Screening of plant species for phytoremediation of synthetic textile dye wastewater

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Research

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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,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 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*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 forphytoremediation of wastewater contaminated with synthetic dyes.

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 [1] and 50% other reactive dyes reported for use in the textile industry which are discharged into water [2]. 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 [3]. Due to textile dye wastewater, the biological oxygen demand, chemical oxygen demand, and suspended solidsincrease 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 many physical and chemical methods, for example, adsorption, coagulation, sedimentation, flocculation, filtration, photodegradation, and chemical oxidation, 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, microorganisms 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 for 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], T*ypha angustifolia* [14], *Chara vulgaris* [15-17], *Eichhornia crassipes* [18],*Lemna minor* [3, 19],*Azolla pinnata*[20], and *Pistia stratiotes* [21], but very few reports are 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 and a mixture of dyes and a textile effluent [23]. *Glandularia pulchella*has been explored to decolorize the dye Green HE4B [24] and *Ipomoea hederfolia* ornamental plant able to decolorize the dye mixtures and Scarlet Red dye [25]. A*lcea 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],among others for dye degradation in aqueous form. There is no research work based on textile dye removal by *Trachyspermum ammi*, *Tagetes erecta*, *Hibiscus rosa-sinensis*, *Chrysanthemum indicum*, *Bryophyllum fedtschenkoi*, and *Catharanthus roseus*. In literature, these plant species have been reported for their potential remediation of heavy metal 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, present research study focused the ability of screened plants for decolorization of Methylene Blue (MB) and Congo Red (CR) dyes.

2. Materials And Method

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 which 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 used were 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 matters 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

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 after the acclimatization period of three days with 10 and 20 mg L^{-1} concentrations of both MB and CR 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). The absorbance of each solution was determined with a 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 [20]:

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

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.

3. 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 via physical examination. The results of different batch experiments for decolorization of dyes with respect to time are shown in Fig. 3. It has been observed from Fig. 3 that the decolorization percentage of dye increases with increase in time. The same pattern of dye decolorization has been reported by various researchers [12-15, 19-20, 24]. For instance, the different Green HE4B dye concentrations were reduced to varying extent during 48 h of contact 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 are summarized in Table 2.

Figure 3a and 3b shows 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. 3b 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 show that *T. ammi* plant is an outstanding plant to decolorize the azo dye CR and triarylmethane dye MB at lower concentration. The decolorization of MB and CR dye by using *B. fedtschenkoi* plant is shown in the Fig. 3c and 3d 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 triaryl methane dye MB.

Figures 3eand 3f 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 the 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 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} concentration 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. Figures 3g and 3h 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, 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 plant is 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.

Figures 3i and 3j 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}.

Figures 3k and 3l 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 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 the 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 wis also not considerable for survival because flowers wither after dye removal. The plant *C. roseus* isable 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. *Eichhornia crassipes* successfully removed MB dye (50 mg L^{-1}) in 20 days up to 98% [18] while *Lemna minor* (2 g) was exposed into 50 mg L^{-1} of MB dyes for 24 h decolorization of 81% [3]. In another study, 98% decolorization has been reported for *Lemna minor in 144 h at 10% concentration and authors claimit*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 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, *Chara vulgaris* [15] and *Pistia stratiotes* [21]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 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 rhizofiltration process, and hence plant could be able to provide 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.

3. Conclusions

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 both dyes. Moreover, survival of both the 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}) and84% (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 on the bases of 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 plants weights, relative growth rate of plants, effect of pH, etc.

Declarations

Availability of data and materials

The data used to support the findings of this study are available from corresponding authors upon request as the relevant data will be used by Ph.D scholar for her future works in continuation.

Competing interests

The authors report that there is no irreconcilable circumstance with respect to the distribution of this original copy. Also, the moral issues, including literary theft, educated assent, unfortunate behavior, and twofold production as well as accommodation and excess have been totally checked by the authors.

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Authors' contributions

Navjeet Kaur: Conducted the experimental studies and drafting 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.

