Article

Phytoremediation Potential of Freshwater Macrophytes for Treating Dye-Containing Wastewater

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Abstract: Phytoremediation is a promising green technology for the remediation of various industrial effluents. Notably, aquatic plants are widely applied to remove dyes and toxic metals from polluted environments. In the present study, the phytoremediation potency of aquatic macrophytes such as *Pistia stratiotes* L., *Salvinia adnata* Desv., and *Hydrilla verticillata* (L.f) Royle were assessed based on the removal capability of pollutants from dyeing effluent. Physicochemical characterizations were carried out for industrial wastewater collected from a cotton material dyeing unit located in the Karur District of Tamilnadu, India. The physicochemical characteristics of the dyeing effluent, such as color, odor, pH, total dissolved solids (TDS), alkalinity, acidity, chloride, sulfate, phosphate, nitrate, chemical oxygen demand (COD), fluoride, and toxic metal levels were determined. The core parameters such as total dissolved solid (TDS), chemical oxygen demand (COD), and chloride level were determined and found to be 6500 mg/L, 2400 mg/L, and 2050 mg/L, respectively, which exceeded the regulatory limit prescribed by the Central Pollution Control Board of India. The levels of toxic metals such as Hg, Ni, and Zn were under the acceptable concentration but Cr and Pb levels in the dyeing effluent were a little bit higher. The effluent was subjected to treatment with *Pistia stratiotes* L., *Salvinia adnata* Desv. and *Hydrilla verticillata* (L.f) Royle separately. After the treatment, the toxic metal results were recorded as below detectable levels and the same results were obtained for all three aquatic plants samples used for treatment. Among the three plants, *P. stratiotes* L. efficiently removed 86% of color, 66% of TDS, 77% of COD, and 61.33% of chloride. The variation in phytochemicals of the macrophytes was studied before and after treatment using GC–MS which revealed the reduction of ascorbic acid in the plant samples. The toxic effect of treated effluent was investigated by irrigating an ornamental plant, *Impatiens balsamina* L. The plant biomass *P. stratiotes* L. obtained after the treatment process was subjected to manure production and its nutrient quality was proved, which can be applied as a soil conditioner. Among the aquatic plants, the results of *P. stratiotes* L. indicated a higher remediation potential, which can be used as an ecologically benign method for treatment of industrial effluents and water bodies contaminated with dyeing effluents.

Keywords: dye effluent; *Pistia stratiotes* L., phytoremediation; GC–MS; compost analysis

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1. Introduction

Water is considered as an important natural resource required for the growth and survival of all living organisms in the biosphere. The blooming of various industries, the human population explosion, and changes in climatic conditions and anthropogenic activities have led to the pollution and deterioration of the environment [1–3]. Textile industries are contributing to the enhancement of the economy in developed and developing countries [4]. In addition to this, these industries have been implicated as a producer of environmental pollution by utilizing and releasing a huge quantity of wastewater into the soil and into water bodies [5,6]. The wastewater of textile and bleaching industries is characterized by higher levels of toxic dye stuffs, chemical oxygen demand, total suspended solids, chloride, and carbonates [7].

The remediation of dye-containing wastewater is carried out by various physical and chemical techniques including reverse osmosis, filtration, adsorption, coagulation, electrocoagulation, flocculation, and oxidation. [8]. Most of these techniques are expensive, ineffective in the removal of certain pollutants, produce secondary pollution, and cause high sludge production [9,10]. Recently, effective biological approaches have been adopted for industrial effluent treatment along with methods to overcome the demerits of usual techniques.

