Design of hydroponic system for screening of ornamental plant species for removal of synthetic dyes using phytoremediation approach

Navjeet Kaur
Chitkara Institute of Engineering and Technology
Jyotsna Kaushal (jyotsna.kaushal@chitkara.edu.in)
Chitkara Institute of Engineering and Technology
Pooja Mahajan
Chitkara Institute of Engineering and Technology
Arun Lal Srivastav
Chitkara University - Himachal Pradesh

Research Article

Keywords: Wastewater Treatment, Congo Red, Methylene Blue, Decolorization, Phytoremediation

Posted Date: February 3rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1301660/v1

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 design an efficient hydroponic system to screen potential ornamental plant species for removal of synthetic dye solution of triarylmethane dye Methylene Blue (MB) and diazo dye Congo Red (CR). The plants selected for screening are *Trachyspermum ammi, Tagetes erecta*, *Hibiscus rosa-sinensis*, *Chrysanthemum indicum*, *Bryophyllum fedtschenkoi*, and *Catharanthus 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 plant species showed active growth in indigenous designed hydroponic system 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* was 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.

Highlights

- A hydroponic system is designed for phytoremediation of dyes using ornamental plants.
- Six different ornamental plant species screened for removal Methylene Blue and Congo Red synthetic dye solution through this system.
- *T. ammi* and *B. fedtschenkoi* plant species showed decolorization potential more than 80% for both dyes.
- Study revealed that dye adsorption occurs through roots of both the plants.
- The proposed remediation system was found to be aesthetically pleasant in industrial set up.

1. Introduction

Due to the increasing world population, there is a tremendous growth of various industries, which uses many harmful chemicals for the generation of different commodities for public demands but the side byproducts 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 (Stolz 2001) and 50% of other reactive dyes are reported for use in the textile industry which is discharged into water (Chen 2002). Azo dyes are extensively used in the dyeing process. The effluent containing dyes released into the surrounding seriously affects the environment by destroying the ecosystem, causing water pollution, and reducing light penetration for aquatic life (Imron et al. 2019). Due to textile dye wastewater, the biological oxygen demand, chemical oxygen demand, and suspended solids increase in the nearest river located beside the textile industry (Ekanayake et al. 2021). So, there is a big challenge to treat textile dyes effluent before released into water bodies.

There are many physical and chemical methods, for example, adsorption, coagulation, sedimentation, flocculation, filtration, photo degradation, and chemical oxidation, for managing contamination produced by textile dyes (Khandare and Govindwar 2015). These methods relate to the high expense, low productivity, require huge space and undependable to work. Because of these issues, there is a requirement for the advancement of productive and cost-effective methods for the treatment of textile dyes. Biological methods are more effective than physical and chemical methods to treat the textile dye wastewater. Biological methods involve different enzymes, microorganisms, and plants for the removal of dyes from wastewater (De Alkimin et al. 2020). From the different biological methods, plant-based phytoremediation is an energy-efficient, solar-driven process to remove contaminants from soil, air, and water (Ubuza et al. 2020). There are many studies reported in the literature on the use of aquatic plant species for the phytoremediation of dye wastewater such as *Ipomoea aquatica* Forssk. (Rane et al. 2016), *Salvinia molesta* Mitchell (Kaushal and Mahajan 2015, 2021; Imron et al. 2019; Al-Baldawi et al. 2020), *Chara vulgaris* L. (Mahajan and Kaushal 2013, 2020; Mahajan et al. 2019), *Eichhornia crassipes* (Mart.) Solms (Tan et al. 2016), *Lemna minor* L.(Reema et al. 2011; Imron et al. 2019), and *Pistia stratiotes* L. (Mahajan and Kaushal 2019), but very few reports are available on phytoremediation textile dye wastewater using ornamental plants. The *Petunia grandiflora* Juss. which is a flowering ornamental plant species reported for its potential to remove the triphenylmethane textile dye Brilliant Blue G (Watharkar et al. 2013). *Aster amellus* L., a herbaceous plant species used to decolorize a sulfonated azo dye Remazol Red and a mixture of dyes and a textile effluent (Khandare et al. 2011). *Glandularia pulchella* (Sweet) Troncoso has been explored to decolorize the dye Green HE4B (Kabra et al. 2011) and *Ipomoea hederfolia* L. ornamental plant able to decolorize the dye mixtures and Scarlet Red dye (Rane et al. 2014). *Alcea rosea* L. plant has the potential to remove Disperse Red 60 and Reactive Blue 19 dye (Mahmoudabadi et al. 2019). The researchers also explored the phytoremediation potential of *Portulaca grandiflora* Hook. (Khandare et al. 2013), *Blumea malcolmii* Hook. F. (Kagalkar et al. 2009), *Typhonium flagelliforme* (G. Lodd.) (Kagalkar et al. 2010), among others for dye degradation in aqueous form. Ornamental plants have advantage of refining the environment aesthetics along with its cleaning and producing additional revenue in the form of the flowers and wood (Kaushal et al. 2021). Ornamental plants have a lot of potential in phytoremediation, however a lot of research reports presented for removal of heavy metals where these plants have an efficient root system and plants do not affect the food chain. But research on the dye remediation is still in its early phases. Hence, screening of more suitable ornamental plant species for the dye remediation provides a new horizon to management of contaminated textile wastewater. From literature review and local survey, some terrestrial ornamental plant species such as *Trachyspermum ammi* (L.) Sprague ex Turrill, *Tagetes erecta* (L.), *Hibiscus rosa-sinensis* L., *Chrysanthemum indicum* L., *Bryophyllum fedtschenkoi* (Raym.-Hamet & H. Perrier) Lauz.-March. and *Catharanthus roseus* (L.) G. Don. have been selected for the present research study (Kumar and Dwivedi 2013; Ahmad and Misra 2014; Bardiya-Bhurat et al. 2017; Chukki et al. 2018; Missoum 2018; Richwagen et al. 2019; Li et al. 2020). There is no report to our knowledge where these terrestrial ornamental plants are exposed in remediation of synthetic dyes in hydroponic medium. Hence, in the present research study, a hydroponic system is designed to engrossed on the ability of terrestrial ornamental plants for

