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Effective removal of chromium from contaminated water using horizontal subsurface flow constructed wetland with Napier grass (*Pennisetum purpureum*)

Taufik Taufikurahman*, Lili Melani, Natasha Lumongga Hugo Sianturi, Ni Komang Devi Amrita Wirawan, Aisyah Fairuz Saifullah

School of Life Science and Technology, Bandung Institute of Technology (ITB), West Java, Indonesia

ABSTRACT

This study aims to explore the potential of using Napier grass (Pennisetum purpureum) as a low-cost alternative for treating wastewater contaminated with chromium (Cr) in the tannery industry. Traditional chemical treatment processes are costly, leading to many industries not committing to treatment. Phytoremediation, the use of plants to remove contaminants from the environment, could be a viable solution. The study conducted an experiment to test the tolerance and effectiveness of P. purpureum in treating wastewater containing Cr(VI) at concentrations of 20 ppm, 40 ppm, and tannery wastewater. The plant was grown in a constructed wetland pond using a batch system for 31 days. The results indicate that P. purpureum can survive and grow well in all treatments, showing tolerance to Cr. The plant's phytoremediation capacity was effective at 20 ppm of Cr(VI) as demonstrated by the chemical and physical characteristics of the medium (BOD, COD, pH, and TDS). The plant was able to remove a significant amount of total Cr and Cr(VI), with removal capacity ranging from 71.79% to 99.96%. The translocation factor (TF) for Cr in the roots was less than one, indicating that the plant has the potential to be used as a phytoremediator for Cr by accumulating it in its roots.

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*Corresponding author:
taufik@sith.itb.ac.id

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1. Introduction

Industrial activities such as textile production will intensify heavy metal accumulation through the process of tannery wastewater. Chromium is one of the prominent heavy metals found in tannery wastewater, but its accumulation in environment must be limited to avoid its negative impacts to the ecosystem. Chromium hexavalent Cr(VI)) is the most observed form of chromium found in industrial waste (Juel et al., 2018). Economical and environmentally friendly wastewater treatment can be done through phytoremediation using plants. Napier grass (*Pennisetum purpureum*) is a hyperaccumulator plant that has high tolerance to heavy metal by accumulate heavy metal in its tissues as micronutrients through a process of phytoextraction (Juel et al., 2018). Napier grass is a popular phytoremediation plant due to its high productivity, easy to grow, and has high endurance in non-ideal cultivation conditions (Mohammed et al., 2015). Through phytoremediation, hyperaccumulator plants can absorb, bind, and stabilise toxic elements in plant biomass (Juel et al., 2018).

Phytoremediation effectivity can be observed from the characteristic of the medium and chromium absorption by the plant. The medium characteristic which are pH, TDS, BOD, and COD of the medium will affect plant growth during the toxic element treatment, by which they will decrease overtime along with plant growth (Taufikurahman et al., 2020). Chromium uptake from medium to plant tissue indicates the phytoremediation runs well (Amin et al., 2019). In this study, all phytoremediation effectivity aspects are tested to measure *P. purpureum* capability to absorb chromium waste.

2. Materials and methods

2.1 Materials

The materials used in this study are clean water from well, tannery wastewater, $K_2Cr_2O_7$, and Napier grass (*Pennisetum purpureum*). The tannery wastewater was obtained from the Small-Scale Tanning Industry Wastewater Treatment Unit in Sukaregang, Garut. The *P. purpureum* plants used were 3 months-old with an average plant height of 199 cm. The plants were obtained from the Haurngombong Village, Sumedang.

2.2 Methods

2.2.1 Horizontal subsurface flow constructed wetlands description

The pilot-scale research was conducted at the Kebun Pendidikan SITH ITB Haurngombong. The pond design used is a horizontal subsurface constructed wetlands (HSSF CWs) carried out in batch system as shown in Fig 1. The pond was composed of bricks with dimensions of 75 cm in length, 40 cm in width, and 40 cm in height. The arrangement of the media from bottom to top is large gravels (1-3 cm in diameter), small gravels (0.5-1 cm in diameter), and sands (<0.5 cm in diameter) (Papaevangelou et al., 2016) with a thickness of 10 cm each (Ding et al., 2018). Each pond is separated into three parts by a 1 mm thick of PVC board partition. The pond was planted with 98 individuals of Napier grass (*Pennisetum purpureum*).

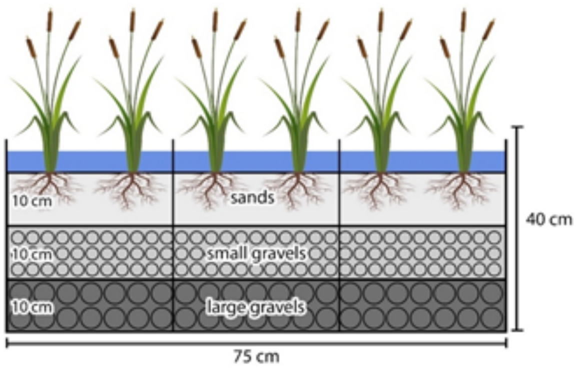

Fig. 1. Layout of horizontal subsurface constructed wetlands (HSSF CWs) pond

2.2.2 Acclimatization

P. purpureum acclimatization in the pond was carried out for two weeks. Each pond was immersed by using 30 L of clean water. The water immersion height is marked and kept constant by adding water to the pond regularly. Before the phytoremediation system operates, the acclimatization water was discharged through the piping system.

2.2.3 Phytoremediation

The ponds were given in several variations of treatment, which were clean water (control), 20 ppm $K_2Cr_2O_7$, 40 ppm $K_2Cr_2O_7$, and tannery wastewater. Each treatment consisted of six repetitions. Each pond was immersed by a solution according to the treatment as much as 30 L with a batch system. The immersion height is further marked and kept constant by adding clean water to the pond regularly. The phytoremediation system lasted for 31 days.

2.2.4 Measurement of pH and total dissolved solids

During the phytoremediation process, the parameters were checked regularly, consist of pH and TDS (Total Dissolved Solids). These two parameters are audit every two days using the Mettler ToledoTM FG2 FiveGoTM Portable pH Meter and TDS & EC Meter (Hold).

