheikh Abdullah:** Supervision, Funding acquisition. **Hassimi Abu Hasan:** Supervision, Funding acquisition. **Setyo Budi Kurniawan:** Writing – review & editing, Writing – original draft, Methodology, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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