decolorization of toxic, carcinogenic, and mutagenic textile dyes Methylene Blue (MB) and Congo Red (CR) dyes.

2. Materials And Methods

2.1 Chemicals and plant material

The triarylmethane dye, MB and a diazo dye, CR dye were used for experimentation. MB is a heterocyclic aromatic chemical compound with molecular formula $C_{16}H_{18}N_3SCl$. The molecular weight of MB dye is 320 g mol^{-1}. CR dye is a diazo dye that 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 its 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 used were of the highest purity and of an analytical grade. The synthetic dye wastewater was prepared at two different concentrations of 10 and 20 mg L^{-1}. The entire 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 matter and acclimatized for three days in distilled water. Table 1 shows the description of screened plants used for the research study.

2.2 Experimental design

A two-stage hydroponic system was designed in which two PVC pipes of 0.30 m diameter and 1m long was horizontally connected via movable stopper as shown in Fig. 2. Both the pipes were attached at an angle of 45°. The bigger holes of 0.05 m diameter were made for keeping the plants in vertical position in each pipe and small sized holes of 0.10 diameter were kept for aeration. The inlet of wastewater was kept above the top of first pipe and final outlet at the lower end of second pipe (Fig. 2).

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 up to three days. The treatment of selected plants was done in the upper pipe of hydroponic system after the acclimatization period of three days with 10 and 20 mg L^{-1} concentrations of both MB and CR dye solution. Each pipe of the system is having two types of holes – one is bigger in which plant is kept and in smaller hole, atmospheric oxygen can enter freely. Synthetic solution was added from the inlet of container attached to upper pipe. The acclimatized plants were transferred to prepared dye solutions of different concentrations. Both biotic and abiotic controls were also maintained. 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). The absorbance of each solution was determined with UV-Visible spectroscopy at its respective absorption maxima (λ_{max} (MB) – 668 nm; λ_{max} (CR) – 498 nm) using Systronic-2202 UV-Vis double beam spectrophotometer. The percentage decolorization was calculated as per equation (Al-Baldawi et al. 2018):

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

Where A_0 is an initial concentration of dye and A_1 is the final concentration of dye. After 40 h of treatment, treated water was drained to lower pipe and same plants were placed on the bigger holes of lower pipe. The lower pipe was to observe the growth of plant roots and it was perceived that after 7 days, there were small growth of newly developed roots. To optimize the efficiency of the hydroponic system, similar set of plants were kept in upper pipe for treatment of synthetic water. Each batch of dye concentration and screened plants had triplicates for each biological sample for obtaining the concordant results. The data was analyzed by using MS-excel 2007 windows.

3. Results And Discussion

The utility of hydroponic system was optimized by using two sets of plants- one set in upper pipe where treatment of synthetic water was screened by different plants and in lower pipe, growth of roots of screened plant were observed in treated water after treatment (Fig. 3). 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 via physical examination (Fig. 4). The results of different batch experiments for decolorization of dyes with respect to time are shown in Fig. 5. It has been observed from Fig. 5 that the decolorization percentage of dye increases with increase in time. The same pattern of dye decolorization has been reported by various researchers (Reemaet al. 2014; Kaushal and Mahajan 2015; Al-Baldawi et al. 2020). For instance, the different Green HE4B dye concentrations were reduced to varying extent during 48 h of contact by *G. pulchella* and maximum decolorization was observed at 48 h in each concentration (Kabra et al. 2011). All these decolorization results and the impact of synthetic dye wastewater on the growth of plant used for screening are summarized in Table 2.

Figure 5a and 5b show the decolorization pattern of MB and CR dye by utilizing *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. 5b 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 was 95 and 84%, respectively. The plant remains survived after the adsorption of dye into the roots. However, percentage decolorization decreases with an increase in concentration. These outcomes show that *T. ammi* plant is an outstanding plant to decolorize the azo dye CR and triarylmethane dye MB at a lower concentration. The decolorization of MB and CR dye by using *B.*

fedtschenkoi plant is shown in Fig. 5c and 5d respectively. The plant *B. fedtschenkoi* shows significant decolorization of triarylmethane dye MB having a 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 of the dye and were able to remove more dye concentration than 20 mg L^{-1}. These results proved that *B. fedtschenkoi* plant has a good tendency to decolorize synthetic wastewater of CR azo dye as well as triarylmethane dye MB.