Phytoremediation is an emerging, ecologically benign, reliable, inexpensive, aesthetically valued, and green approach that applies plants for the treatment of diverse industrial effluents as well as contaminated soil [11]. Naturally, plants are involved in some specific enzymatic pathways to degrade complex compounds to non-toxic compounds which reduce the pollution effect of contaminated areas [12]. Plants uptake the pollutants present in the contaminated environment through the root system and facilitate detoxification or degradation and/or accumulate pollutants via various plant mechanisms such as phytoextraction, rhizofiltration, phytostabilization, phytotransformation, rhizodegradation, and the phytovolatilization process [1,13,14]. Aquatic plants are widely used for the remediation of dyeing effluent due to their rapid growth, higher yield of plant biomass, and potency in the accumulation of nutrients and/or pollutants and toxic tolerant capability [15,16]. *Eichhornia crassipes* [17], *Salvinia molesta* [10], *Salvinia cucullata* [18], *Lemna minor* [19], *Pistia stratiotes* [15], and *Chara vulgaris* [6] are the water plants widely used for the treatment of wastewater.

The present study aimed to investigate the phytoremediation of dye-containing wastewater collected from the cotton dyeing industry using aquatic plants including *Pistia stratiotes* L, *Salvinia adnata* Desv, and *Hydrilla verticillata* (L.f) Royle. The reusability of the treated effluent and manure production from the obtained biomass was also evaluated. Methanolic extracts of aquatic plants were obtained and analyzed for their phytochemical content before and after treatments using gas chromatography–mass spectrometry (GC–MS).

2. Materials and Methods

2.1. Wastewater Collection and Characterization

The dyeing effluent sample was collected from the effluent treatment system of an ordinary cotton material dyeing industry located in the Karur district of Tamilnadu, India. The physicochemical parameters such as color, odor, pH, total dissolved solids (TDS), alkalinity, acidity, chloride, sulfate, phosphate, nitrate, chemical oxygen demand (COD), and fluoride were determined according to the standard protocol of APHA (American Public Health Association) [20]. Toxic metals such as mercury, lead, zinc, nickel, and chromium were analyzed by atomic absorption spectroscopy (Perkin-Elmer model 3110, Waltham, MA, USA).

2.2. Collection and Authentication of Aquatic Plants

Pistia stratiotes L (family: *Araceae*; common name: water lettuce), *Salvinia adnata* Desv (family: *Salviniaceae*; common name: water fern), and *Hydrilla verticillata* (L.f) Royle (family: *Hydrocharitaceae*; common name: water thyme) (Figure 1) were collected from freshwater

without the influence of dyeing effluent. The collected plants were authenticated by the botanical survey of India, Southern Regional Centre (TNAU campus, Lawley Road, Coimbatore, Tamilnadu, India) (Ref. No.: BSI/SRC/5/23/2017/Tech.2837).

Figure 1. Aquatic macrophytes were used in this study.

2.3. Experimental Setup for Phytoremediation

For the phytoremediation process, the plants were washed thoroughly with tap water and distilled water to remove dirt. The acclimatization was done in laboratory conditions with tap water only for 20 days. The alkaline nature of the effluent leads to the death of macrophytes. Hence, the pH was neutralized to 7.2 using acetic acid (1%) for further treatment processing. After the neutralization of pH, the aquatic macrophytes such as *P. stratiotes* L., *S. adnata* Desv., and *H. verticillata* (L.f) Royle were grown for evaluation of pollutant removal potential. Approximately 250 g of each plant was introduced into glass tanks containing 5 L of dyeing wastewater, separately. The effluent without plant was maintained as a control. The reduction of core parameters such as TDS, COD, and chloride were analyzed for treated effluent [20]. The toxic metals such as Pb and Cr were analyzed by AAS (Atomic Absorption Spectroscopy) after digestion of plant materials by the acid method using nitric acid and hydrogen peroxide digestion. In order to stabilize the tissue and to stop the enzymatic reactions, the plant samples were washed in deionized water, dried at 80 °C for 24 h, and then powdered. Later they were digested with nitric acid followed by hydrogen peroxide in a repeated heating process [21]. The methanolic extracts of all three varieties of aquatic plants were prepared using Soxhlet apparatus and phytochemical constituents were analyzed by gas chromatography–mass spectroscopy (GC–MS System; Agilent Technologies, CA, USA). The phytoconstituents were identified using NIST and Wiley databases. The decolorization efficacy of aquatic plants was determined by a UV-visible spectrophotometer (Elico Serial No. 218) based on the intensity of color at the wavelength of 540 nm observed before and after the phytoremediation process. All experiments were carried out in triplicate.