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Tables

Table1 Description of screening plants used for phytoremediation study

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

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

Plant species	Point for % 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 Methylene Blue

Plant	Dye	Dye concentration (mg L^{-1})	Time (h)	Decolorization (%)	References
Lemna minor	MB	10	144	98	[19]
		50	24	80	[3]
Azzolapinatta	MB	25	24	85	[20]
Eichhornia crassipes	MB	50	20d	98	[18]
Chara vulgaris	CR	50	24	95	[15]
Pistia stratiotes	CR	40	72	90	[21]
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

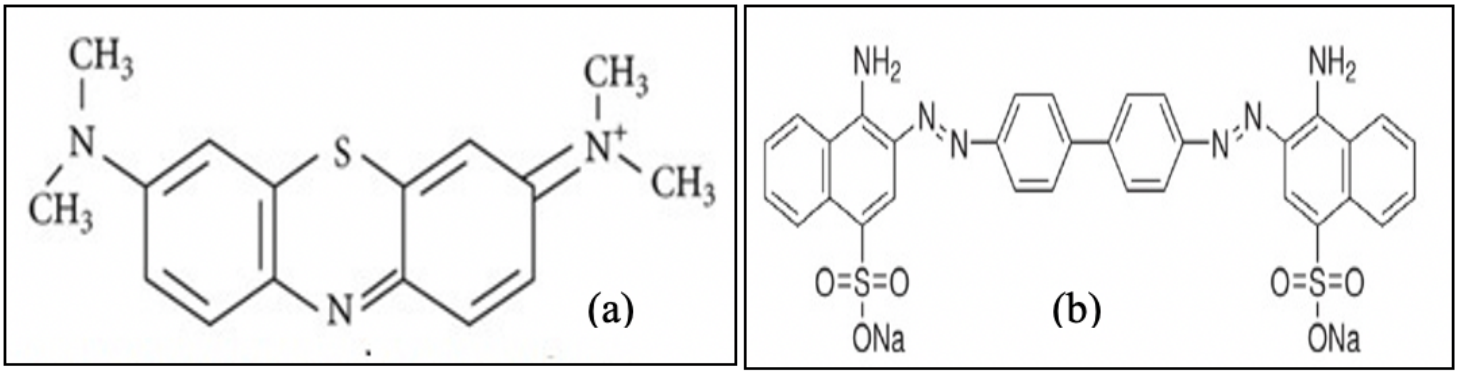

Figure 1

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

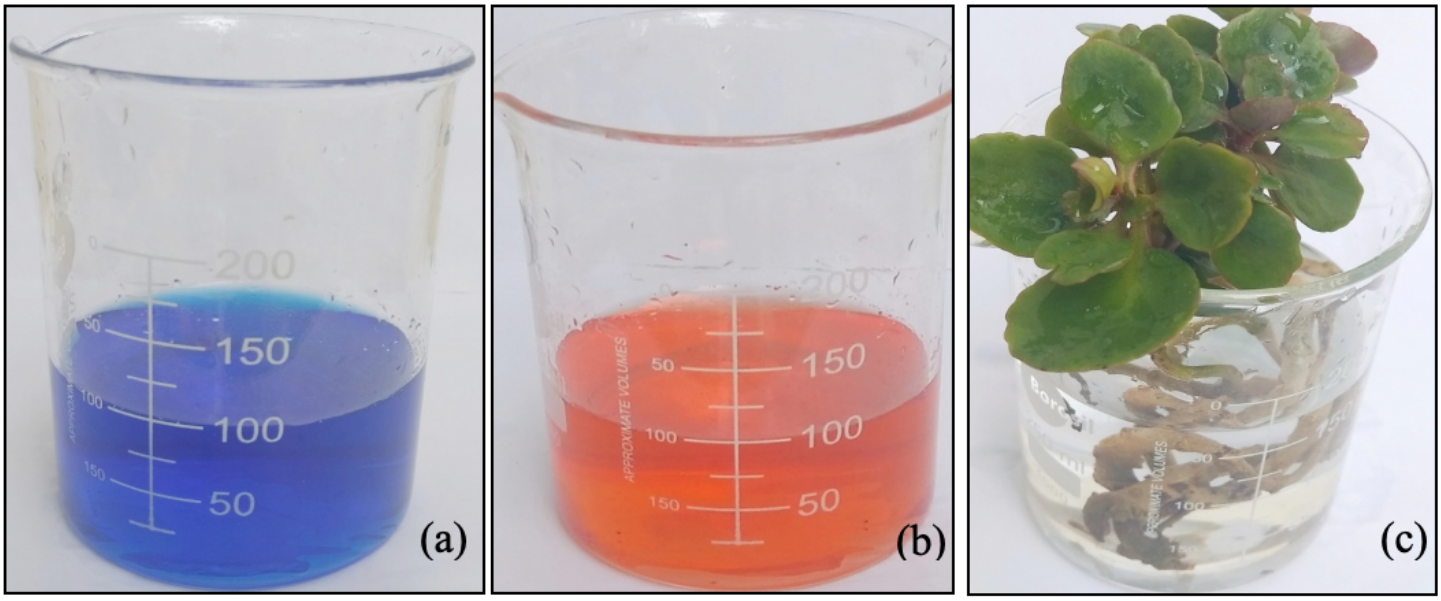

Figure 2

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

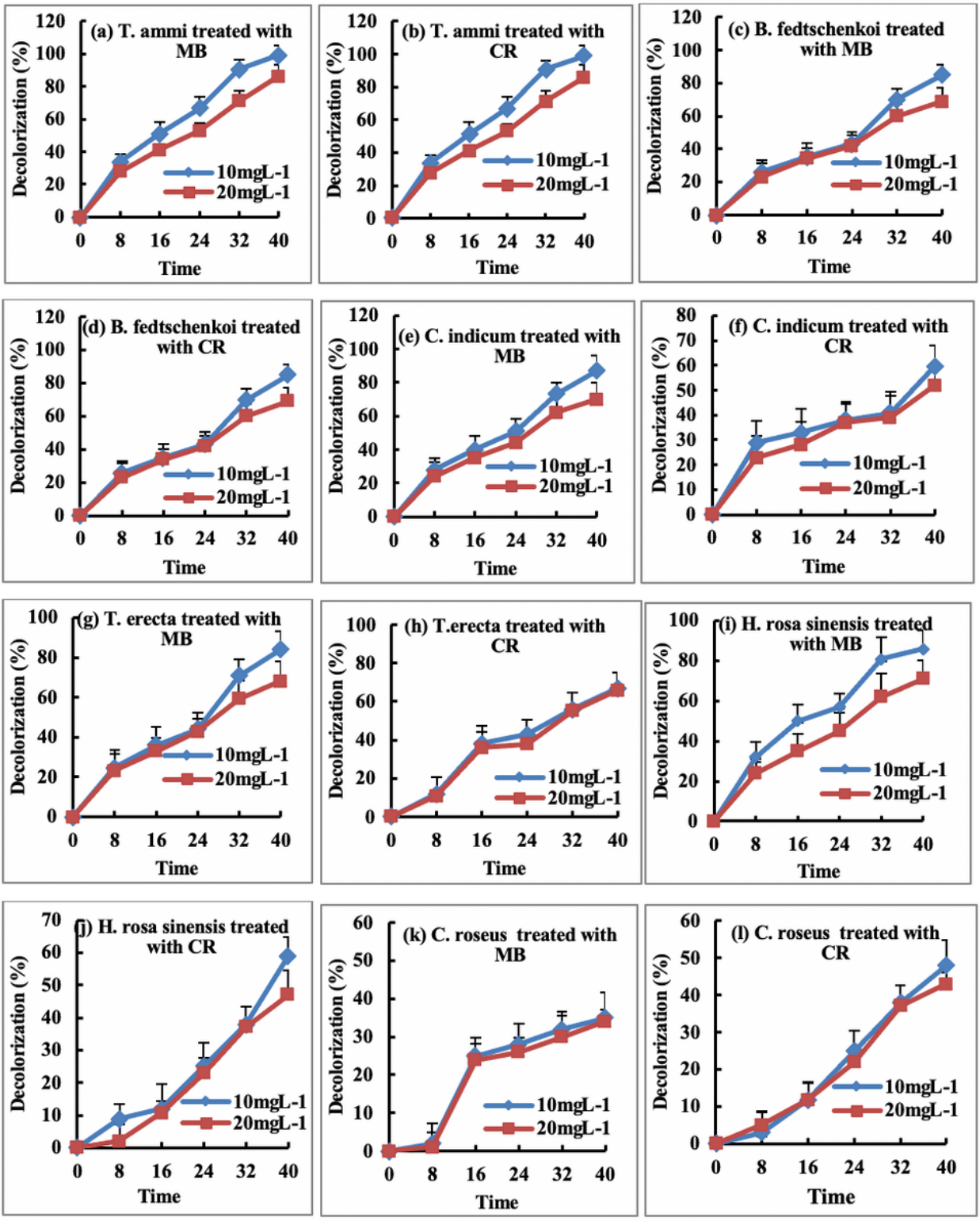

Figure 3

Decolorization potential of screened plants for Methylene Blue (MB) and Congo Red (CR) dyes at concentration 10 mg L-1 ( ) and 20 mg L-1 ( )after a regular interval of 8 h up to 40 h