Enhanced laccase expression and azo dye decolourization during co-interaction of *Trametes versicolor* and *Phanerochaete chrysosporium*

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Received: 19 October 2019 / Accepted: 28 April 2020 / Published online: 19 May 2020
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Abstract

In the present investigation, azophloxine dye decolourization with lignolytic enzyme producing white rot fungi, *Trametes versicolor* (TV) and *Phanerochaete chrysosporium* (PC) co-cultures, was investigated. Co-culturing of TV and PC extended the laccase activity by 8.2 times as compared to monocultivation of TV. *Phanerochaete chrysosporium*, a non-laccase producing fungus, produced the enzyme due to hyphal modifications and synergistic interaction with *Trametes versicolor*. The crude laccase extracted from TV + PC co-cultures showed 87.6% decolourization when subjected to azophloxine dye for 48 h. Contrary, laccase extracted from TV self-pairing plates showed decolourization of 14.4%. Henceforth, this investigation demonstrated that co-culturing of two white rot strains improved dye decolourization by increasing laccase enzymatic action.

Keywords Laccase · Azo dye · Decolourization · White rot fungi · Co-culturing · *Trametes versicolor* · *Phanerochaete chrysosporium*

1 Introduction

Commercially 100,000 dyes are used worldwide throughout the year. Out of one million tons of dyes that is produced every year, 50% of the unbound dyes are lost to the environment as textile dye effluent [1]. The textile industry effluent when released into the water bodies (lakes, rivers and ponds) reduces the penetration of sunlight and causes severe damage to the photosynthetic activity. It decreases the oxygen concentration in the water bodies and leads to the death of the aquatic organisms [2]. Textile dyes adversely effects the natural biological cycles of the aquatic living system due to their toxicity-linked metabolic stress, growth reduction, neurosensory damage and death. Among the synthetic dyes, around 70% of dyes used in textile industries belong to azo dyes. Azo dyes are toxic, mutagenic and carcinogenic in nature [1].

The adverse effects of dyes necessitate the treatment of textile effluent before it enters into the environment [3]. Physicochemical methods like adsorption, sedimentation, flocculation, coagulation and ozonation are usually carried out. Although these methods are effective, still their application is limited due to various demerits such as huge space requirement, chemical sludge production and high cost [4].

Low-cost and eco-friendly nature of biological methods have made them popular among other physical and chemical methods of treatment. Fungal strains like *Rhizopus arrhizus*, *Aspergillus niger*, *Rhizopus oryzae*, *Pleurotus florida* and *Rhizoctonia solani* have already been reported in dye degradation [5, 6]. Among the various fungal strains, white rot fungi (WRF) have been reported as the most effective fungi in dye decolourization process. *Phanerochaete chrysosporium*, *Pleurotus ostreatus*

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and *Trametes versicolor* are the few popular WRF that is extensively reported in the previous literature for dye decolourization [7, 8]. WRF produces nonspecific extracellular oxidative enzymes such as laccase, lignin peroxidase (LiP) and manganese peroxidase (MnP) that biotransforms and detoxifies the dyes [9]. Due to the nonspecific nature of the lignolytic enzymes (laccase, lignin peroxidase and manganese peroxidase), the use of WRF has been directly associated with bioremediation of dyes [10, 11].

Among the lignolytic enzymes, laccase expressed a great potential in dye degradation as it does not require a mediator or a costly co-substrate, except molecular oxygen [12, 13]. Laccase enzyme is a multi-copper containing protein that catalyses the oxidation of a various organic and inorganic substrates simultaneously by reducing molecular oxygen into water. It removes hydrogen atom from the hydroxyl group by electron oxidation and generates nontoxic by-products during the dye degradation process [14]. Mehra et al. [15] reported that phenolic compounds induced the production of laccase enzyme in fungus. Laccase oxidizes the phenolic group of the azo dye with just one electron, creating a phenoxy radical which is successively trailed by oxidation to form a carbonium particle. Water does a nucleophilic attack on the carbon of the phenolic ring and results in the formation of 3-diazenyl-benzenesulfonic corrosive (III) and 1, 2-naphthoquinone [14]. The objective of this study was to estimate the potential of laccase enzyme in the decolourization of azophloxine dye using co-culturing technique. Among the various WRF strains reported in the literature, *T. versicolor* and *P. chrysosporium* were selected on the basis of their potential to degrade complex organic pollutants [16]. *P. chrysosporium* itself does not produce laccase, but it triggers the laccase production in co-culture of *Aspergillus niger* and *Aspergillus oryzae* [17]. In the same way, it can also be hypothesized that co-culturing of *T. versicolor* and *P. chrysosporium* can enhance the laccase production resulting in improved and rapid decolourization of dyes.

