Screening of plant species for phytoremediation of synthetic textile dye wastewater

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Abstract

Most of the dyes are carcinogenic and mutagenic in nature. Plants are potential candidates to remediate textile dye wastewater from contaminated sites. The present study aimed to screen potential plant species for removal of synthetic dye solution of triarylmethane dye Methylene Blue (MB) and diazo dye Congo Red (CR). The six plants selected for screening are *Trachyspermum ammi* (*T. ammi*), *Tagetes erecta* (*T. erecta*), *Hibiscus rosa-sinensis* (*H. rosa-sinensis*), *Chrysanthemum indicum* (*C. indicum*), *Bryophyllum fedtschenkoi* (*B. fedtschenkoi*), and *Catharanthus roseus* (*C. roseus*). The phytotreatment of dyes was done up to 40 h for two different concentrations of dyes i.e. 10 and 20 mg L⁻¹. Among screened plant species, the maximum decolorization was obtained from *T. ammi* followed by *B. fedtschenkoi*. Both of these plant species showed active growth even after the phytoremediation process. *T. ammi* decolorized the MB dye 99% (10 mg L⁻¹) and 86% (20 mg L⁻¹) while the decolorization of the CR dye solution was up to 95% (10 mg L⁻¹) and 84% (20 mg L⁻¹). *T. ammi* found to have maximum potential among screened plants for the removal of MB and CR dye from synthetic dye solution and can be used for phytoremediation of wastewater contaminated with synthetic dyes.

Introduction

Due to the increasing world population, there is a tremendous growth of various industries, which uses many harmful chemicals for the generation of a commodity for public demands but the side products such as contaminants not only affect water bodies but also the air and soil. Dyes have a major demand and application in the textile industries for the dyeing process. About 10-15% of the azo dyes get lost in the effluent during the dyeing process [1] and 50% other reactive dyes reported for use in the textile industry which throw waste into water [2]. Azo dyes are extensively used in the dyeing process. The effluent containing dyes released into the surrounding thereby seriously affecting the atmosphere by destroying the ecosystem, causing water pollution, and reducing light penetration for aquatic life [3]. Due to textile dye wastewater, the Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), suspended solid values enhance for river water in the nearest river located besides the textile industry [4]. So, there is a big challenge to treat textile dyes effluent before released into water bodies.

There are so many physical and chemical methods, for example, adsorption, coagulation, sedimentation, flocculation, filtration, photodegradation, and chemical oxidation, are accessible for managing contamination produced by textile dyes [5, 6]. These methods relate to the high expense, low productivity, require huge space and undependable to work. Because of these issues, there is a requirement of the advancement of productive and cost-effective method for the treatment of textile dyes [6]. Biological methods are more effective than physical and chemical methods to treat the textile dye wastewater. Biological methods involve different enzymes, microorganism and plants for removal of dyes from wastewater [7-9]. From the different biological methods, plants-based phytoremediation is an energy-efficient, solar-driven process to remove the contaminants from soil, air and water [6, 9]. Phytoremediation is also used to remove pollutants from textile dye wastewater. There are various phytoremediation mechanisms as phytoextraction, phytodegradation, rhizofiltration, phytostabilization, phytovolatilization which helps in the dye removal [10]. Due to these different processes, plants are used for the treatment of textile dye wastewater.