Figure 5e and 5f show the decolorization 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 became dried, later stems and roots of the plant also showed dryness after the removal of dyes. The plant becomes died after treatment with higher dye concentrations. However, the MB color removal by this plant was acceptable yet plant endurance was not significant for the treatment of triarylmethane dye, MB. The results with CR dye synthetic wastewater revealed only 44 and 42% decolorization at 10 and 20 mg L^{-1} concentrations, respectively. Wilting of the plant takes place after treatment of CR dye. The plant was not able to treat dye concentration higher than 20 mg L^{-1}. Hence, *C. indicum* is not suitable for the phytotreatment of CR synthetic dye 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. 5g and 5h show 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, the plant was no more active for treatment with more MB dye concentrations than 20 mg L^{-1}. The percentage decolorization was observed 67 and 66% for 10 and 20 mg L^{-1} CR dye concentrations, respectively. Though the plant can 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.

Figure 5i and 5j show 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 at 10 and 20 mg L^{-1} CR dye solution. It indicates the potential of *H. rosa-sinensis* for MB synthetic dye wastewater decolorization. But the toxicity of dye effects on plant growth results in its inability to remove dye concentrations than 20 mg L^{-1}.

Figure 5k and 5l show the percentage decolorization of MB and CR dye respectively by *C. roseus*. The decolorization percentage obtained for MB 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 the case of *C. roseus* plant, it is found that the plant remains active after dye removal however plant removal efficiency 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 plants also remain active after removal both MB and CR dyes. *C. indicum* and *T. erecta* plants also show 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 wither after dye removal. The plant *C. roseus* can 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 the phytoremediation technique as shown in Table 3. *E. crassipes* successfully removed MB dye (50 mg L^{-1}) in 20 days up to 98% (Tan et al. 2016) while *L. minor* (2 g) was exposed to 50 mg L^{-1} of MB dyes for 24 h decolorization of 81% (Imron et al. 2019). In another study, 98% decolorization has been reported for *L. minor* in 144 h at 10% concentration and authors claimed it as a phytoremediation agent to remove MB dye from wastewater (Reema et al. 2011). Another aquatic species *Azolla pinata* also reported in literature for removal of MB dye (Al-Baldawi et al. 2018). In literature, MB remediation is mostly reported by using aquatic plant species. 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 has been proven to be more effective than *E. crassipes* and *L. minor*. Again, for phytoremediation of CR dye, *C. vulgaris* (Mahajan and Kaushal 2013) and *P. stratiotes* (Mahajan and Kaushal 2019) aquatic species are reported for maximum decolorization 95 and 90% respectively. In the present study, *T. ammi* exhibited the maximum decolorization up to 95 and 84% at 10 and 20 mg L^{-1} CR dye concentrations respectively and remained active after the decolorization process. However, it has been observed that the dye was found to be adsorbed on the roots of *T. ammi* plant possibly due to the rhizofiltration process, and hence plant could be able to provide maximum decolorization. Therefore, *T. ammi* plant acts as a potential candidate for future research where it can be used as a phytoremediator for decolorization of dye wastewater.

4. Conclusion

The design of hydroponics system shows the efficient utilization of system for screening the plants and developing the growth of the root system of plants in optimum time by using alternative two pipe system. The results from the present research support the ability of six screened plants for the removal of MB and CR dyes. *T. ammi* and *B. fedtschenkoi* are the most efficient plants for the removal of both dyes. Moreover, the survival of both plants seems to be significant. Maximum percentages of decolorization obtained from the *T. ammi* plant are 99 (10 mg L^{-1}) and 86% (20 mg L^{-1}) for MB dye, and 95 (10 mg L^{-1}) and 84% (20 mg L^{-1}) for CR dye due to its adsorption on the roots of the plant. Therefore, further research work can be focused on dye removal by using *T. ammi* plant based on the adsorption mechanism. In the future, adsorption mechanism explored by using different instrumental techniques such as Fourier Transform Infrared spectroscopy, Scanning Electron Microscopy, and statistical analysis can also be

done with different operational parameters such as plant weights, the relative growth rate of plants, the effect of pH, etc.

Declarations

Competing interests The authors declare that there is no competing interests.

Ethics approval and consent to participate “Not applicable”, as research does not report on or involve the use of any animal or human data or tissue.

Consent for publication Not Applicable.

Funding

This research work did not receive any funding.

Authors' contributions

Navjeet Kaur: Conducted the experimental studies and drafted the manuscript; Jyotsna Kaushal: Conceptualization, expert view, and overall Supervision; Pooja Mahajan: Data interpretation; Arun L. Srivastva: Suggestions and interpretation on the chemical analysis. All authors read and approved the final manuscript.

Acknowledgements

The authors express their gratitude to the Chitkara University, Rajpura for providing required facilities to complete their research completely.