In the present study, the growth rate and laccase activity during interspecific interaction of *T. versicolor* and *P. chrysosporium* on agar medium were determined. A comparative study on the enzymatic decolourization of azophloxine dye using crude laccase enzyme extracted from the different zones of pair culture (TV+TV and PC+PC) on agar plates was carried out. This new approach will contribute to the potential applicability of co-culturing the WRF strains in enhanced dye decolourization in wastewater effluent. The aim of the present study was to evaluate dye decolourization efficacy of two fungi *P. chrysosporium* and *T. versicolor* using effective co-culture technology.

2 Materials and methods

2.1 Chemicals

2,2'-Azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) was purchased from Sigma-Aldrich. Azophloxine dye, potato dextrose agar (PDA) and all other chemicals were purchased from Hi-Media, India. All chemicals and reagents used in the study were of analytical grade.

2.2 Fungal strains and culture conditions

Trametes versicolor (NCIM-1086) and *Phanerochaete chrysosporium* (NCIM-1106) fungal strains were procured from National Collection for Industrial Microorganisms (NCIM), Pune, India. Cultures of *T. versicolor* (NCIM-1086) and *P. chrysosporium* (NCIM-1106) were preserved on potato dextrose agar (PDA) medium at pH 6 and 28 °C. Fungal plugs of size ~ 10 mm from fully cultures grown on PDA plates were used as an inoculum and sub-cultured regularly at intervals of 15 d.

2.3 Paired interaction tests on agar plates

The qualitative laccase activity assay was determined during the intra- and interspecific interactions of *T. versicolor* and *P. chrysosporium* on PDA agar plates [18]. Fungal plugs of size ~ 10 mm were cut from actively growing mycelium, inoculated on PDA agar plates and incubated for 5 d at 28 °C. Self-pairing interaction plates consisted of fungal plugs of the same species and interspecific interaction plates consisted of fungal plugs of *T. versicolor* and *P. chrysosporium*. Plates of *T. versicolor* (TV+TV) and *P. chrysosporium* (PC+PC) were used as a control. The fungal growth and interaction among cultures on PDA plates were observed at regular intervals of 24 h. The laccase production in the PDA plates was estimated qualitatively by swamping ABTS for 5 min. The colour developed on the plates indicated the extracellular activity of laccase enzyme. The intensity of developed colour was evaluated visually and articulated in arbitrary units ranging from 0 to 5 [19].

2.4 Dye decolourization studies

Azophloxine dye of concentration 50 mg/L was added to autoclaved PDA media. The PDA plates containing 50 mg/L azophloxine dye were inoculated with ~ 10 mm actively growing fungal plugs of *T. versicolor* and *P. chrysosporium* and incubated at 28 °C. The dye decolourization in interspecies (TV+PC) and self-pairing of

fungal strains (*T. versicolor* (TV + TV) and *P. chrysosporium* (PC + PC)) on agar plates were evaluated.

2.5 Crude enzyme extraction

The enzymatic activity in the agar plates was determined at the point where the hyphae of *T. versicolor* and *P. chrysosporium* (TV + PC) and the hyphae of TV + TV and PC + PC meet each other. Fungal plugs were cut from each of the three regions (T, P and TP) of interacting mycelia as depicted in Fig. 1. In the figure, regions T and P represent *T. versicolor* and *P. chrysosporium*, respectively, and TP corresponds to interspecific interaction zone of both fungal strains (TV + PC). The cut plugs were transferred to culture tubes containing sodium acetate buffer (pH-4.5) and incubated in an orbital shaker at 150 rpm for 12 h at 4 °C. The extract was centrifuged at 4000 rpm for 10 min at 4 °C, and the supernatant was filtered using Whatman filter paper no.1 to remove fungal mycelia. The filtrate was collected and again filtered through syringe filters (0.45 µm) and stored at 4 °C for enzyme assay [20].

Fig. 1 Regions of fungal inoculation and enzyme extraction: Circular region shows the inoculation point, and rectangles are sampling region in interacting mycelia for enzyme extraction (P: *P. chrysosporium* T: *T. versicolor*)

2.6 Determination of Crude laccase enzyme activity

Using ABTS as the oxidation substrate the activity of crude laccase enzyme was determined spectrophotometrically at 420 nm ($\epsilon = 3600 \text{ M}^{-1} \text{ cm}^{-1}$). Briefly, the reaction mixture contained 250 µL of crude enzyme extract and 1 mL of 0.5 mM ABTS in 20 mM sodium acetate buffer (pH 4.5) [21]. One unit of enzyme (laccase) activity was defined as the amount of enzyme required to oxidize 1 mmol of substrate (ABTS) per minute. All the experiments were run in triplicate.