2.2.5 Sampling

Napier grass in the phytoremediation pond was sampled out at the beginning and the end of the phytoremediation process. Furthermore, the plants that are taken from 1 partition of the phytoremediation pond were separated based on their plant parts, namely roots, stems, and leaves. All of these samples will be processed by weighting fresh and dry weight using an analytical balance. Dry weight was obtained by drying the sample in an oven at 80°C for 24 hours (Li et al., 2016).

2.2.6 Total Cr, Cr(VI), BOD, and COD testing

Total Cr, Cr(VI), BOD, and COD contents were tested out refers to APHA 23rd edition 2017.

2.2.7 Relative growth (RG)

Relative growth (RG) is a parameter to measure plant growth conditions based on the plant's fresh weight. The RG value can be calculated according to research (Reale et al., 2016) and is in Equation 1 below.

$$RG = \frac{final\ fresh\ weight\ (g)}{initial\ fresh\ weight\ (g)}$$

2.2.8 Removal percentage

The reducing chromium levels in the waste is indicated by the percentage of chromium removal. The percentage of removal can be calculated according to research (ZhiGang et al., 2009). It is in Equation 2 below.

$$Removal(\%) = \frac{initial\ Cr\ conc.\ in\ medium - final\ Cr\ conc.\ in\ medium}{initial\ Cr\ concentration\ in\ medium}\ x\ 100\%$$

2.2.9 Bio concentration factor (BCF)

The bioconcentration factor (BCF) is an indicator to assess the ability of plants to absorb heavy metals from the substrate. The BCF value can be calculated according to research (ZhiGang et al., 2009). It can be seen in Equation 3 below.

$$BCF = \frac{final\ Cr\ concentration\ in\ plant\ parts}{initial\ Cr\ concentration\ in\ medium}\ x\ 100\%$$

2.2.10 Translocation factor (TF)

Translocation factor (TF) can indicate the ability of plants to transfer heavy metals from the treatment medium to the plant tissue. The TF value can be calculated according to research (ZhiGang et al., 2009) and can be seen in Equation 4 below.

$$TF = \frac{Cr\ concentration\ in\ shoots}{Cr\ concentration\ in\ roots}\ x\ 100\%$$

3. Results and discussion

3.1 Plants conditions

In this study, *P. purpureum* plants were used in phytoremediation process for four kinds of treatments, media with clean water (control), Cr(VI) 20 ppm and 40 ppm, and tannery wastewater in 31 days. Each variation undergo six repetition. The comparison of *P. purpureum* growth in these four treatments is shown in Fig 2 below.

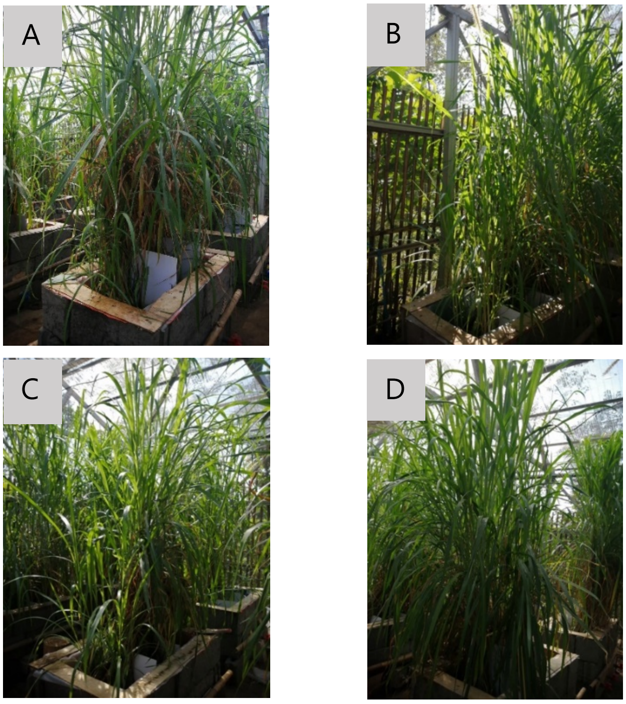

Fig. 2. Phytoremediation process on day 31 in four treatments: A control; B 20 ppm; C 40 ppm; and D tannery wastewater

Based on fig 2 above, it shown that *P. purpureum* can still grow well even in environmental conditions that contain heavy metal chromium. It also can be seen that the best *P. purpureum* growth was in the control, which was followed by the treatment of tannery wastewater, the concentration of Cr(VI) 20 ppm, and the concentration of Cr(VI) 40 ppm. The growth of *P. purpureum* in tannery wastewater (with a concentration of Cr(VI) < 0.01) showed the best growth in chromium treatment and followed by 20 ppm and 40 ppm treatments respectively. The growth was indicated by the number of flowers produced, height of the plant, and root system of the plant.

The decreasing of growth quality when the concentration of Cr increase is because of the formation of a concentration gradient of nutrients or heavy metals in the growing media is associated with the distribution of the root system that takes these chemicals and is used by plants for growth (Ma et al., 2015). In addition, the cavities/pores in the growing media indicate that the root system of this plant creates micro/macropores to provide a certain amount of water and be used by plants to grow and develop (Jozefaciuk et al., 2006; Tejada et al., 2006). Another study also stated that *P. purpureum* can absorb a media contaminated with heavy metals and stored them in *P. purpureum* plant tissues (Ma et al., 2015). It also may caused by the presence of a certain amount of heavy metals chromium in plant media can reduce plant growth by inducing ultrastructural modifications of cell membranes and chloroplasts, causing chlorosis in leaves, damaging cells in roots, reducing pigment content, interfering with the relationship between water, nutrients and minerals, affecting transpiration and nitrogen assimilation by altering the enzymatic activity (Reale et al., 2016). In addition, the biomass produced in the 40 ppm concentration was less than the other treatments. This can be due to the maximum concentration of Cr(VI) that can be handled by *P. purpureum* is at a concentration of 40 ppm, at a concentration of 50 ppm this amount of Cr(VI) has become toxic and inhibits the growth of *P. purpureum* plants (ZhiGang et al., 2009).