References

1. Ahmad R, Misra N (2014) Evaluation of Phytoremediation potential of *C. roseus* with respect to Chromium contamination. Am J Plant Sci 5:2378–2388. https://doi.org/10.4236/ajps.2014.515251
2. Al-Baldawi IA, Abdullah SRS, Alman Soory AF, Ismail NI, Abu Hasan H, Anuar N (2020) Role of *Salvinia molesta* in biodecolorization of methyl orange dye from water. Sci Rep–UK 10:13980. https://doi.org/10.1038/s41598-020-70740-5
3. Al-Baldawi IA, Abdullah SRS, Anuar N, Abu Hasan H (2018) Phytotransformation of methylene blue from water using aquatic plant (*Azolla pinnata*). Environ Technol Inno 11:15–22. https://doi.org/10.1016/j.eti.2018.03.009
4. Bardiya-Bhurat K, Sharma S, Mishra Y, Patankar C (2017) *Tagetes erecta* (marigold), a phytoremediant for Ni- and Pb-contaminated area: a hydroponic analysis and factors involved. Rend Lincei-Sci Fis 28:673–678. https://doi.org/10.1007/s12210-017-0636-9

5. Chen BY (2002) Understanding decolorization characteristics of reactive azo dyes by *Pseudomonas luteola*: toxicity and kinetics. Process Biochem 38:437–446. https://doi.org/10.1016/S0032-9592(02)00151-6
6. Chukki J, Abinandan S, Shanthakumar S (2018) *Chrysanthemum indicum* microparticles on removal of hazardous Congo red dye using response surface methodology. Int J Ind Chem 9:305–316. https://doi.org/10.1007/s40090-018-0160-5
7. De Alkimin GD, Paisio C, Agostini E et al (2020) Phytoremediation processes of domestic and textile effluents: evaluation of the efficacy and toxicological effects in *Lemna minor* and *Daphnia magna*. Environ Sci Pollut Res 27:4423–4441. https://doi.org/10.1007/s11356-019-07098-3
8. Ekanayake MS, Udayanga D, Wijesekara I et al (2021) Phytoremediation of synthetic textile dyes: biosorption and enzymatic degradation involved in efficient dye decolorization by *Eichhornia crassipes* (Mart.) Solms and *Pistia stratiotes* L. Environ Sci Pollut Res 28: 20476–20486. https://doi.org/10.1007/s11356-020-11699-8
9. Imron MF, Kurniawan SB, Soegianto A, Wahyudianto FE (2019) Phytoremediation of methylene blue using duckweed (*Lemna minor*). Heliyon. 2019; 5: e02206. https://doi.org/10.1016/j.heliyon.2019.e02206
10. Kabra AN, Khandare RV, Kurade MB, Govindwar SP (2011) Phytoremediation of a sulphonated azo dye Green HE4B by *Glandularia pulchella* (Sweet) Tronc. (Moss Verbena). Environ Sci Pollut Res 18:1360–1373. https://doi.org/10.1007/s11356-011-0491-7
11. Kagalkar AN, Jagtap UB, Jadhav JP, Bapat VA, Govindwar SP (2009) Biotechnological strategies for phytoremediation of the sulfonated azo dye Direct Red 5B using *Blumea malcolmii* Hook. Bioresour Technol 100:4104–4110. https://doi.org/10.1016/j.biortech.2009.03.049
12. Kagalkar AN, Jagtap UB, Jadhav JP, Govindwar SP, Bapat VA (2010) Studies on phytoremediation potentiality of *Typhonium flagelliforme* for the degradation of. Brilliant Blue R Planta 232:271–285. https://doi.org/10.1007/s00425-010-1157-2
13. Kaushal J, Mahajan P (2015) Exploring the Phytoremediation Potential of *Salvinia molesta* for the degradation of Malachite green dye. Res J Chem Environ 19:1–8
14. Kaushal J, Mahajan P (2015) Exploring the Phytoremediation Potential of *Salvinia molesta* for the degradation of Malachite green dye. Res J Chem Environ 19:1–8
15. Kaushal J, Mahajan P (2021) Kinetic Evaluation for Removal of an Anionic Diazo Direct Red 28 by Using Phytoremediation Potential of *Salvinia molesta* Mitchell. Bull Environ Contam Toxicol 17:1–6. https://doi.org/10.1007/s00128-021-03297-2
16. Khandare RV, Govindwar SP (2015) Phytoremediation of textile dyes and effluents: current scenario and prospects. Biotechnol Adv 33:1697–1714. https://doi.org/10.1016/j.biotechadv.2015.09.003
17. Khandare RV, Kabra AN, Awate AV, Govindwar SP (2013) Synergistic degradation of diazo dye Direct Red 5B by *Portulaca grandiflora* and *Pseudomonas putida*. Int J Environ Sci Tech 10:1039–1050. https://doi.org/10.1007/s13762-013-0244-x