There are many studies reported in literature on the use of aquatic plant species for the phytoremediation of dye wastewater such as *Ipomoea aquatic* [11], *Salvinia molesta* [12, 13], *Typha angustifolia* [14], *Chara vulgaris* [15-17], *Eichhornia Crassipes* [18], *Lemna minor* [3, 19], *Azolla pinnata* [20], *Pistia stratiotes* [21], but still very few reports available on phytoremediation textile dye wastewater using ornamental plants. The *Petunia grandiflora* which is a flowering ornamental plant species reported for its potential to remove the triphenylmethane textile dye Brilliant Blue G [22]. *Aster amellus*, a herbaceous plant species used to decolorize a sulfonated azo dye Remazol Red (RR), a mixture of dyes and a textile effluent [23]. *Glandularia pulchella* explored to decolorize the dye green HE4B [24] and *Ipomoea hederifolia* ornamental plant able to decolorize the dye mixtures and scarlet red dye [25]. *Alcea rosea* plant has the potential to remove disperse red 60 and reactive blue 19 dye [26]. The researchers also explored the phytoremediation potential of *Portulaca grandiflora* [27], *Blumea malcolmii* [28], *Typhonium flagelliforme* [29] etc for dye degradation in aqueous form. There is no research work based on textile dye removal by *Trachyspermum ammi* (*T. ammi*), *Tagetes erecta* (*T. erecta*), *Hibiscus rosa-sinensis* (*H. rosa-sinensis*), *Chrysanthemum indicum* (*C. indicum*), *Bryophyllum fedtschenkoi* (*B. fedtschenkoi*), *Catharanthus roseus* (*C. roseus*). In literature, these plant species reported for their potential of heavy metal remediation in different studies [30-37] where these plants have an efficient root system and plants do not affect the food chain. Due to less explore of these ornamental plants for dyes removal, this research study focussed the ability of screened plants for decolorization of Methylene Blue and Congo Red dyes.

Material And Method

Chemicals and plant material

The triarylmethane dye (Methylene Blue) and a diazo dye (Congo Red) dye used for experimentation. Methylene Blue (MB) is a heterocyclic aromatic chemical compound with molecular formula $C_{16}H_{18}N_3SCl$. The molecular weight of MB dye is $319.85 \text{ g mol}^{-1}$. Congo Red (CR) dye is a diazo dye can be synthesized by a coupling reaction containing hydroxyl, amino or other groups with an aromatic diazotized base. The chemical formula of CR dye is $C_{32}H_{22}N_6Na_2O_6S_2$ and molecular weight is 696 g mol^{-1} . The chemical structure of MB and CR is given in Fig. 1. MB dye and CR dyes were purchased from Sanjay lab Amritsar, India. All the chemicals were used of the highest purity and of an analytical grade on the market. The synthetic wastewater was prepared with the help of MB and CR dye with two different concentrations as 10 mg L^{-1} and 20 mg L^{-1} . The whole apparatus was sterilized before experimentation. Screened ornamental plants *T. ammi*, *T. erecta*, *H.rosa-sinensis*, *C. indicum*, *B. fedtschenkoi*, *C. roseus* were harvested from the Botanical garden of Guru Nanak Dev University campus, Sathiala and Government High School, Sathiala (Punjab), India. The plants were washed completely to remove mud, dirt and particulate matters and acclimatized for three days in distilled water. Table 1 shows the description of screened plants used for the research study.

Experimental design

Initial experiments were performed to identify the plants having the potential to decolorize the textile dyes, for which *T. ammi*, *T. erecta*, *H.rosa-sinensis*, *C. indicum*, *B. fedtschenkoi*, and *C. roseus* plants were selected. Firstly, the roots of these plants were washed with running tap water to remove adherent soil after which plants were entirely washed with distilled water. Plants were put into distilled water for hydroponic treatment (without soil) and the growth of the plants is checked in to water up to three days. The treatment of selected plants was done after the acclimatization period of three days with 10 and 20 mg L^{-1} concentrations of both dye solution. The beakers of 250 mL capacity were used as batch reactors for the phytoremediation process, and each was filled with 100 mL of synthetic dye solution. The acclimatized plants were transferred to prepared dye solutions of different concentrations. Both biotic and abiotic controls were also maintained as shown in Fig. 2. The abiotic controls contained the MB and CR dye solution without plants whereas plants in distilled water were kept as biotic controls. The decolorization was noticed up to 40 h ($0, 8, 16, 24, 32$, and 40 h). The absorbance of each solution was determined with the help of UV-Visible spectroscopy at its respective absorption maxima (as mentioned in Table 1) using Systronic-2202 UV-visible double beam spectrophotometer. The percentage decolorization was calculated as per equation [20]:

$$\text{Decolorization (\%)} = \frac{A_0 - A_1}{A_0} \times 100$$

Where A_0 is an initial concentration of dye and A_1 is a final concentration of dye. Each batch of dye concentration and screened plants had triplicates for each biological sample for obtaining concordant result. The data was analyzed by using MS-excel 2007 windows.