3.2. Biomass production and relative growth

The dry weight and relative growth (RG) of Napier grass were obtained from clean water (control), 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatments with six samplings per variation. RG values were obtained from the ratio of the final to the initial fresh weight of the plant. The dry weight and RG of Napier grass at all treatments are shown in Fig 3.

Based on Fig 3, a further decrease in dry weight and RG was found in roots compared to the stems and leaves. The maximum roots dry weight and RG was obtained in control and followed by tannery wastewater, 20 ppm Cr(VI), and 40 ppm Cr(VI) treatment (Fig 3). It shows that the roots dry weight and growth decreased along with the increasing concentration of Cr(VI) given to the pond media.

Decreased root dry weight and growth could be due to the highest accumulation of Cr(VI) located in the roots compared to the leaves and stems of plants. Plant protection mechanism through Cr accumulation in vacuoles of the root cells can further inhibit cell division or extent the cell cycle, thereby causing a decrease in root weight (Ertani et al., 2017).

The highest leaves dry weight and RG were found in control compared to 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatment (Fig 3). Decreased leaves growth could be caused by chromium disruption of root cells' plasma membrane. Thus, inhibition of minerals and water uptake by the roots. In addition, decreased leaves dry weight and growth can result from reduced photosynthesis efficiency. Chromium can disturbs carbon dioxide fixation, the transport of electrons, photophosphorylation, and photosynthetic enzyme activity (Amin et al., 2019; Ertani et al., 2017; Jobby et al., 2018).

However, the highest stems RG was shown at 20 ppm Cr(IV). An improved stem growth at 20 ppm Cr(VI) can be caused by plant growth stimulation at low chromium concentrations (Hamid et al., 2012; Iyaka, 2009; Zayed and Terry, 2003). It could be due to chromium influence on the levels of gibberellin, cytokinin, or other plant growth hormones (Atici et al., 2005; Ertani et al., 2017). Cr at low concentrations could induce plant growth hormones such as GA3 which is one of the gibberellin hormones (Atici et al., 2005). In addition, low concentrations of Cr(VI) can increase the net photosynthetic rate and promote the growth of plants by enhancing the electron transfer activity of PSII. (Suseela et al., 2002). Although there was a decrease in plant growth at higher concentration of Cr(VI) exposure, Napier grass still showed good tolerance to Cr.

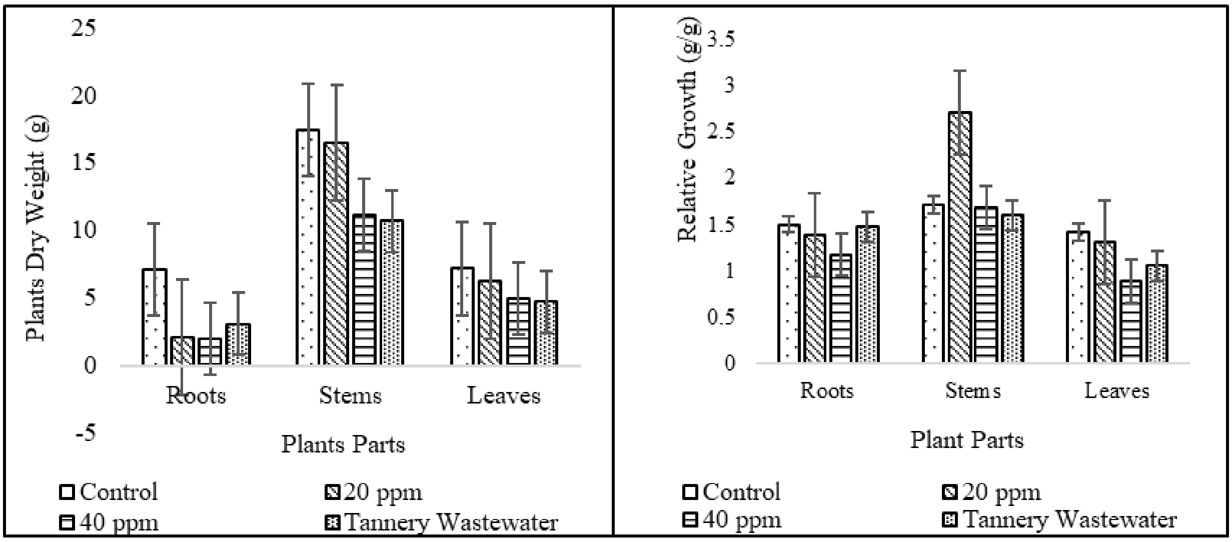

Fig. 3. Plant dry weight and RG in control, 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatment for a period of 31 days

3.3. Phytoremediation effectivity

3.3.1. pH and total dissolved solids (TDS)

Plant medium can affect plant performance during the phytoremediation process. In this study, the measured pH and TDS value of the pond medium is used to see the performance of *P. purpureum* plant in remediate the medium. The pH and TDS value of the medium for each variation of the phytoremediation pond for 31 days can be seen in Fig 4 below.

The pH aspect of the phytoremediation medium affects the solubility of nutrients that support plant growth. Napier grass has a pH range that supports its growth, which is 4.5-8.2 (Osman et al., 2020). Based on Fig 4 (a), the pH value of the pond medium range of 7,00-8,03 and still meets the optimal pH growth range. The occurrence of pH instability is due to plants carrying out photosynthesis and respiration in water because plants use hydrogen ions in water which will increase the pH of the water. However, the respiration process will lower the pH value. Besides that, dead plants are decomposed by decomposer microorganisms and pH value of water addition which will lower the pH of the water. However, most of the water bodies can act as buffer compounds in these fluctuation conditions because the high alkalinity of the water can neutralize the pH of the water. As the pH value of the solution increases, the solubility of nutrient compounds that become nutrients for plants will decrease. In 20 ppm, 40 ppm, and tannery wastewater Cr(VI) treatment ponds, the pH of the solution should be decreased constantly due to the plant releasing metabolites into the medium (Ratzke and Gore, 2017). The change in pH will make heavy metal compounds in the medium precipitate and bind to the surface of plant roots. The binding and precipitation of contaminants is a process of phytofiltration. It gives a cleaner solution (Rahman et al., 2008). This condition was proven on the surface of the pond medium water, each variation which became cleaner after 31 days of the phytoremediation process. The process of absorption of heavy metals and other nutrients by plants takes place in the phytoextraction process. Therefore, pH plays a role in support the binding and absorption of heavy metal chromium by the plant rhizosphere.