2.7 Dye decolourization assay with crude enzyme extract

The crude enzyme was mixed with sodium acetate buffer containing azophloxine dye of concentration 50 mg/L. The mixture was incubated at 150 rpm, 30 °C for 48 h. The dye solution was adjusted to pH 4.5 before incubating with the crude enzyme extract. The decrease in intensity of dye in the sample was measured in spectrophotometer at a wavelength of 533 nm. The dye decolourization per cent was calculated as per the formula (1).

$$\text{Dye decolourization rate (\%)} = \frac{A_0 - A_t}{A_0} \times 100 \quad (1)$$

where A_0 and A_t are initial and final absorbance, respectively, at λ_{max} (533 nm).

2.8 Statistical analysis

All the experiments were performed in triplicate ($n = 3$). Mean and standard deviation were calculated with Microsoft Office Excel 2007 spreadsheet, and values were represented as mean $\pm$ SD ($n = 3$). The error bars in the figures represent standard deviation ($n = 3$).

3 Results and discussion

3.1 Hyphal interaction in agar plates

P. chrysosporium and *T. versicolor* are white rot fungi with potential to secrete laccase enzyme. Their behaviour during intraspecific and interspecific interaction was studied in PDA plates. Figure 2 (a) and (b) depicts the intraspecific interaction, while Fig. 2c depicts the interspecific interaction. From the figure, it is clearly evident that *P. chrysosporium* during its intraspecific pairing showed luxurious growth and occupied the entire plate unlike the plates with *T. versicolor* that showed an

Fig. 2 Co-culturing of *P. chrysosporium* and *T. versicolor* **a** self-pairing of *P. chrysosporium*, **b** interspecific pairing of *T. versicolor* and *P. chrysosporium*. **c** Self-pairing of *T. versicolor*

extension of growth to 3.5 cm away from the point of inoculation after 6 days of incubation. Intraspecies interaction showed no deadlocks or replacements unlike interspecific interactions. Plates with *T. versicolor* and *P. chrysosporium* showed changes in the hyphal morphology at the point of interaction between the two mycelia. The mycelial of *P. chrysosporium* surrounded the mycelium of *T. versicolor* and became dense. Moreover, at the junction of interaction a deadlock occurred (Fig. 2c). According to Kennedy [22], interspecific interaction between two fungi results in the alteration of mycelial functioning, distribution and nutrient allocation. Qian and Chen [25] in their study too reported the occurrence of deadlock interaction during the co-culturing of *T. versicolor* and *P. chrysosporium*.

3.2 Laccase activity and inter- and intraspecific interaction

The laccase activity during interspecific and intraspecific interaction was determined by flooding the ABTS in the Petri plates (Fig. 3). Laccase activity in self-pairing *T. versicolor* (TV + TV), *P. chrysosporium* (PC + PC) and pairing of *T. versicolor* and *P. chrysosporium* (TV + PC) is depicted in Fig. 3a–c, respectively. Blue colour development indicates the laccase production. From the figure, it can be inferred that *P. chrysosporium* did not show laccase production during self-pairing and hence no colour formation was observed. *T. versicolor* self-pairing plates showed laccase production at the mycelial edges as indicated by the blue colour development. Contrary, co-cultured plates exhibited a different pattern of laccase production. A high laccase activity was observed in the co-cultured (TV and PC) plates, especially in the zone of interaction of the mycelia. No such interaction was observed in the self-pairing

Fig. 3 Laccase enzyme localized through ABTS addition on interaction regions on PDA agar plates. **a** Self-pairing of *P. chrysosporium*. **b** Self-pairing of *T. versicolor* and **c** Interspecific pairing of *P. chrysosporium* and *T. versicolor* (f: front side, r: rear side)

plates. Briefly, maximum laccase activity was observed in the TP zone followed by the T zone. No laccase activity was observed in the P zone as *P. chrysosporium* does not produce laccase enzyme. Studies by Martinez et al. [24] and Qian [16] also confirmed that *P. chrysosporium* does not produce laccase enzyme. *P. chrysosporium* produced laccase only in the presence of other fungal species [17]. The maximum laccase activity was observed on the 5th day of incubation after the two fungal mycelia met each other on the 3rd of incubation. The laccase activity was found to decrease after the 5th day.

Mycelial invasion of one fungus might have induced the other fungi to produce laccase during its defence [23]. A similar observation was also reported by Hiscox et al. [20] during the interaction of *Trametes versicolor* and *Bjerkandera adusta* on malt agar plates, thereby supporting the hypothesis of Score et al. [23]. Hiscox et al. [20] also reported that during interspecific interactions the production of oxidative enzymes increases. The results of this study are also comparable to that of Lakovlev and Stenlid [18], that reported a high laccase activity at the interaction zone in the PDA plate. Qian and Chen [16] also reported that *P. chrysosporium* stimulated and increased the laccase activity in *T. versicolor*.