2.4. Reusability of Phytoremediated Effluent

The reusability of treated effluent was assessed by growing an ornamental plant named *Impatiens balsamina* L (family: *Balsaminaceae*). The experiments were conducted in Kodaikanal during the months of July–September under uniform conditions of light intensity, photoperiod, and temperature. An equal amount of soil was placed in three containers. All containers were maintained in an open air environment. Two sets of experiments were conducted. The healthy seeds of the *Impatiens balsamina* L were procured from a local market. The seeds were surface sterilized with 0.1% HgCl_2 and allowed to grow in three sets of containers. The first set was maintained as control which was irrigated with clean (tap) water every day. The second one was irrigated with *P. stratiotes* L-treated dyeing effluent regularly (DI, daily irrigation). The third set was alternatively flooded with tap water and *P. stratiotes* L-treated effluent (ADI, alternative day irrigation/first day irrigated with tap water second day irrigated with treated effluent, third day tap water, and likewise). The irrigation was done every morning at 8.30 am. The mean length of root, shoot, leaf, and number of flowers of 65-day-old plants were determined. An ANOVA calculation was done for the growth parameters of the control plant, ADI, and DI. The

difference between the control plant and treated effluent irrigated plants was confirmed using an ANOVA test (IBM SPSS Version 20 package).

2.5. Manure Production Using Plant Biomass

The plant biomass obtained after the phytoremediation process was utilized for manure production. In total, four compost sets were carried out with different proportions of plant biomass with cow dung, agriculture waste, and filter papers used for filtration purposes. *Pistia stratiotes* L plant after phytoremediation was subjected to composting process with two different combinations including Set A (cow dung and *P. stratiotes* L biomass and agricultural waste in the ratio 1:2:1), Set B (cow dung, *Pistia stratiotes* L biomass and used filter papers 1:1:1), Set C (only cow dung), and Control (only *Pistia stratiotes* L biomass). These sets were allowed to undergo aerobic digestion and their moisture levels were maintained by a frequent sprinkling of water during the process. Furthermore, thorough mixing of the contents was done regularly. The physicochemical characteristics such as color, odor, pH, moisture content, organic carbon, nitrogen, phosphorous, potassium, iron, and copper content in decomposed matter of the compost sets were analyzed. The manure value of the processed compost was investigated using a standard procedure [22].

3. Results and Discussion

3.1. Wastewater Characterization

The physical and chemical characteristics of cotton dyeing wastewater are given in Table 1. The color of the effluent was dark reddish due to the application of reactive red dyes for the dyeing process. The odor of wastewater was unpleasant. The TDS were determined to be 6500 mg/L. The pH of the wastewater sample indicated quite high alkalinity (pH 10.5). The disposal of highly concentrated dye-containing wastewater characterized with an elevated level of dissolved solids into the aquatic ecosystem prevents the penetration of sunlight which affects the photosynthetic process of aquatic vegetation as well as impeding the re-oxygenation potential of receiving water bodies [23]. The visible dye contaminants in the water resources reduce its aesthetic value and cause harmful effects such as allergy, cancer, and teratogenic effects in humans [24]. The total hardness, alkalinity, and COD of the wastewater were much higher than the regulatory level. Notably, the COD value is the typical factor for evaluating the quality of a water sample. Common anions in waters such as chloride, fluoride, phosphate, sulfate, and nitrate existed in the wastewater at a relatively high concentration. Nitrate and phosphate at a high level in wastewater can damage ecosystems by causing eutrophication [25]. Five representative toxic metals including Hg, Ni, Zn, Pb, and Cr were slightly higher than the standard limit recommended by the Central Pollution Control Board of India (CPCB). The other metals were below the standard limit and below the detectable level. [26].