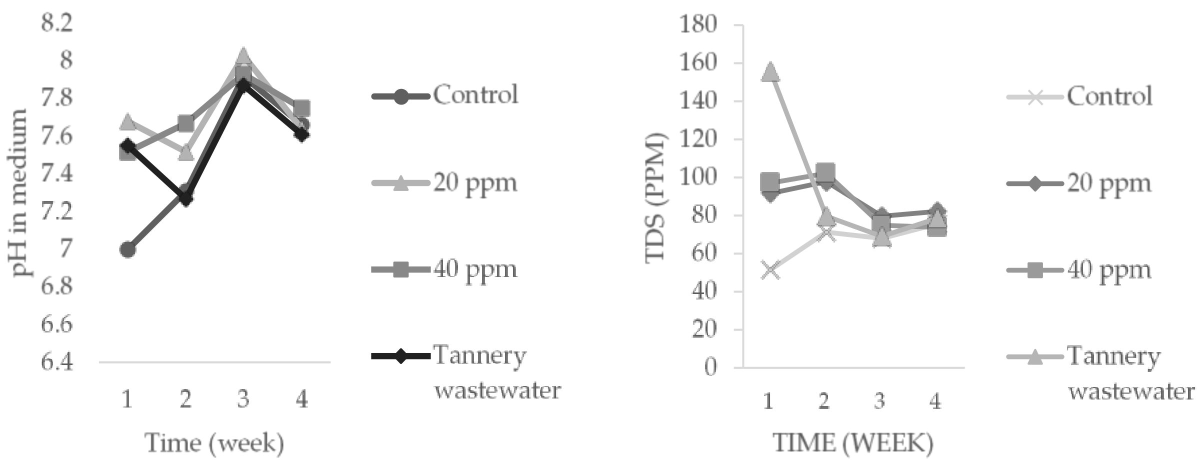

Fig. 4. The pH and TDS value of the 20 ppm pond, 40 ppm pond, tannery wastewater pond, and control pond for 31 days of the phytoremediation process

Based on Fig 4 (b) above, it can also be seen that the TDS value of each treatment from week 1 to week 4 shows a tendency to decrease in value, especially in the treatment of tannery wastewater. It can be happen because naturally, plants will absorb organic and inorganic substances through the roots which will be transported to other plant tissues and accumulated in plant tissues (Abinaya et al., 2018). Therefore, the measured TDS value on the media will decrease along with phytoremediation time. The decrease in TDS value in the media can be caused by the activity of microorganisms in the media. The presence of microorganisms in the roots will break down organic and inorganic substances into simpler compounds so that plant roots can easily absorb these substances (Suriawira, 2005). However, a slight increase in the TDS value in the media could be due to an increase in organic substances in the plant, such as from plant parts that die over time (Kustiyaningsih and Irawanto, 2020), or due to the presence of some organic substances in the water that are added periodically to the pond. In addition, the increase in TDS values can be caused by exudates released by plants because they have accumulated heavy metals (Borker et al., 2013).

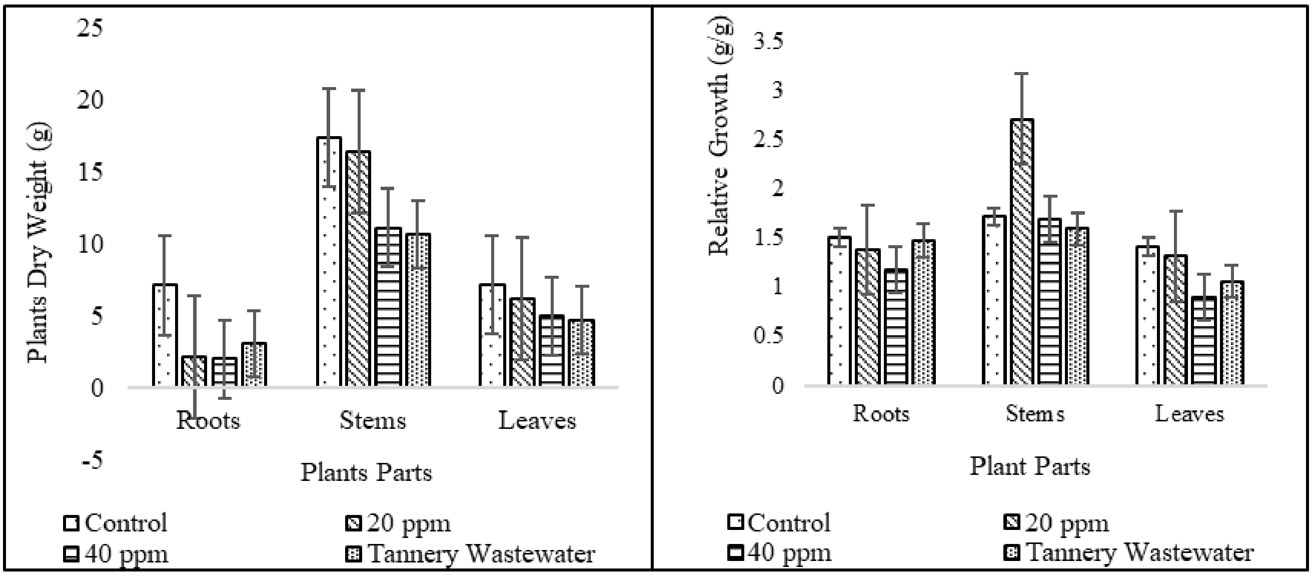

Fig. 5. A total Cr and B Cr(VI) accumulation in the roots, stems, and leaves in control, 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatment for 31 d

3.3.2. Biological oxygen demand (BOD) and chemical oxygen demand (COD)

BOD and COD values can indicate the level of pollution in a wastewater. BOD and COD values from day 1 to day 31 in the treatment of tannery wastewater is shown in Table 1 below.

