Acta Scientiarum

http://periodicos.uem.br/ojs/acta
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v40i1.35610

BIOTECHNOLOGY

Strategies for decolorization of textile industry effluents by white-rot-fungi with peach palm residue

Juliane Andressa Chicatto[1*], Hayssa Carolini Alamar Nunes[1], Marcel Jefferson Gonçalves[2], Cristiane Vieira Helm[3], Deisi Altmajer Vaz[4] and Lorena Benathar Ballod Tavares[1]

*[1]Programa de Pós-Graduação em Engenharia Ambiental, Universidade Regional de Blumenau, Rua São Paulo, 3250, 89030-000, Blumenau, Santa Catarina, Brazil. [2]Departamento de Engenharia Química, Universidade Regional de Blumenau, Blumenau, Santa Catarina, Brazil. [3]Embrapa Florestas, Empresa Brasileira de Pesquisa Agropecuária, Colombo, Paraná, Brazil. [4]Departamento de Engenharia Química, Universidade de Granada, Av. del Hospicio, s/n, 18010 Granada, Spain. *Author for correspondence. E-mail: julianech@correo.ugr.es*

ABSTRACT. The aim of this interdisciplinary approach is to provide innovative solutions to environmental problems, in particular, improving the treatment of textile industrial effluents and finding a use for the residual biomass generated from palm tree (*Bactris gasipaes*) extraction. Three types of white-rot fungi were cultivated applying different strategies for the decolorization the textile effluents: i) solid-state fermentation (SSF), ii) submerged fermentation (SF), and iii) adsorption. In all cases, it was used the peach-palm residue. In the SSF strategy, the decolorization process and laccase production were enhanced by increasing the concentration of final effluent. Even though the highest decolorization percentage (80%) was attained after 10 days of fermentation with *G. lucidum* EF 31 applied in the treatment of a final effluent, no significant differences were found in relation to the other two fungi. The decolorization efficiency obtained in the SF was lower compared with SSF, however, the presence of final effluent in the SF process improved the laccase activity. It was noted that the addition of peach-palm residue in this system provides a habitat for the fungus as well as a suitable source material for laccase production with the consequent decolorization of the effluent.

Keywords: *Ganoderma lucidum*; *Trametes versicolor*; *Bactris gasipaes*; laccases.

Estratégias de descoloração de efluentes da indústria têxtil por fungos de podridão branca com resíduo de pupunha

RESUMO. O objetivo desta abordagem interdisciplinar é fornecer soluções inovadoras para problemas ambientais, em particular, na melhoria do tratamento de efluentes industriais têxteis e encontrar um uso para a biomassa residual gerada a partir da extração de palmeiras (*Bactris gasipaes*). Três tipos de fungos de podridão-branca foram cultivados aplicando diferentes estratégias para a descoloração dos efluentes têxteis: i) fermentação em estado sólido (SSF), ii) fermentação submersa (SF), e iii) adsorção. Em todos os casos, foi utilizado o resíduo de pupunha. Na estratégia SSF, o processo de descoloração e a produção de lacase aumentaram conforme a concentração de efluente final aumentava. Embora a maior percentagem de descoloração (80%) tenha sido obtida após 10 dias de fermentação com *G. lucidum* EF 31 aplicado no tratamento com efluente final, não foram encontradas diferenças significativas em relação aos outros dois fungos. A eficiência de descoloração obtida no SF foi menor em comparação com SSF, no entanto, a presença de efluente final no processo SF aumentou a produção da lacase. Foi observado que a adição do resíduo de pupunha neste sistema serviu como habitat natural para o fungo, além do mais, serviu como material de suporte e fonte adequada para a produção de lacase, como consequência descoloração do efluente.

Palavras-chave: *Ganoderma lucidum*; *Trametes versicolor*; *Bactris gasipaes*; lacases.

Introduction

In recent decades, environmental problems have increased due to population growth and industrial expansion, resulting in the widespread generation of wastes and the excessive consumption of natural resources.

The concept of environmental sound practices at industry has emerged as a response to the need to reduce environmental impacts and the costs (Zhang, Zheng, & Fath, 2014; Wang, Feng, & Chu, 2014). Hence, efforts have been made to treat and reuse industrial waste.