3.2. Phytoremediation Potency of Aquatic Plants

The phytoremediation potency of three aquatic macrophytes is illustrated in Figures 2 and 3, and the removal efficiency is summarized in Table 2. In the initial test, the aquatic plants wilted immediately due to the alkaline nature of the dye effluent, which was also explained previously. Therefore, the effluent was neutralized using 1% acetic acid which might also act as an enhancer for efficient treatment. After 48 h of incubating with aquatic plants, a color reduction in the wastewater was observed. However, the plants started to decay after the extension of treatment up to 72 h due to the uptake of contaminants and color (data not shown).

Table 1. Physicochemical and heavy metal analysis of cotton dyeing effluent.

Parameters	Results	Regulatory Level *
Color	Dark red	Colorless
Odor	Unpleasant	Odorless
pH	10.5	5.5–9.0
TDS	6500	2100
Total hardness	280	100
Alkalinity	910	200
Acidity	230	-
COD	2400	250–400
Chloride	2050	600–1000
Fluoride	1.84	1.0
Phosphate	6.4	-
Sulphate	750	1000
Nitrate	90	45
Lead	0.014	0.01
Mercury	BDL **	0.001
Nickel	BDL **	0.02
Zinc	0.034	5
Chromium	0.078	0.05

All the values are expressed as mg/L except color, odor, and pH. * Acceptable level was regulated by the Central Pollution Control Board of India (CPCB). ** BDL: below detectable level.

Figure 2. Removal percentage of pollutants from the effluent by aquatic macrophytes.

Figure 3. Decolorization of effluent by aquatic macrophytes.

Table 2. Effect of aquatic macrophytes on the removal of color, TDS (total dissolved solids), COD (chemical oxygen demand), and chloride from cotton dyeing effluent.

Aquatic Macrophytes	Pollutants Reduction after Treatment (48 h) (mg/L)				Heavy Metal in Treated Effluent and Used Plant Samples	
	Color *	TDS	COD	Chloride	Pb	Cr
Control	Colorless	6500	2400	2050	0.014	0.078
<i>Pistia stratiotes</i> L **	86 ± 3.202	4290	1848	1250.5	BDL	BDL
<i>Salvinia adnata</i> Desv **	82 ± 2.22	4030	1632	1209.5	BDL	BDL
<i>H. verticillata</i> (L.f) Royle **	73 ± 4.36	3835	1512	1148.5	BDL	BDL

* Color expressed in %. ** The Pb and Cr levels of used plant samples were BDL.

The obtained results indicated that a removal efficiency higher than 50% was achieved for color, TDS, COD, and chloride after 48 h of treatment by the three plants. Among the three plants, *Pistia stratiotes* L showed the best performance for the removal of color, chloride, TDS, and COD, whereas *H. verticillata* (L.f) Royle exhibited the lowest removal efficiency (Figure 2). The TDS, COD and chloride level of *Pistia stratiotes* L-treated dyeing effluent were found to be 4290 mg/L, 1848 mg/L, and 1250.5 mg/L, respectively. The values of toxic metals, Pb, and Cr of treated effluent and plant samples used for treatment were found to be below the detectable level (Table 2). Among the four environmental factors investigated during the phytoremediation, color was removed more efficiently than other factors such as TDS, COD, and chloride. A color removal efficiency of 73–86% was achieved after 48 hr of treatment by the three plants (Figure 3). Chloride seemed to be removed less than other parameters. Only 56–61.33% of chloride was removed at the end of incubation of all plants. The pH of the effluent was neutralized before subjecting it to phytoremediation. After treatment, there was no significant change in pH observed. Similarly, the maximum decolorization potential of *Eichhornia* sp. in textile effluent was recorded by Anjana and Thanga [27]. *P. stratiotes* L was reported as an effective hyperaccumulator and could