Table 1. BOD and COD in medium from day 1 to day 31 in tannery wastewater treatment

Parameter	Day 1	Day 31
BOD (mg/L)	3.95	2.09
COD (mg/L)	13.26	18.06

Based on Table 1, it can be seen that there is a decrease in the BOD value from day 1 to day 31 and there is an increase in COD value from day 1 to day 31 in tannery wastewater treatment. The BOD value represents the amount of dissolved oxygen required by microorganisms for the aerobic decomposition of organic matter. The BOD value is also used as an indicator to determine the number of organic pollutants in most aquatic ecosystems (Sricoth et al., 2018). The decrease in BOD value along with phytoremediation time can occur because plants undergo the process of photosynthesis. This photosynthesis process increases the dissolved oxygen in the water and creates aerobic conditions in the medium that support the activity of aerobic bacteria to break down some organic materials in the water. The decomposition of organic matter in the water reduces the BOD value (Singh et al., 2012). This reduced BOD value indicates that wastewater will have a lower negative impact on the environment after being treated using the phytoremediation method (Alkimin et al., 2019).

The COD value represents the amount of oxygen needed to oxidise organic substances in wastewater through chemical reactions. This chemical reaction will convert organic substances into CO2 and H2O (Tangahu and Putri, 2017). Similar to BOD value, a decrease in COD value in wastewater indicates that wastewater will have a lower negative impact on the environment (Alkimin et al., 2019). However, in Fig 4 it can be seen that the COD value increased from day 1 to day 31. It can be happen because the plant will produce exudate if it accumulates heavy metals (Borker et al., 2013). The presence of toxic heavy metals will be absorbed by plants and the plants will produce exudate. This exudate increases the organic content in the water so that the COD value can increase (WHO, 1996). In addition, an increase in COD value along with phytoremediation time is an increase in environmental temperature. High ambient temperature will increase evaporation rate and increasing evaporation rate will cause water to become concentrated. This makes the organic content in the water increase and also increases the COD value (Wirosoedarmo et al., 2020). The COD value which increased along with phytoremediation time could also be caused by the process of assimilation organic carbon from suspended solids that attached to plant roots and released into the medium gradually (Ng and Chan, 2017).

The limited biodegradability of tannery wastewater due to the presence of recalcitrant compounds (Carballeira et al., 2016) can be estimated by the ratio of BOD/COD (Siwiec et al., 2018). In other words, the ratio of BOD/COD can be used to determine the level of biodegradability of organic substances in wastewater. Wastewater can be classified as stable if it has a BOD/COD ratio value less than 0.1 (Tangahu and Putri, 2017). The value of BOD/COD ratio of tannery wastewater treatment on day 1 and day 31 can be seen in Table 2 below.

Table 2. Value of BOD/COD ratio of tannery wastewater on day 1 and day 31

Day	BOD/COD Ratio
1	0.30
31	0.12

Based on Table 2 above, it can be seen that on day 1 and day 31, both value of BOD/COD ratio has a value above 0.1. It shows that the wastewater is still classified as unstable. However, there was a significant decrease in BOD/COD ratio from day 1 to day 31 thus indicating that the phytoremediation process in this study can reduce some organic content in tannery wastewater so that the negative impact produced by wastewater on the environment is lower.

3.3.3. Chromium uptake

Accumulation of total Cr and Cr(VI) in the roots, stems, and leaves of *P. purpureum* in control, 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatment for 31 days were shown respectively in Fig 5.

Based on Fig 5, the accumulated values of total Cr and Cr(VI) in the plant roots showed a more significant difference between treatments and had a higher value than the accumulation in the stems and leaves. It could be due to the plant protection mechanism through heavy metal immobilization. It can be caused either by accumulation in vacuoles of root cells, retention of cation exchange sites of xylem parenchyma cells and binding to proteins (Ertani et al., 2017; Diwan et al., 2012; Dey et al., 2016). In addition, the tendency of binding and precipitation of Cr ions in the insoluble form can also cause Cr immobilization. Thus, it does not spread to other plant tissue parts (Ertani et al., 2017).

Enhanced accumulation of chromium in the root may be due to organic acids in the root exudates. Root exudates can form complexes with chromium making them available for uptake by plant roots (Diwan et al., 2012). *P. purpureum* can be classified as a Cr(VI) excluder because of its ability to limit Cr transport and maintain relatively low Cr levels in the stems and leaves of plants (Hayat et al., 2012). In general, the accumulation of total Cr and Cr(VI) in the stems and leaves showed not very significant differences. The original plants used contained a certain level of total Cr and Cr(VI) concentration. The accumulated value of Cr(VI) also increased along with the concentration of exposure to Cr(VI) in the pond medium. This is in agreement with other studies of Cr(VI) phytoremediation (Skinner et al., 2007; Ye-Tao et al., 2009; Soda et al., 2012; Madera-Parra et al., 2014).

BCF and TF values obtained from each 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatments are shown in Table 3.

Table 3. BCF and TF values of *P. purpureum* at 20 ppm Cr(VI), 40 ppm Cr(VI), and tannery wastewater treatments for 31 days

Treatments	BCF Cr(VI) roots	BCF Cr(VI) stems	BCF Cr(VI) leaves	TF Cr(VI)
20 ppm Cr(VI)	0.120	0.062	0.114	0.732
40 ppm Cr(VI)	0.089	0.034	0.058	0.511
Tannery wastewater	172.167	142.407	167.481	0.900

The bioconcentration factor (BCF) is an indicator to assess the ability of plants to absorb heavy metals from the substrate (Amin et al., 2019). BCF Cr(VI) roots in each treatments had higher values than BCF Cr(VI) on stems and leaves. These results are in agreement with other Cr(VI) phytoremediation studies (Taufikurahman et al., 2020; Woldemichael et al., 2011). It can be caused by plant protection mechanisms through an accumulation of Cr(VI) in vacuoles of root cells. The plant protection mechanism can minimize the accumulation of ions in the stems and leaves of plants that harm the photosynthesis process (Ertani et al., 2017; Taufikurahman and Suryati, n.d.). In addition, the reduction of Cr(VI) to low soluble form Cr(III) can lead to higher Cr accumulation in plant roots (Zhigang et al, 2009). BCF Cr(VI) values in each part of the plant also decreased with increasing Cr(VI) concentration. It is due to the increased accumulation of heavy metals by plants (Lu et al., 2005).