Results And Discussion

The decolorization results of each plant were compared with the abiotic and biotic control dye solution. The roots of plants were found to have dye pigmentation in comparison to biotic control in physical examination. The results of different batch experiments for decolorization of dyes with respect to time were shown in Fig. 3. It has been observed from Fig 3. that the decolorization percentage of dye increases with increase in the time. The same pattern of dye decolorization has been reported in literature by various researchers [12-15, 19-20, 24]. For instance, the different dye concentrations green HE4B decolorize to varying extent during 48 h of contact period by *Glandularia pulchella* and maximum decolorization was observed at 48 h in each concentration [24]. All these decolorization results and impact of synthetic dye wastewater on growth of plant used for screening were summarized in Table 2.

Fig. 3 (a) and (b) shows the decolorization pattern of MB and CR dye by utilising *T. ammi* plant. Out of six screened plants, excellent decolorization of MB was observed in the case of *T. ammi* plant. The decolorization of 10 and 20 mg L^{-1} MB was 99 and 86% respectively. Plant growth was normal after adsorption of the dye into the roots. The decolorization (%) of CR dye by *T. ammi* shown in Fig. 3 (b) clearly indicates the admirable efficiency of *T. ammi* to decolorize the CR. The percentage decolorization of 10 and 20 mg L^{-1} of CR dye were 95 and 84% respectively. The plant remains survived after adsorption of dye into the roots. However, percentage decolorization decreases with increase in the concentration. These outcomes showed that *T. ammi* plant is an outstanding plant to decolorize the azo dye CR and triarylmethane dye MB at lower concentration. The decolorization graph of MB and CR dye by using *B. fedtschenkoi* plant was shown in the Fig. 3 (c) and (d) respectively. The plant *B. fedtschenkoi* shows significant decolorization of triarylmethane dye MB having percentage decolorization of 85% (10 mg L^{-1}) and 69% (20 mg L^{-1}). The response of *B. fedtschenkoi* plant towards the removal of a toxic azo dye, CR was also observed as significant for textile wastewater treatment. The *B. fedtschenkoi* decolorized the CR dye 77 and 70% for 10 and 20 mg L^{-1} dye concentrations respectively. It was observed that plant parts remained active after adsorption the dye and plant was able to remove

more dye concentration than 20 mg L⁻¹. These results proved that *B. fedtschenkoi* plant has good tendency to decolorize synthetic wastewater of CR azo dye as well as MB, triaryl methane dye.

Fig. 3 (e) and (f) showed the decolorization (%) graph of MB and CR respectively by using *C. indicum*. The percentage decolorization obtained for 10 and 20 mg L⁻¹ MB dye concentrations were 87 and 70 % respectively. Initially plant leaves becomes dried, later stems and roots of the plant also showed the dryness with the removal of dyes. The plant becomes died after treatment with more dye concentrations. However, the MB color expulsion by this plant was acceptable yet plant endurance was not significant for treatment of triarylmethane dye, MB. The results with CR dye synthetic wastewater revealed only 44 and 42% decolorization with the 10 and 20 mg L⁻¹ concentration respectively. Wilting of the plant takes place after treatment of CR dye. The plant was not able to treat with more dye concentration than 20 mg L⁻¹. Hence, *C. indicum* is not suitable for the phytotreatment of CR dye synthetic wastewater.