18. Khandare RV, Kabra AN, Tamboli DP, Govindwar SP (2011) The role of *Aster amellus* Linn. in the degradation of a sulfonated azo dye Remazol Red: a phytoremediation strategy. Chemosphere 82:1147–1154. https://doi.org/ 10.1016/j.chemosphere.2010.12
19. Kumar G, Dwivedi H (2013) Genotoxic effects of heavy metals in Trachyspermum ammi (L.) Sprague. Chromosome Bot 8:81–86. https://doi.org/10.3199/iscb.8.81
20. Li FL, Yang F, Chen YH, Jin H, Leng YL, Wang JD (2020) Chemical reagent-assisted phytoextraction of heavy metals by *Bryophyllum laetivirens* from garden soil made of sludge. Chemosphere 253:126574. https://doi.org/10.1016/j.chemosphere.2020.126574
21. Mahajan P, Kaushal J, Upmanyu A, Bhatti J (2019) Assessment of phytoremediation potential of *Chara vulgaris* to treat toxic pollutants of textile effluent. J Toxicol 2019:8351272. https://doi.org/ 10.1155/2019/8351272
22. Mahajan P, Kaushal J (2013) Degradation of Congo red dye in aqueous solution by using phytoremediation potential of *C. vulgaris*. Chitkara Chem Rev 1:67–75
23. Mahajan P, Kaushal J (2020) Phytoremediation of azo dye methyl red by macroalgae *Chara vulgaris* L.: kinetic and equilibrium studies. Environ Sci Pollut Res 27:26406–26418. https://doi.org/10.1007/s11356-020-08977-w
24. Mahajan P, Kaushal J (2019) Phytoremediation of carcinogenic diazo Congo Red dye by using *Pistia stratiotes* (water lettuce). Res J Chem Environ 23:65–73
25. Mahmoudabadi TZ, Talebi P, Jalili M (2019) Removing Disperse red 60 and Reactive blue 19 dyes removal by using *Alcea rosea* root mucilage as a natural coagulant. Amb Express 9:113. https://doi.org/10.1186/s13568-019-0839-9
26. Missoum A (2018) An update review on *Hibiscus rosasinensis* phytochemistry and medicinal uses. J Ayur Herb Med 4:135–146
27. Rane NR, Chandanshive VV, Khandare RV, Gholave AR, Yadav SR, Govindwar SP (2014) Green remediation of textile dyes containing wastewater by *Ipomoea hederifolia* L. RSC Adv 4:36623–36632. https://doi.org/10.1039/C4RA06840H
28. Rane NR, Patil SM, Chandanshive VV, Kadam SK, Khandare RV, Jadhav JP et al (2016) *Ipomoea hederifolia* rooted soil bed and *Ipomoea aquatic* rhizofiltration coupled phytoreactors for efficient treatment of textile wastewater. Water Res 96:1–11. https://doi.org/10.1016/j.watres.2016.03.029
29. Reema RM, Saravanan P, Kumar MD, Renganathan S (2011) Accumulation of methylene blue dye by growing *Lemna minor*. Sep Sci Technol 46:1052–1058. https://doi.org/10.1080/01496395.2010.528503
30. Richwagen N, Lyles JT, Dale BLF, Quave CL (2019) Antibacterial activity of *Kalanchoe mortage*i and *K. fedtschenkoi* against ESKAPE pathogens. Front Pharmacol 2019; 10:67. https://doi.org/10.3389/fphar.2019.00067
31. Stolz A (2001) Basic and applied aspects in the microbial degradation of azo dyes. Appl Microbiol Biot 56:69–80. https://doi.org/10.1007/s002530100686

32. Tan KA, Morad N, Ooi JQ (2016) Phytoremediation of methylene blue and methyl orange using *Eichhornia crassipes*. Int J Environ Sci Develop 7:724–728
33. Ubuza LJ, Padero PC, Nacalaban CM, Tolentino JT, Alcoran DC, Tolentino JC, Ido AL, Mabayo VI, Arazo RO (2020) Assessment of the potential of duckweed (Lemna minor L.) in treating lead-contaminated water through phytoremediation in stationary and recirculated set-ups. Environ Eng Res 25(6):977–982
34. Watharkar AD, Khandare RV, Kamble AA, Mulla AY, Govindwar SP, Jadhav JP (2013) Phytoremediation potential of *Petunia grandiflora* Juss., an ornamental plant to degrade a disperse, disulfonated triphenylmethane textile dye Brilliant Blue G. Environ Sci Pollut Res 20:939–949. https://doi.org/10.1007/s11356-012-0904-2

Tables

Table 1. Description of screening plants used for phytoremediation study

Plant species	Common name	Family	References
Trachyspermum ammi	Ajwain	Apiaceae	Kumar and Dwivedi 2013
Bryophyllum fedtschenkoi	Lavender scallops	Crassulaceae	Richwagen et al. 2019
Chrysanthemum indicum	Guldaudi	Asteraceae	Chukki et al. 2018
Tagetes erecta	Marigold	Asteraceae	Bardiya-Bhurat et al. 2017
Hibiscus rosa-sinensis	Chiana rose	Malvaceae	Missoum 2018
Catharanthus roseus	Periwinkle	Apocynaceae	Ahmad and Misra 2017

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

Plant species	% Decolorization				Plant growth (after removal of dye)
	Methylene Blue		Congo Red		
	10	20	10	20	
	(mg L^{-1})				
Trachyspermum ammi	99 ± 6	86 ± 7	95 ± 6	84± 7	Active
Bryophyllum fedtschenkoi	85 ± 6	69 ± 7	77 ± 6	70± 6	Active
Chrysanthemum indicum	87 ± 9	70 ± 10	60 ± 9	52 ± 9	Inactive
Tagetes erecta	84 ± 8	68 ± 8	67 ± 8	66 ± 7	Inactive
Hibiscus rosa-sinensis	86 ± 6	71 ± 7	59 ± 7	47 ± 6	Inactive
Catharanthus roseus	35 ± 6	34 ± 3	48 ± 5	43 ± 3	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 MB and CR