uptake the contaminants as well as nutrients through rhizofiltration mechanism and was utilized for growth, which resulted in a high biomass production [28]. In this study, the accumulation of dye stuffs was observed in the roots and leaves of *P. stratiotes* L and *S. adnata* Desv plants (Figure 4). Anuradha et al. [29] stated that plant peroxidase is involved in the deterioration of textile dye substances. Ugya et al. [30] have reported the TDS- and TSS-reducing efficiency of *P. stratiotes* form textile wastewater. Ng et al. [31] achieved 39% of COD and 95% of phosphate removal from palm oil mill effluent using *Salvinia molesta*. Likewise, Chandanshive et al. [10] reported the Rubine GFL dye decolourizing efficiency of *Salvinia molesta* D.C Mitch through the activation of oxidoreductase (azo-reductase, lacase, and catalase) and peroxidase enzymes. The phenolic compounds of plants were chiefly involved in the antioxidant activity during physiological stress that occurs in plants [32,33]. Xue and Yan [34] proved the arsenic-removal capability of *H. verticillata* (L.f) Royle through the phytoaccumulation and phytofiltration mechanism, by immobilizing arsenic in plant shoots. In the same pathway, *P. stratiotes* L might eliminate the pollutants from the dyeing effluent. Fonkou et al. [35] studied the efficiency of *P. stratiotes* L to remove suspended solids, sulfates, phosphates, and turbidity from the wastewater. Al-Baldawi et al. [36] reported the methyl orange dye removal efficiency of *Salvinia molesta* and its FTIR test also confirmed the phytotransformation of methyl orange.

Dye Accumulation by in *P.Stratiotes* L and *S.adnata* Desv

Figure 4. Accumulation of dyes in *P. stratiotes* L and *S. adnata* Desv.

3.3. GC–MS Analysis of Aquatic Plants before and after Phytoremediation

The methanolic extract of total aquatic plants before and after testing was measured using GC–MS analysis and the GC–MS patterns showed various peaks corresponding to many phytochemicals. The methanolic extract of *P. stratiotes* L showed nine peaks indicating the presence of phytochemicals including 14-methyl-8-hexadecen-1-ol, pentadecanol, 9-eicosyne, oxirane, cyclodecanol, pentadecanoic acid, hexadecanoic acid, L-ascorbic acid, 11, 14, 17-eicostrienoic acid and stigmasterol (Figure 5a and Supplementary Table S1). The existence of hexadecanoic acid in the methanolic extract of *Pistia stratiotes* L and the antioxidant activity of this compound was noted by Tyagi and Agarwal [37]. The GC–MS pattern of treated *Pistia stratiotes* L showed the occurrence of hexadecyne, pentadecanol, cyclodecanol, hexadecanoic acid, tetradecanoic acid, and oleic acid (Figure 5b and Supplementary Table S2). After phytoremediation, the absence of L-ascorbic acid was observed in the extract of *Pistia stratiotes* L. It could be concluded that the antioxidant compounds might bind with contaminants and reduce the pollutants from the effluent. The phytochemical compounds in *Salvinia adnata* Desv extract were found to be pentadecanol, oleyl alcohol, L-ascorbic acid, tridecanoic acid, oleic acid, erucic acid, 1-naphthalene anthracene, and phenanthrene. The phytochemicals were determined based on the library search of observed peaks (Figure 5c and Supplementary Table S3). In the extract of *Salvinia adnata* Desv after phytoremediation, nonanoic acid, undecanoic acid, cyclopent-

tane, tridecene, 4-n-butylthiane, 2-isopropyl, tetradecanoic acid, and stigmasterol-5 were observed (Figure 5d and Supplementary Table S4).

Figure 5. GC–MS chromatogram of *Pistia stratiotes* L (a,b), *Salvinia adnata* Desv (c,d) and *Hydrilla verticillata* (e,f) before and after phytoremediation.

The phytocompounds including 6-methyl-cyclodec-5-enol, 6-caranol, oxirane, oleyl alcohol, ascorbic acid, phytol-2-hexadecen, and 7-tetradecenal were found in the methanolic extract of *Hydrilla verticillata* (L.f) Royle (Figure 5e and Supplementary Table S5). In the extract of *H. verticillata* (L.f) Royle after phytoremediation, the disappearance of some peaks was observed. The detected phytocompounds in the extract of *H. verticillata* (L.f) Royle after phytoremediation include tetradecanoic acid, phytol, octadecatrienoic acid, oleic acid, and stigma sterol (Figure 5f and Supplementary Table S6). The decline in the level of some metabolites after treatment with plants might have contributed to improved tolerance in the plants. The alcoholic extracts of the three plants used for treatment showed the absence of ascorbic acid. Ascorbic acid can be deemed as a potential candidate for the removal of Pb and Zn from soil [38]. Ascorbic acid is a well-known antioxidant that might have been involved in the degradation of color molecules and substances found in dye effluent.