T. erecta plant was also used for a screening test to remove MB dye from synthetic wastewater. It was observed that plant had the more capacity to decolorize the triarylmethane dye, MB in comparison to CR dye. Fig. 3 (g) and (h) shows the decolorization (%) of MB and CR dye respectively. The decolorization for 10 and 20 mg L⁻¹ MB dye wastewater was 84 and 68% respectively. After decolorization the MB dye plant shows withering. Initially, the leaves become dry then subsequently stems and roots. Due to these conditions, plant was no more active for treatment with more MB dye concentrations than 20 mg L⁻¹. The percentage decolorization was observed 67 & 66 % for 10 and 20 mg L⁻¹ CR dye concentrations respectively. Though, plant was able to decolorize the azo dye, CR and MB but *T. erecta* plant dryness after removal of the toxic dye makes it unsuitable for the treatment of synthetic dye wastewater.

Fig. 3 (i) and (j) shows the decolorization of MB and CR respectively by *H. rosa-sinensis* plant. The decolorization obtained were 86 and 71% from the 10 and 20 mg L⁻¹ MB concentrations respectively and 41 and 39 % decolorization obtained from the 10 and 20 mg L⁻¹ CR dye solution. It indicated the potential of *H. rosa-sinensis* for MB synthetic dye wastewater decolorization. But the toxicity of dye affects on plant's growth and plant was unable to remove dye concentrations than 20 mg L⁻¹.

Fig. 3 (k) and (l) shows the percentage decolorization of MB and CR dye respectively by *C. roseus*. The decolorization percentage obtained for MR 10 and 20 mg L⁻¹ was 35 and 34 % respectively and 48 and 43% for CR 10 and 20 mg L⁻¹ respectively. In case of *C. roseus* plant, it was found that plant remain active after dye removal however plant removal rate is quite slow for both the dyes. It was observed that plant could not effectively decolorize the synthetic wastewater up to 40 h.

Hence, the results obtained from the screening experiments clearly indicate that the maximum percentage decolorization obtained from the *T. ammi* plant followed by *B. fedtschenkoi* and both the plant also remained active after removal the both MB and CR dyes. *C. indicum* and *T. erecta* plants also showed their potential for decolorization of synthetic dye wastewater however, their survival rate makes them insignificant for phytoremediation process. *H. rosa-sinensis* plant was also not considerable for survival because flowers withered after dye removal. The plant *C. roseus* able to bear the toxic impact of dyes but the rate of decolorization is quite slow for both MB and CR dyes.

In the literature, the removal of MB and CR was reported by a few researchers by using phytoremediation technique as shown in Table 3. *E. crassipes* successfully removed MB dye (50 mg L⁻¹) in 20 days experiment up to 98.4% [18] while *L. minor* (2 g) was exposed into 50 mg L⁻¹ of MB dyes for 24 h decolorize up to was 80.5% [3]. In another study, 98% decolorization has been reported for *L. minor* in 144 h for 10% concentration and claimed *L. minor* as a phytoremediation agent to remove MB dye from wastewater [19]. Another aquatic species *Azolla piñata* also reported in literature for removal of MB dye [20]. In literature, MB remediation reported by using aquatic plant species mostly. In the present research work, ornamental plant *T. ammi* plant showed the decolorization up to 99% (10 mg L⁻¹) and 86% (20 mg L⁻¹) for MB dye in 40 h experiment only. Hence, *T. ammi* plant proven to be more effective than *E. crassipes* and *L. minor*. Again, for phytoremediation of CR dye, *Chara vulgaris* [15] and *Pistia stratiotes* [21] aquatic species are reported for maximum decolorization 95 and 90% respectively. In present study, *T. ammi* reported for maximum decolorization up to 95 and 84% from the 10 and 20 mg L⁻¹ CR dye concentrations respectively and remain active after decolorization process. However, it has been observed that the maximum dye was found to adsorb on the roots of *T. ammi* plant and it is possibly due to rhizofiltration process, plant could able to give maximum decolorization. Therefore, *T. ammi* plant acts as potential candidate for future research where it can be used as phytoremediator for decolorization of dye wastewater.