Plant	Dye	Dye concentration ($mg\ L^{-1}$)	Time (h)	Decolorization (%)	References
Lemna minor	MB	10	144	98	Reema et al. 2011
		50	24	80	Imron et al. 2019
Azzola pinatta	MB	25	24	85	Al-Baldawi et al. 2018
Eichhornia crassipes	MB	50	20d	98	Tan et al. 2016
Chara vulgaris	CR	50	24	95	Mahajan and Kaushal 2013
Pistia stratiotes	CR	40	72	90	Mahajan and Kaushal 2019
Trachyspermum ammi	MB	10	40	99	Present study
		20		86	
	CR	10		95	
		20		84	
Bryophyllum fedtschenkoi	MB	10	40	85	Present study
		20		69	
	CR	10		77	
		20		70	

Figures

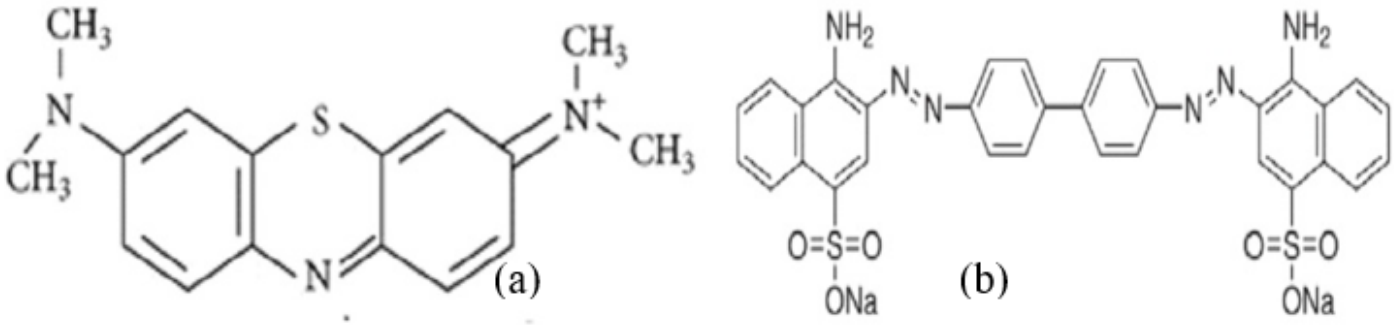

Figure 1

Chemical structure of (a) Methylene Blue (MB) (b) Congo Red (CR)

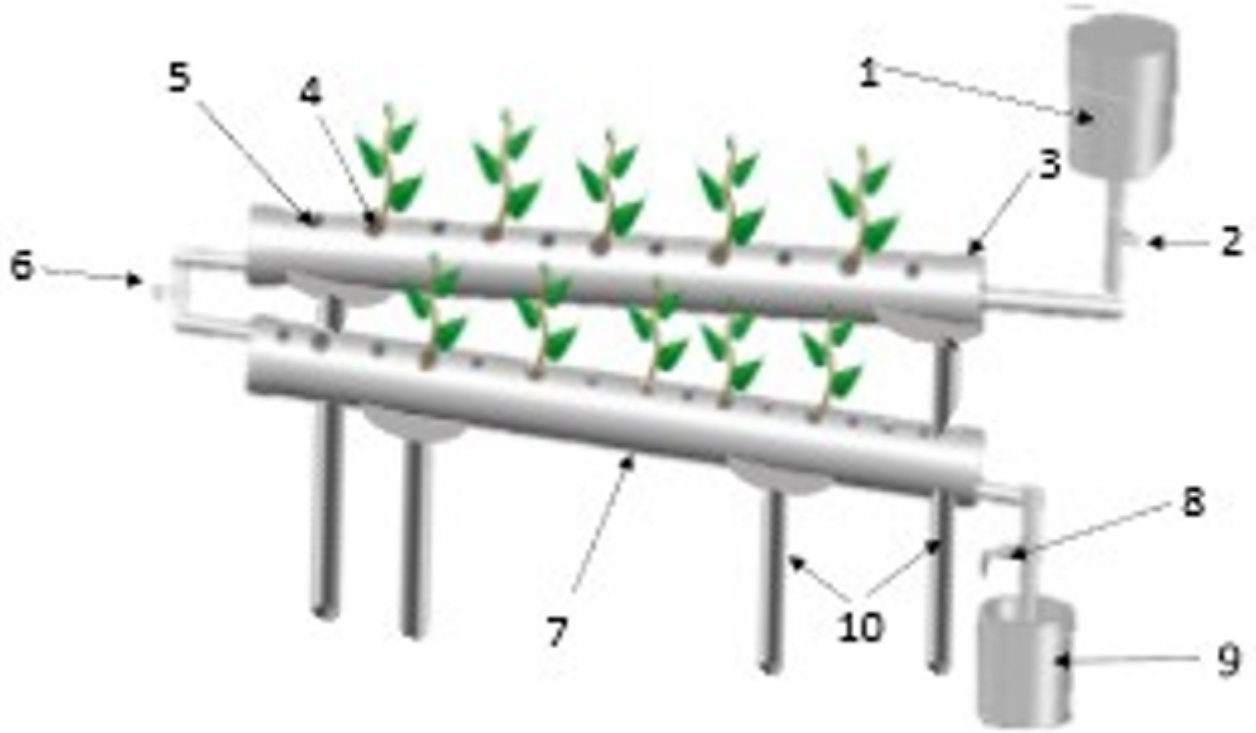

Figure 2

2-D Experimental design of hydroponic system for synthetic wastewater treatment (Inlet Chamber (1); PVC pipes (3, 7) Big Hole (4); Small holes (5)- Stoppers (2, 6, 8); Outlet tank (9); Stand (10)