Translocation factor (TF) can indicate the ability of plants to transfer heavy metals from the treatment medium to the plant tissue. Based on Table 3, values of TF < 1 indicate that *P. purpureum* has a limited ability to transport Cr from the roots to the plant shoot. The limited Cr(VI) transfer to shoots could be due to the plant protection mechanism. *P. purpureum* can be classified as Cr(VI) excluder because of its ability to limit Cr transport and maintain relatively low Cr levels in plant shoots (Lu et al., 2005). Cr stabilization in the root and limited Cr transport to shoots is suitable to *P. purpureum* role as animal feed. This mechanism can prevent animal consumption of Cr and restrict Cr mobility in the soil. Thus, it can reduce the transmission of Cr in the food chain (Ram et al., 2019).

3.3.4. Chromium removal

Phytoremediation of chromium by Napier grass effectiveness can be measure from the efficiency of reducing chromium levels in the waste as indicated by the percentage of chromium removal. In this study, the levels of total chromium (Cr total) and hexavalent chromium (Cr(VI)) were measured on day 1 and day 31 of the phytoremediation process in control, 20 ppm, 40 ppm, and tannery wastewater treatments. Changes levels of total Cr and Cr (VI) in each treatment are shown in Table 4 below.

Based on Table 4, the changes in total Cr and Cr(VI) levels in each treatment were due to the absorption of chromium metal from the medium to the Napier grass-root tissue and evaporation of the medium during the phytoremediation process. The absorption of chromium from the medium to the roots was shown in the BCF and TF parameters, where there was an increase in chromium levels in all parts of the plant, which corresponded to the decrease in chromium levels in the waste. Napier grass acts as a bio-accumulator because it can accumulate more than 1 mg/g of Cr metal in the dry weight of the plant. Cr metal content decreased due to the conversion of Cr(VI) to Cr(III) that is easier to absorbed by plants. However, excessive chromium uptake can cause chlorosis and fragility of plant cells (Taufikurahman and Suryati, n.d.).

Table 4. Total Cr and Cr(VI) levels at the beginning and end of phytoremediation at 20 ppm Cr(VI), 40 ppm (VI), and tannery wastewater

Variation	Total Cr (mg/L)		Cr(VI) (mg/L)	
	Day 1	Day 31	Day 1	Day 31
20 ppm	20	0.01	20	0.01
40 ppm	40	0.037	40	0.015
Tannery wastewater	26	0.007	0.001	0.001

The efficiency of chromium removal from the wastewater increased with time, which on the 31st day of phytoremediation, the percentage of total Cr removal in synthetic waste 20 ppm and 40 ppm respectively was 99.95%, and 99.91%, while the treatment of tannery wastewater is 71.79%. This percentage shows a decrease in both Cr(III) and Cr(VI) levels. The percentage of Cr(VI) removal in the synthetic waste treatment of 20 ppm and 40 ppm was 99.95% and 99.96%, respectively. These percentages are shown in Table 5.

Table 5. Percentage of chromium removal in each treatment

Variation	Removal (%)	
	Total Cr	Cr(VI)
20 ppm	99.95	99.95
40 ppm	99.91	99.96
Tannery wastewater	71.79	-

Based on Table 5, the removal efficiency of the combined Cr(III) and Cr(VI) compounds shown from the total Cr and Cr(VI) removal values in synthetic waste treatment was higher than that of tannery wastewater. It can be generated by differences in the type of metal wherein synthetic wastewater, potassium dichromate ($K_2Cr_2O_7$) used, while tannery wastewater contains various heavy metals such as Zn, Cd, Cu, Cr, and Fe. The type of chromium in tannery wastewater is chromate (CrO_4^{2-}), which is more easily absorbed by plants, however, due to the presence of various other metals, the uptake by the plant is not optimal for chromium. Zn metal can be absorbed in an amount that is not much different from Cr so that the reduction of Cr in the waste is not optimal. Dichromate and chromate compounds have similar structures with some anions, which can affect plant mineral nutrition (Ortiz-Castro et al., 2007). Dichromate concentrations above 40 ppm can cause greater damage to plant cells, so in synthetic waste at a concentration of 40 ppm, there is a slight decrease in the percentage of total Cr removal compared to a concentration of 20 ppm.

4. Conclusion

The results of the study showed that phytoremediation of wastewater with varying total Cr and Cr(VI) concentrations increased Cr uptake and accumulation and also affected the growth of Napier grass. Napier grass can tolerate all treatments, which are Cr(VI) at concentration of 20 ppm, 40 ppm, and tannery wastewater. Phytoremediation effectivity was evaluated based on the treated wastewater characteristics. The treated wastewater characteristics were more in line with environmental quality standards. The removal capacity of the plant to total Cr was varied from 71.79% to 99.96%, while for Cr(VI) was varied from 99.95% to 99.96%. The highest BCF values were found in the roots and TF values are <1. Thus, Napier grass can be classified as a Cr(VI) excluder and a good remediator of chromium by stabilize Cr in root and limit Cr transport to shoots. During the phytoremediation process, it is recommended to use clean water from distilled or bottled mineral water to ensure consistency of pH, TDS, and organic substance. In addition, it is recommended for further research to check Dissolved Oxygen (DO) to complete the data.

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Conflict of interest

The authors declare there is no conflict of interest in this study.

References

Abinaya S, Saraswathi R, Rajamohan S, Ansari M S M. 2018. Phyto-remediation of total dissolved solids (TDS) by *Eichhornia Crassipes, Pistia Stratiotes and Chrysopogon Zizanioides* from second stage RO-Brine solution. *Res J Chem Environ* 22(5): 36-41.