Conclusion

The results from present research support the ability of six screened plants for removal of MB and CR dyes. *T. ammi* and *B. fedtschenkoi* are the most efficient plants for removal the both dyes. Moreover, survival of both the plants seems to be significant. Maximum percentage of decolorization obtained from the *T. ammi* plant as 99% (10 mg L⁻¹), 86% (20 mg L⁻¹) for MB dye and 95% (10 mg L⁻¹), 84% (20 mg L⁻¹) for CR dye might be due to maximum adsorption on the roots of the plant. Therefore further research work can be focus on the dye removal by

using *T. ammi* plant on the bases of adsorption mechanism. In future, adsorption mechanism explored by using different instrumental techniques such as Fourier Transform Infrared spectroscopy, Scanning Electron Microscopy etc. and statistical analysis can also be done with different operational parameters such as plants weights, relative growth rate (RGR) of plants, effect of pH etc.

Declarations

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Tables

Table1 Description of screening plants

Plant species	Common name	Family	References
<i>Trachyspermum ammi</i>	Ajwain	Apiaceae	[34]
<i>Bryophyllum fedtschenkoi</i>	Lavender scallops	Crassulaceae	[35]
<i>Chrysanthemum indicum</i>	Guldaudi	Asteraceae	[36]
<i>Tagetes erecta</i>	Marigold	Asteraceae	[31]
<i>Hibiscus rosa-sinensis</i>	Chiana rose	Malvaceae	[37]
<i>Catharanthus roseus</i>	Periwinkle	Apocynaceae	[33]

Table 2 Decolorization pattern of Methylene Blue and Congo Red dyes and their impact on plant growth

Plant species	% Decolorization				Plant Growth (After dye removal)
	MB (10 mg L ⁻¹)	MB (20 mg L ⁻¹)	CR (10 mg L ⁻¹)	CR (20 mg L ⁻¹)	
<i>Trachyspermum ammi</i>	99.0±6	86.0±7.5	95.0±6	84.0±7.2	Active
<i>Bryophyllum fedtschenkoi</i>	85.0±6.2	69.0±7.2	77.0±6.0	70.0±6.5	Active
<i>Chrysanthemum indicum</i>	87.0±9.2	70±10	60±8.7	52±9.5	Inactive
<i>Tagetes erecta</i>	84.0±8.2	68.0±8.5	67.0±7.6	66.0±6.6	Inactive
<i>Hibiscus rosa-sinensis</i>	86±6.7	71±7.0	59±7.5	47±6.0	Inactive
<i>Catharanthus roseus</i>	35±6.7	34±3.2	48±5.5	43±3.5	Active

Remark: All data values are median ± S.D., n = 3

Table 3 Comparison of results of present study with existing literature for phytoremediation of Methylene Blue and Congo Red Dye

Dye	Reported Literature					Present Study			
	Plant	Concentration (mg L ⁻¹)	Time (h)	Decolorization (%)	Reference Cited	Plant	Concentration (mg L ⁻¹)	Time (h)	Decolorization (%)
MB	<i>Lemna minor</i>	10	144	98	[19]	<i>Trachyspermum ammi</i>	10	40	99
		50	24	80	[3]		20	40	86
	<i>Azolla pinatta</i>	25	24	85	[20]	<i>Bryophyllum fedtschenkoi</i>	10	40	85
	<i>Eichhornia crassipes</i>	50	20 days	98	[18]		20	40	69
CR	<i>Chara vulgaris</i>	50	24	95	[15]	<i>Trachyspermum ammi</i>	10	40	95
							20		84
	<i>Pistia stratiotes</i>	40	72	90	[21]	<i>Bryophyllum fedtschenkoi</i>	10	40	85
							20		69

Figures

Figure 1

Chemical structure of (a) triaryl methane dye Methylene Blue (MB) (b) diazo dye Congo Red (CR)

Figure 2

(a) Abiotic control of triaryl methane dye Methylene Blue (b) Abiotic control of diazo dye Congo Red (c) Biotic control of *B. fedtschenkoi*.

Figure 3

Decolorization potential of screened plants for Methylene Blue (MB) and Congo Red (CR) dyes after a regular interval of 8 h up to 40 h.