3.3 Effect of co-culturing on dye decolourization

The influence of *T. versicolor*, *P. chrysosporium* and their co-cultures in azophloxine dye decolourization was assessed in PDA plates incubated for 5 days with 50 mg/L of dye. Figure 4 illustrates the dye decolourization potential

of *P. chrysosporium* (a_f), *T. versicolor* (b_f) and co-cultured (*P. chrysosporium* and *T. versicolor* c_f) fungal species. The results of the study indicate that after 5 days of incubation, plates inoculated with TV + PC (c_f) co-cultures showed 100% dye decolourization as compared to monocultured plates of *P. chrysosporium* (a_f) and *T. versicolor* (b_f) which showed a minimum decolourization. A control run without any fungal inoculation showed no decolourization. The complete dye decolourization in co-cultured plates may be attributed to the improved laccase production due to the synergistic action of the fungal species. Generation of free radicals such as reactive oxygen species (ROS) is a result of oxidative stress condition during hyphal interaction owing to the competition among fungi for nutrient and space. This proves coordination among species in dye decolourization [6, 26]. Moreover, an enhanced expression of phenol oxidase could have also attributed to dye decolourization [27]. The formation of phenol oxidase can be evidenced by the appearance of dark brown colour at the overlapping of fungal (TV + PC) hyphae (Fig. 3C_f). According to Cheng and Chan [28], intermediate compounds obtained during metabolic degradation might have been utilized effectively for rigorous metabolic activities, thereby making such synergistic combinations more effective.

3.4 Dye decolourization by crude enzyme extract

The crude enzyme was extracted from the interspecific interacting areas of TV + PC and intraspecific interacting areas of TV + TV, and their activities were quantified. Table 1 summarizes the laccase activity of the TV + PC and

Fig. 4 Decolourization of azophloxine dye by *P. chrysosporium* (a_f and a_f), *T. versicolor* (b_f and b_f) and co-cultivation of *T. versicolor* and *P. chrysosporium* (C_f and C_f) and (d_f) control plate

Table 1 Laccase enzyme activities of mono- and co-cultivation of TV-TV, PC-PC and TV-PC

S. no.	Strain	Laccase (U/L)
1.	TV-TV	104.15 ± 3.12
2.	PC-PC	nd
3.	TV-PC	861.11 ± 15.32

TV + TV cultures after 5 days of incubation. Maximum laccase activity of 861.11 ± 15.32 U/L was recorded in crude enzyme extracted from co-cultured plates. Around 8.2 times higher laccase activity was observed in co-cultured plates as compared to TV + TV plates that recorded laccase activity of 104.15 ± 3.12 U/L. The efficiency of the crude fungal laccase obtained from TV + PC and TV + TV was assessed in azophloxine dye solution (Fig. 5). During the 48-h incubation period, the crude fungal laccase obtained from TV + PC showed a decolourization efficiency of 50% at 24th hour and 87.6% at the 48th hour. Likewise, crude laccase of TV + TV showed a maximum decolourization efficiency of 14.4% after 48 h of incubation. The results of the present study are in complete agreement with Dwivedi et al. [29] and Wang et al. [30] that reported enhanced lignocellulolytic enzymes during the co-culturing of *Pleurotus ostreatus* and *Penicillium oxalicum*. In co-culture systems, the combined and inductive effects of various enzymes can work synergistically over monocultures [31, 32]. The results of the present study signify

that co-culturing can be efficiently used for degradation of dyes to maintain tighter stringent government standards with respect to disposal of dye effluents into the environment.

4 Conclusion

The observations recorded in this study confirmed the production of 8.2 times higher laccase activity at the interaction zone of co-cultured *T. versicolor* and *P. chrysosporium* as compared to self-pairing plates of *T. versicolor*. The *T. versicolor* and *P. chrysosporium* co-cultures showed excellent potential and decolourized the azophloxine dye completely in PDA plates incubated for 5 days. The crude fungal laccase extracted from the co-cultured and self-pairing plates of *T. versicolor* also showed azophloxine dye decolourization of 87.6% and 14.4%, respectively, within 48 h of incubation. Co-culturing has brought changes in the hyphal morphology in the fungal strains and initiated synergistic interaction to enhance the laccase production and dye decolourization. Thus, co-culturing of fungal strains holds great potential for the decolourization of recalcitrant textile dyes.

Fig. 5 Decolourization profiles of azophloxine dye by crude enzyme extract of TV-PC and monocultivation of TV

Acknowledgements The authors are grateful to University Grants Commission (UGC), New Delhi, India, for providing financial support.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights This article does not contain any studies involving animals or human participants performed by any of the authors.

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