Wastewater from the textile industry is one of the most problematic types of effluent to treat due to its color and its high chemical oxygen demand (COD) and biochemical oxygen demand (BOD),

along with the presence of suspended solids, turbidity and toxic compounds (Kanu, Ijeoma, & Achi, 2011). The dye concentrations in the textile processing wastewaters are in the range of 10-200 mg L^{-1} (Kadam, Telke, Jagtap, & Govindwar, 2011), which interferes in the penetration of sunlight into waters, retards photosynthesis, inhibits the growth of aquatic biota and affects gas solubility in water bodies (Banat, Nigam, Singh, & Marchant, 1996). Furthermore, many dyes are believed to be carcinogenic or are synthesized from known carcinogens (Clarke & Anliker, 1980). In addition, effluents from the textile industry contain many toxic compounds (Szalinska, Dominik, Vignati, Bobrowski, & Bseasonal, 2010). The decolorization of this industrial waste represents a considerable challenging because certain dyes are resistant to degradation. Chemical, physical and biological methods are used for the removal of dyes from wastewater (Kadam, Lade, Patil, & Govindwar, 2013), however, several of them have disadvantages such as high costs and/or limited applicability. Also, due to the low efficacy of the traditional approaches to treatment, the development of new processes are required.

White-rot fungi (WRF) are by far the most efficient micro-organisms in breaking down synthetic dyes, due to their ability to produce nonspecific extracellular lignin-degrading enzymes (Wesenberg, Kyriakides, & Agathos, 2003). Considering their ability to produce large amounts of ligninolytic enzymes, along different types of phenoloxidases, with a broad range of substrates, WRF offer excellent 'green' potential for the handling of many problematical types of persistent organic pollutants (Kües, 2015).

The use of agro-industrial residues as the culture medium for WRF could offer some advantages: they are easily available at low cost, can act as a selective carbon source for fungi, represent a physical support, serve as an adsorption agent for further biodegradation, can provide a habitat for these fungi, can also, enhance the expression of ligninolytic enzymes, and are a source of natural mediators (Palli et al., 2015), which are often necessary for the degradation of non-phenolic compounds by laccases (Guiza, Ghiloufi, & Bagane, 2014). In addition, this technique allows the utilization of diverse agro-industrial wastes as support-substrate, making the process more economical and eco-friendly (Kadam, Kamatkar, Khandare, Jadhav, & Govindwar, 2013).

The peach palm (*Bactris gasipaes* Kunth) plant is widespread in Brazil and is one of the major producers of the hearts of palm (locally known as 'palmito') (Helm, Raupp, & Santos, 2014), with a harvested area of 22, 537 ha and a production of 109, 409 tons in 2015. The residue (leaf sheath) of the stem generated by the industry during the processing of canned hearts of palm corresponds to around 85-95% of the weight of the palm depending on the species. Currently, it has no economic value and it has the potential for important environmental impact (*Instituto Brasileiro de Geografia e Estatística* [IBGE], 2015).

In this context the aim of this interdisciplinary approach was to provide innovative solutions to environmental problems, in particular, finding a use for the residual biomass generated from peach palm extraction and improving the treatment of effluents generated by the textile industry. Tests were carried out to investigate the potential of the ligninolytic complex produced by fungi grown applying submerged and solid-state fermentation to remove the color from dye effluents. The significance of the dye adsorption onto peach palm residue was also studied.

Material and methods

Microorganisms and inoculum

Three white-rot fungi (WRF) were used in this study: (i) *Ganoderma lucidum* EF 31, which was kindly provided by the National Research Center for Forestry/Embrapa Forests (Colombo, state Paraná, Brazil), (ii) *Ganoderma lucidum* DSM 9621, from the German Collection of Microorganisms and Cell Cultures, and (iii) *Trametes versicolor* CECT 20817, acquired from the Spanish Type Culture Collection. The WRF were cultivated in Petri dishes containing potato dextrose agar (PDA) medium for seven to ten days at 25±1°C in the absence of light. The cultures were then stored at 4°C for a maximum of 2 weeks.

Industrial dyeing waste waters

Two waste waters from a textile dyeing process were employed in the decolorization tests:(i) the effluent produced from the washing of the dyed material, called the residual dye bath effluent (RDB), and (ii) the final effluent (FE) collected at the end of the primary physicochemical treatment and prior to biological treatment in the treatment plant. Both effluents were kindly supplied by a textile plant located in Santa Catarina State, Brazil. Since the RDB is generated during only one operation of the industrial process, its volume is low when compared to the final effluent. However, it

contains much higher levels of organic matter, color, total solids, and other important parameters, compared with FE. The chemical and physical characterization of the effluents was carried out applying the Standard Methods for the Examination of Water and Wastewater.