Alkimin GDD, Paisio C, Agostini E, Nunes B. 2019. Phytoremediation processes of domestic and textile effluents: Evaluation of the efficacy and toxicological effects in *Lemna minor* and *Daphnia magna*. *Environ Sci Pollut Res.* 4: 4423–41. doi: 10.1007/s11356-019-07098-3

Amin H, Ahmed Arain B, Abbasi MS, Amin F, Jahangir TM, Soomro NA. 2019. Evaluation of chromium phyto-toxicity, phyto-tolerance, and phytoaccumulation using biofuel plants for effective phytoremediation. *Int J Phytoremediation* 1–12. doi: 10.1080/15226514.2018.1524837.

Atici Ö, Ağar G, Battal P. 2005. Changes in phytohormone contents in chickpea seeds germinating under lead or zinc stress. *Biol Plant* 49: 215–22. doi: 10.1007/s10535-005-5222-9

Borker AR, Mane AV, Saratale GD, Pathade GR. 2013. Phytoremediation potential of *Eichhornia Crassipes* for the treatment of cadmium in relation with biochemical and water parameters. *Emir J Food Agric* 25(6): 443-56. doi: 10.9755/ejfa.v25i6.13970

Carballeira T, Ruiz I, Soto M. 2016. Effect of plants and surface loading rate on the treatment efficiency of shallow subsurface constructed wetlands. *Ecol Eng* 90: 203–14. doi: 10.1016/j.ecoleng.2016.01.038

Dey U, Mondal NK. 2016. Ultrastructural deformation of plant cell under heavy metal stress in Gram seedlings. *Cogent Environ Sci* 2: 1–12. doi: 10.1080/23311843.2016.1196472

Ding Y, Lyu T, Bai S, Li Z, Ding H, You S, Xie Q. 2018. Effect of multilayer substrate configuration in horizontal subsurface flow constructed wetlands: assessment of treatment performance, biofilm development, and solids accumulation. *Environ Sci Pollut Res* 25(2): 1883-91. doi: 10.1007/s11356-017-0636-4

Diwan H, Ahmad A, Iqbal M. 2012. Chromium-induced alterations in photosynthesis and associated attributes in Indian mustard. *J Environ Biol* 33: 239–44.

Ertani A, Mietto A, Borin M, Nardi S. 2017. Chromium in agricultural soils and crops: a review. *Water Air Soil Pollut* 228(5): 190. doi: 10.1007/s11270-017-3356-y

Hamid R, Parray JA, Kamili AN, Mahmooduzzafar M. 2012. Chromium stress in Brassica juncea L. cv.'Pusa Jai Kissan'under hydroponic culture. *Afr J Biotechnol* 11(90): 15658-63. doi: 10.5897/AJB11.4042

Hayat S, Khalique G, Irfan M, Wani AS, Tripathi BN, Ahmad A. 2012. Physiological changes induced by chromium stress in plants: an overview. *Protoplasma* 249(3): 599-611. doi: 10.1007/s00709-011-0331-0

Iyaka YA. 2009. Chromium in soils: a review of its distribution and impacts. *Int J Environ Sci* 5(3000): 30-300. doi: 10.1007/s11270-017-3356-y

Jobby R, Jha P, Yadav AK, Desai N. 2018. Biosorption and biotransformation of hexavalent chromium [Cr (VI)]: a comprehensive review. *Chemosphere* 207: 255-66. doi: 10.1016/j.chemosphere.2018.05.050

Jozefaciuk G, Toth T, Szendrei G. 2006. Surface and micropore properties of saline soil profiles. *Geoderma* 135: 1–15. doi: 10.1016/j.geoderma.2005.10.007

Juel M, Dey T, Akash M, Das K. 2018. Heavy metals phytoremediation potential of Napier grass cultivated in tannery sludge. *4th International Conference on Civil Engineering for sustainable Development* (pp. 1-9). Bangladesh: Research Gate.

Kustiyaningsih E, Irawanto R. 2020. Measurement of total dissolved solid (TDS) upon detergent phytoremediation using *Sagittaria lancifolia* (in Indonesia). *J Tanah Sumberdaya Lahan* 7(1): 143-8. doi: 10.21776/ub.jtsl.2020.007.1.18

Li X, Geng X, Xie R, Fu L, Jiang J, Gao L, Sun J. 2016. The endophytic bacteria isolated from Napier grass (*Pennisetum purpureum* Schumach) promote plant growth and enhance salt tolerance of hybrid *Pennisetum*. *Biotechnol Biofuels* 9: 190. doi: 10.1186/s13068-016-0592-0. eCollection 2016

Lu X, Kryuatrachue M, Pokethitiyook P, Homyok K. 2004. Removal of cadmium and zinc by *E. crassipes*, *Eichhornia crassipes*. *Sci Asia* 30: 93-103. doi: 10.2306/scienceasia1513-1874.2004.30.093

Ma C, Ming H, Lin C, Naidu R, Bolan N. 2015. Phytoextraction of heavy metal from tailing waste using Napier grass. *Catena* 1-10. doi: 10.1016/j.catena.2015.08.001

Madera-Parra CA, Peña-Salamanca EJ, Peña MR, Rousseau DPL, Lens PNL. 2014. Phytoremediation of landfill leachate with *Colocasia esculenta*, *Gynerum sagittatum* and *Heliconia psittacorumin* constructed wetlands. *Int J Phytoremediation* 17(1): 16–24. doi: 10.1080/15226514.2013.828014

Mohammed I, Abakr Y, Kazi F, Yusup S, Alshareef I, Chin S. 2015. Comprehensive characterization of napier grass as a feedstock for thermochemical conversion. *Energies* 3403-17. doi: 10.3390/en8053403

Ng YS, Chan DJC. 2017. Wastewater phytoremediation by *Salvinia molesta*. *J. Water Process Eng* 15: 107–15. doi: 10.1016/j.jwpe.2016.08.006

Ortiz-Castro R, Trujillo M, Lopez-Bucio J. 2007. Effects of dichromate on growth and root system architecture of *Arabidopsis thaliana* seedlings. *Plant Sci* 684-91. doi: 10.1016/j.plantsci.2006.11.004

Osman N, Roslan A, Ibrahim M, Hassan M. 2020. Potential use of *Pennisetum purpureum* for phytoremediation and bioenergy production: a mini review. *Asia-Pac J Mol Biol Biotechnol* 14-26. doi: 10.35118/apjmbb.2020.028.1.02