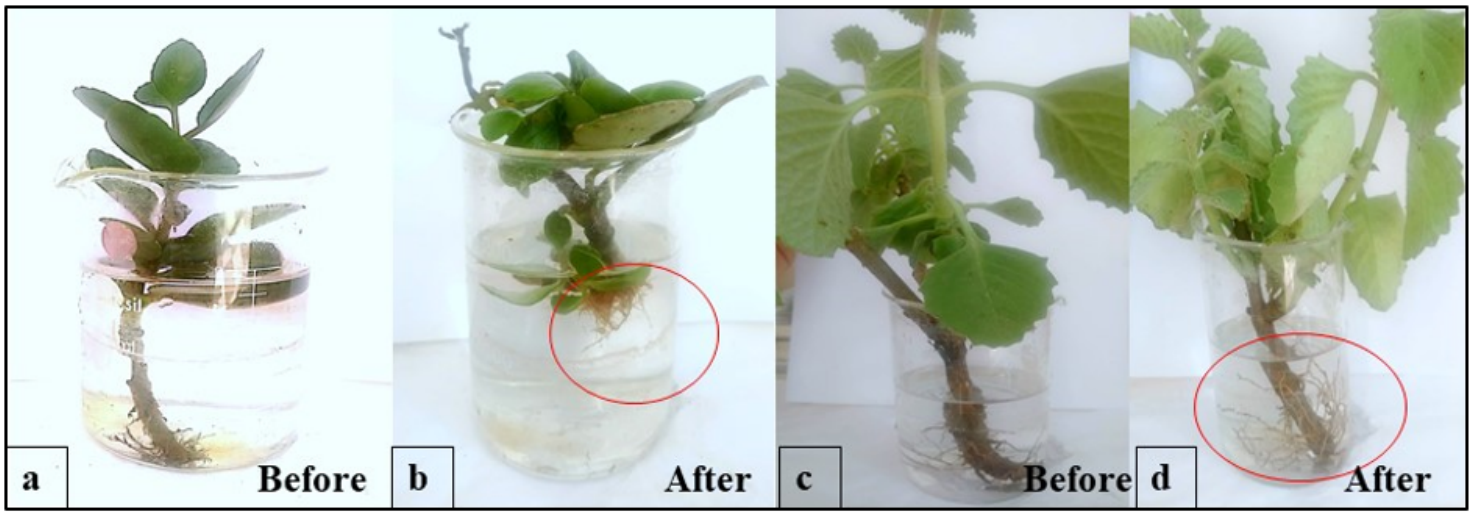

Figure 3

Image depicting growth of (a) *B. fedtschenkoi* and (b) *T. ammi before and after 2-step treatment in hydroponic system. Red circles showed the growth of roots enhanced after treatment.*