3.4. Reusability of Phytoremediated Effluent

The reusability of phytoremediated effluent was assessed by using it for irrigation purposes for the growth of the ornamental plant *Impatiens balsamina* L (balsam), because most of the partially treated dyeing industry effluents are directly utilized for agriculture purposes [39]. Because the maximum treatment efficiency was obtained by *P. stratiotes* L,

its treated effluent was utilized for a reusability study. The shoot length, root length, the number of flowers, leaf length, fresh weight, and dry weight were determined. The plant irrigated with phytoremediated effluent showed fine growth and the total length of the plant was found to be 107 cm, leaf length was 10 cm, and root length was 8–10 cm. The number of flowers was found to be 15–20. The normal growth of *Impatiens balsamina* L proves the reduction of the toxic level of the dyeing effluent after the phytoremediation treatment (Table 3). Similarly, Shanmugam et al. [40] studied the effect of textile effluents phytoremediated with *Bacopa monnieri* plant on the seed germination, growth, shoot and root length of oilseeds and cereal plants. They also reported that the presence of antioxidative and oxidative enzymes in roots and leaves are involved in the degradation of dyes. The effect of treated textile effluent on the growth of plants such as *P. mungo*, *V. mungo* [41], wheat cultivar [42], peanut [43], and *Sorghum vulgare* [44] has also been investigated previously. The effect of treated dyeing effluent on the growth of the *Impatiens balsamina* L plant was statistically proved by ANOVA calculation and showed 0.05% significance; the null hypothesis was accepted, in that there was no significant difference between the control plant and the alternative day irrigated (ADI) balsam plant (Table 4). Thus, the present result concluded that a reduction in toxicity of fabric dyeing effluent using eco-friendly phytoremediation techniques is possible.

Table 3. Effect of treated effluent on the growth parameters of *Impatiens balsamina* L plant.

Growth Parameters	Control	Daily Irrigation	Alternative Day Irrigation
Height	107 ± 0.33 ^a	96 ± 0.5 ^a	101 ± 0.5 ^a
Root length	10 ± 0.44 ^b	8 ± 0.44 ^b	9 ± 0.15 ^b
Shoot length	97 ± 0.30 ^c	88 ± 0.51 ^c	92 ± 0.47 ^c
Leaf length	11 ± 0.15 ^d	10 ± 0.18 ^d	10 ± 0.28 ^d
Number of Flowers	22 ^e	13 ^e	20 ^e

Superscript letters indicate the statistical significance.

Table 4. Statistical analysis (ANOVA).

	Source of Variance	Sum of the Squares	Degrees of Freedom	Mean Squares	F-Ratio	Calculated <i>p</i> -Value	Level of Significance
Control and Daily irrigation	Between groups	102.4	1	102.4	9.84615	0.03492	<i>p</i> > 0.05 Significant
	Within groups	17,409.2	8	2176.15			
Control and Alternative Day Irrigation	Between groups	22.5	1	22.5	8.18182	0.045912	<i>p</i> > 0.05 Significant
	Within groups	17,842.4	8	2230.3			

3.5. Reuse of Plant Biomass for Manure Production

Pistia stratiotes L plant after phytoremediation was subjected to composting process with two different combinations including Set A, Set B, Set C (only cow dung), and Control (only *Pistia stratiotes* L biomass). The compost nutrient quality of all sets is given in Table 5.

The pH of all composts is comparable, but the compost of only *Pistia stratiotes* L biomass is slightly lower than others. Nitrogen and potassium content in the compost of only *Pistia stratiotes* L biomass was much higher than other composts while its phosphorus content was much lower than others. The organic carbon content of the compost of only *Pistia stratiotes* L biomass was the highest whereas its moisture content was the lowest. Iron and copper were not detected in the compost of only *Pistia stratiotes* L biomass. The level

of NPK (Nitrogen, phosphorus, potassium) indicated that the compost maturity of Set B was optimal.