Papaevangelou V, Gikas GD, Tsihrintzis VA. 2016. Chromium removal from wastewater using HSF and VF pilot-scale constructed wetlands: Overall performance, and fate and distribution of this element within the wetland environment. *Chemosphere* 1-15. doi: 10.1016/j.chemosphere.2016.11.002

Rahman M, Ishii Y, Niimi M, Kawamura O. 2008. Effect of salinity stress on dry matter yield and oxalate content in napiergrass (*Pennisetum purpureum* Schumach). *Asian-australas J Anim Sci* 1599-603. doi: 10.5713/ajas.2008.80217

Ram BK, Han Y, Yang G, Ling Q, Dong F. 2019. Effect of hexavalent chromium [Cr (VI)] on phytoremediation potential and biochemical response of hybrid napier grass with and without EDTA application. *Plants* 8(11): 515. doi: 10.3390/plants8110515

Ratzke C, Gore J. 2017. Modifying and reacting to the environmental pH can drive bacterial interactions. *Plos Biol* 195. doi: 10.1371/journal.pbio.2004248

Reale, L, Ferranti F, Mantilacci S, Corboli M, Aversa S, Landucci F, Baldisserotto C, Ferroni L, Pancaldi S, Venanzoni R. 2016. Cyto-histological and morpho-physiological responses of common duckweed (*Lemna minor* L.) to chromium. *Chemosphere* 145: 98–105. doi: 10.1016/j.chemosphere.2015.11.047

Singh D, Tiwari A, Gupta R. 2012. Phytoremediation of lead from wastewater using aquatic plants. *J Agric Sci Technol* 8: 1–11. doi: 10.7439/ijbr.v2i7.124

Siwiec T, Reczek L, Michel MM, Gut B, Hawer-Strojek P, Czajkowska J, Jóźwiakowski K, Gajewska M, Bugajski P. 2018. Correlations between organic pollution indicators in municipal wastewater. *Arch Environ Prot* 44: 50–7. doi: 10.24425/122296

Skinner K, Wright N, Porter-Goff E. 2007. Mercury uptake and accumulation by four species of aquatic plants. *Environ Pollut* 145: 234–7. doi: 10.1016/j.envpol.2006.03.017

Soda S, Hamada T, Yamoaka Y, Ike M, Nakazato H, Saeki Y, Kasamatsu T, Sakurai Y. 2012. Constructed wetlands for advanced treatment of wastewater with a complex matrix from a metalprocessing plant: bioconcentration and translocation factors of various metals in *Acorus gramineus* and *Cyperus alternifolius*. *Ecol Eng* 39: 63–70. doi: 10.1016/j.ecoleng.2011.11.014

Sricoth T, Meeinkuirt W, Pichtel J, Taeprayoon P, Saengwilai P. 2018. Synergistic phytoremediation of wastewater by two aquatic plants (*Typha angustifolia* and *Eichhornia crassipes*) and potential as biomass fuel. *Environ Sci Pollut Res* 25: 5344–58. doi: 10.1007/s11356-017-0813-5

Suriawira, U. 2005. *Basic Microbiology* (in Indonesian). Jakarta: Papas Sinar Sinanti.

Suseela MR, Sinha S, Singh S, Saxena R. 2002. Accumulation of chromium and scanning electron microscopic studies in *Scirpus lacustris* L. treated with metal and tannery effluent. *Bull Environ Contam Toxicol* 68(4): 540-8. doi: 10.1007/s001280288

Tangahu BV, Putri AP. 2017. The degradation of BOD And COD of batik industry wastewater using *Egeria densa* and *Salvinia molesta*. *Jurnal Sains dan Teknologi Lingkungan* 9(2): 82-91. doi: 10.20885/jstl.vol9.iss2.art2

Taufikurahman, T, Suryati A. (n.d.). Phytoremediation of chromium polluted water using water hyacinth (*Eichhornia crassipes* (Mart.) Solms), water lettuce (*Pistia stratiotes* L.) and water Hyysop (*Baccopa monnieri* L.). The 7th Basic Science International Conference (pp. 1-12). Malang: BaSIC.

Taufikurahman T, Rahmawati A, Ardiansyah MA, Ilhamsyah D, Rosanti S. 2020. Physiological strategies of *Eichhornia crassipes* (Mart.) Solms to tolerate Cr(VI) accumulation, compared to a sensitive species *Pistia stratiotes* L. *Jurnal Ilmu Lingkungan* 82-8. doi: 10.14710/jil.18.1.82-88

Tejada M, Garcia C, Gonzalez JL, Hernandez MT. 2006. Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. *Soil Biol Biochem* 38: 1413–21. doi: 10.1016/j.soilbio.2005.10.017

WHO. 1996: Total dissolved solids in drinking-water. Geneva: World Health Organization.

Wirosoedarmo R, Anugroho F, Mustaqiman AN, Amanah R, Gustinasari K. 2020. Phytoremediation of chrome in batik industry wastewater using *Cyperus haspan*. *Nanotechnol Environ Eng* 5(2): 1-7. doi: 10.1007/s41204-019-0064-4

Woldemichael D, Zewge F, Leta S. 2011. Potential of *E. crassipes* (*Eichhornia crassipes*) for the removal of chromium from tannery effluent in constructed pondsystem. *Ethip J Sci.* 34(1): 49-62.

Ye-Tao T, Qiu RL, Zeng XW, Ying RR, Yu FM, Zhou XY. 2009. Lead, zinc, cadmium hyperaccumulation and growth stimulation in *Arabis paniculata* Franch. *Environ Exp Bot* 66: 126–34. doi: 10.1016/j.envexpbot.2008.12.016

Zayed AM, Terry N. 2003. Chromium in the environment: factors affecting biological remediation. *Plant Soil* 249(1): 139-56. doi: 10.1023/A:1022504826342

ZhiGang L, LiMin M, XueGin W, SuLi L, He L, ZhengWen L. 2009. Effects of low concentrations of heavy metal Cr(VI) on physiological and biochemical characteristics of *Pennisetum purpureum* Schum. *Guangxi Agr Sci* 40(5): 478-82. doi: 10.3390/plants8110515