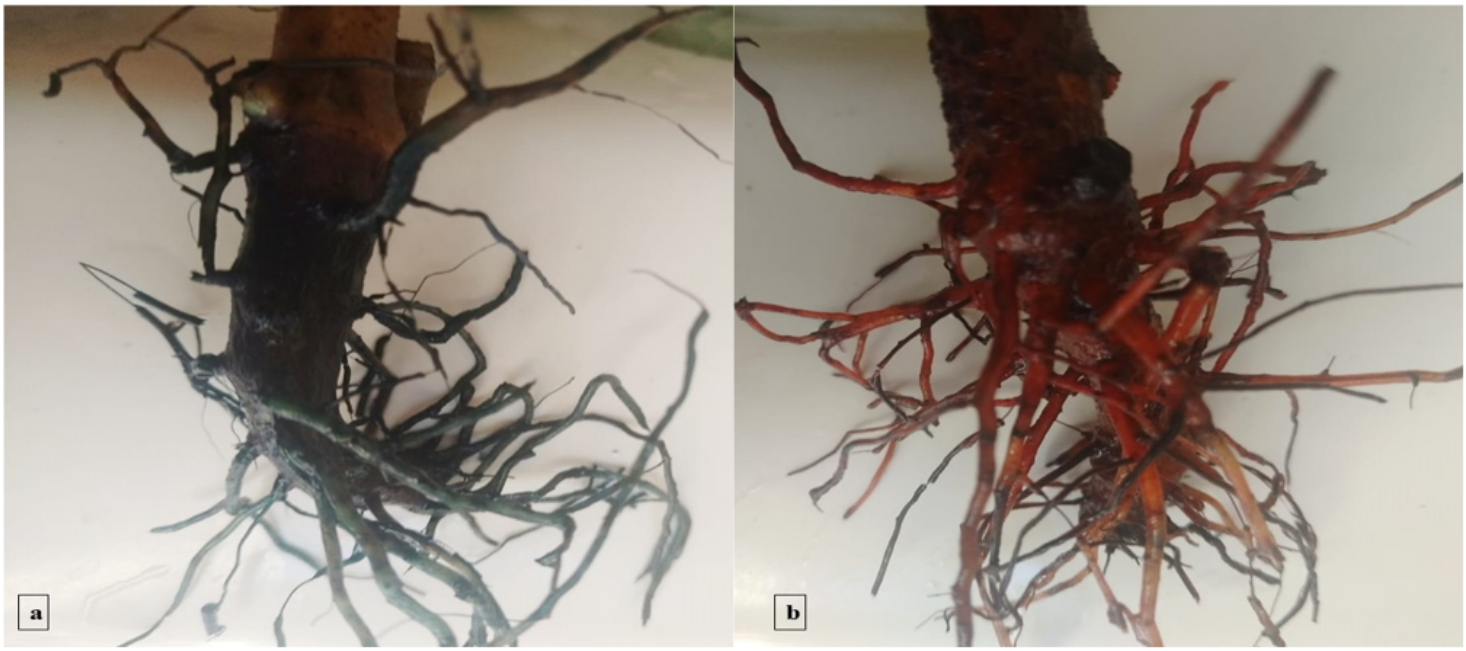

Figure 4

Visual pigmentation of (a) MB (b) CR dye on roots of *T. ammi* after 8 h

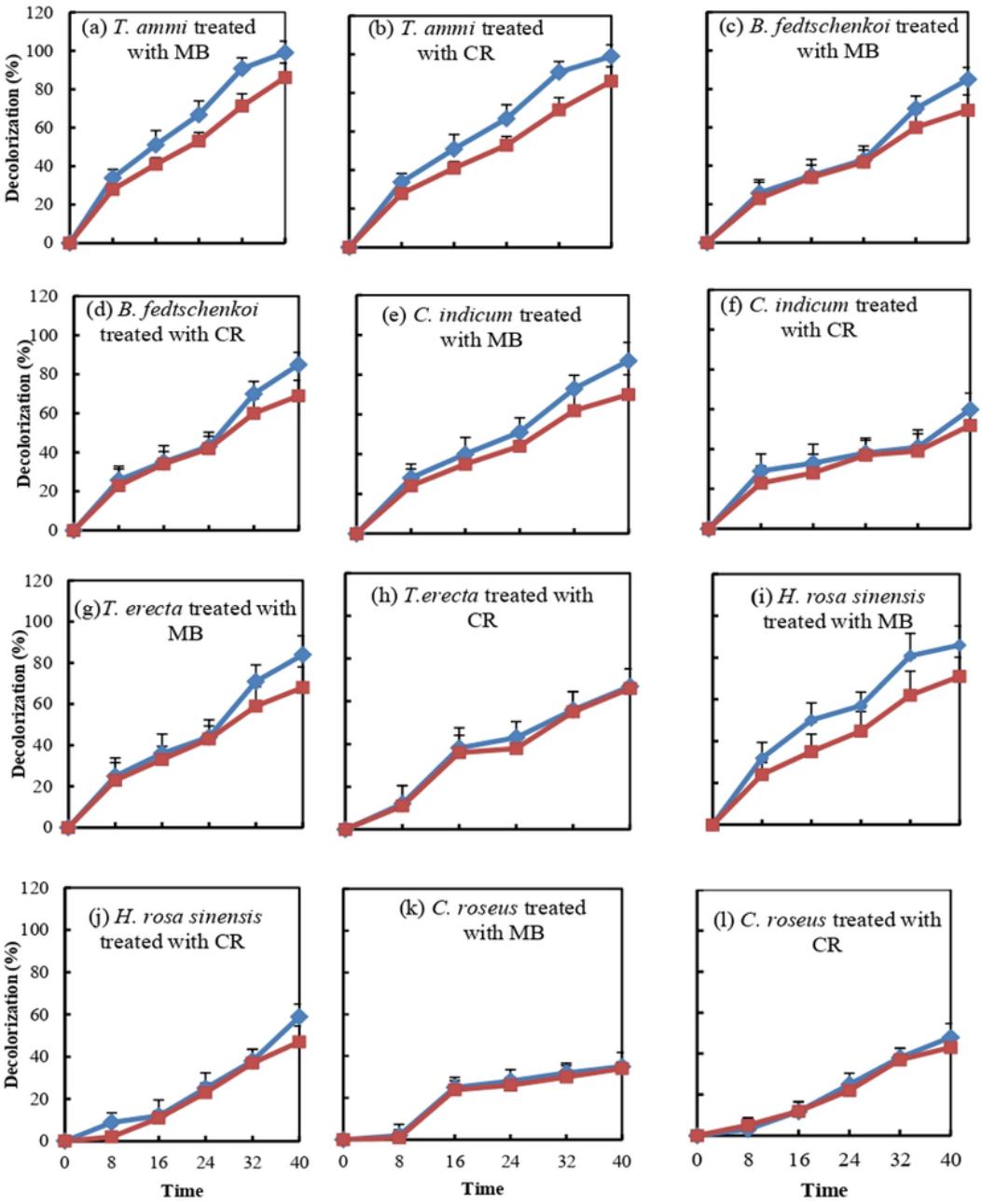

Fig. 5 Decolorization potential of screened plants for MB and CR dyes at concentration 10 mg L^{-1} ( ) and 20 mg L^{-1} ( ) after a regular interval of 8 h up to 40 h

Figure 5

See image above for figure legend.