Table 5. The manure value analysis of composts.

	Set A	Set B	Set C	Control
Color	Brownish black	Brownish black	Brown	Brown
Odor	Earthy	Earthy	Earthy	-
pH	8.64	8.42	8.41	8.20
Nitrogen	1.01%	1.12%	0.97%	2.71%
Phosphorus	0.23%	0.23%	0.23%	0.03%
Potassium	0.68%	0.72%	0.58%	2.62%
Organic Carbon	14.10%	11.70%	8.70%	31.40%
Moisture content	33.7%	24.0%	22.1%	9.80%
Iron	3121 ppm	3335 ppm	2230 ppm	-
Copper	23.5 ppm	23.5 ppm	21.0 ppm	-
C/N	14.5:1	10.4:1	8.6:1	11.6:1

The carbon to nitrogen ratio of the compost was also another factor used to confirm the maturity of the composting process. The C:N ratio of Set A (cow dung and *P. stratiotes* L biomass and agricultural waste in the ratio 1:2:1) was the highest (14.5:1), followed by that of the control (only *Pistia stratiotes* L biomass). The lowest C:N ratio was observed in the composting of Set C (only cow dung). Vasanthy et al. [17] prepared manure using treated aquatic plants and analyzed total nitrogen, organic carbon, and total phosphorous content in their samples. The compost maturity was confirmed based on the C:N ratio after the composting process. Decomposition of the plant material with cow dung to compost may occur through the activity of thermophilic microorganisms. During the decomposition process, the carbon content in the sample converted into CO₂, and the nitrogen level was elevated when the protein-rich compounds cleaved the nitrogen-containing compounds to ammonia and other byproducts [45]. Shukla et al. [46] reported the preparation of compost using tannery effluent treated with aquatic plant *Vallisneria spiralis* L biomass.

4. Conclusions

The present study revealed the phytoremediation potential of *Pistia stratiotes* L, *Salvinia adnata* Desv, and *Hydrilla verticillata* (L.f) Royle. Among these three aquatic plants, *P. stratiotes* L effectively reduced contaminants from the dyeing effluent without any change of pH. The GC–MS analysis confirmed the changes in the phytochemical content, especially for ascorbic acid in the aquatic plants before and after the phytoremediation process. The reusability and detoxification of the treated effluent were confirmed based on the growth of *I. balsamina* L plant. The biomass obtained after treatment was used for compost production. The composting of cow dung and *P. stratiotes* L biomass and agricultural waste in the ratio 1:2:1 showed a higher content of nutrients than the other three composting sets. This study suggested the phytoremediation potential of *P. stratiotes* L which served as a sustainable approach for dyeing wastewater treatment. The plant biomass and liquid produced after the treatment process were recycled and used for composting and ornamental plant irrigation, which indicated a promising process for zero-waste discharge from dyeing industries. The utilization of *P. stratiotes* L for the treatment of dyeing industry wastewater may help to grow more plants and commercialize the plant products for these purposes, and this could be an efficient alternative method for wastewater treatment. The concept of reusing treated industrial effluent is one of the vital points in modern industry. The reuse of industrial effluent for irrigation and for industrial purposes provides major benefits in conserving water resources and preventing water scarcity issues.

Supplementary Materials: The following are available online at <https://www.mdpi.com/2071-1050/13/1/329/s1>, Table S1: GC–MS analysis of *P. stratiotes* L before treatment, Table S2: GC–MS analysis of *P. stratiotes* L after treatment, Table S3: GC–MS analysis of *Salvinia adnata* Desv before treatment, Table S4: GC–MS analysis of *Salvinia adnata* Desv after treatment, Table S5: GC–MS analysis of *Hydrilla verticillata* (L.f) Royle before treatment, Table S6: GC–MS analysis of *Hydrilla verticillata* (L.f) Royle after treatment.

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