Peach-palm residue

The peach-palm (*Bactris gasipaes*) residue was employed in all decolorization tests performed in this study. The residue is an abundant agro-industrial waste generated from palm tree extraction, and it was kindly provided by an agribusiness company (Santa Catarina State, Brazil). Briefly, the residue was milled in a knife mill to give a particle size of 2 mm and dried at 60ºC for 24 hours prior to use.

Experimental strategy

In order to minimize the impact of textile industry effluents on the environment, three different strategies for the decolorization of dyeing waste waters were tested: (1) solid-state fermentation (SSF); (2) submerged fermentation (SF); and (3) adsorption onto peach-palm residue. In all cases, peach-palm residue was used in the treatment process.

Solid-state fermentation

Solid-state fermentation by white-rot fungi in the presence of industrial effluent and peach palm residue was carried out in flasks with a 1 L capacity. In this procedure, 10 g of peach-palm residue were transferred to each flask together with 20 mL of a mineral medium (Zhou, Su, & Zhan, 2011) and autoclaved (121°C for 15 min). The effluent (RDB or FE, previously autoclaved) and the inoculum (1/6 of a Petri dish of the fungus) were transferred to the flasks. Liquid extracts (LEs) were prepared by mixing the sample from the flasks with 50 mL of distilled water for 3 hours at 100 rpm and 20±1°C. The solids were separated from the LEs by vacuum filtration followed by centrifugation (15 min at 4ºC and 5000 rpm). The liquid extracts were then used to evaluate all analyses. Table 1 presents the experimental planning for solid-state fermentation.

Submerged fermentation

Submerged fermentation assays were carried out on a rotary shaker at 28ºC and 150 rpm for 14 days. The culture medium was composed of 12 mL of final effluent, 48 mL of mineral medium (Zhou et al., 2012) and 2 g of peach-palm residue. The Erlenmeyer flasks (250 mL capacity) containing the culture medium were autoclaved and 0.5 cm micellium PDA agar plugs were inoculated with *G. lucidum* EF 31. After 14 days of incubation, the biomasses were filtered and the remaining solids were separated by centrifugation at 9000 rpm for 15 min at 4ºC. All experiments were performed in triplicate. A control assay was performed with distilled water, i. e., without the addition of the final effluent.

Table 1. Solid-state fermentation by WRF with textile effluent and peach-palm residue.

Assay	WRF	Type of effluent	Effluent concentration (%)	Volume of liquid (mL)	Fermentation time (d)
1	*G. lucidum* EF 31	FE	0, 25, 50, 75, 100	60	14
2	*G. lucidum* EF 31	RDB	0, 25, 50, 75, 100	60	14
3	*G. lucidum* EF 31	FE	100	20	30
4	*G. lucidum* EF 31	FE	100	40	30
5	*G. lucidum* EF 31	FE	100	60	30
6	*G. lucidum* DSM 9621	FE	100	40	30
7	*T. versicolor*	FE	100	40	30

Adsorption experiments

The adsorption experiments were performed with 60 mL of the RDB or FE (25, 50, 75 and 100%) for 14 days. In these tests, the experimental conditions described in the section on the solid-state fermentation were applied, but without the addition of the inoculum. All experiments were performed in triplicate. A control assay was carried out with distilled water, i. e., without the addition of an effluent.

Evaluation of the decolorization process

The color removal efficiency (E_D, %) was determined by comparing the initial absorbance value for the dyeing wastewaters with the value obtained at the end of the SSF and SLF fermentations. Initially, as wept-wavelength absorbance value was obtained (Pereira, Bueno, Santos, Lima, & Dias, 2010) for the residual dye bath and final effluents, the maximum absorption of the dyes present being 593 nm.

Laccase and manganese peroxidase activities

Laccase activity (A_{la}) was determined from samples of the liquid extracts, as described by Hou, Zhou, Wang, Du, and Yan (2004). In this procedure, 0.1 mL of LE were transferred to test tubes with 0.8 mL of 2, 2'-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) solution, 0.1 mL of acetate buffer (pH 4.0) and 0.1 mL of distilled water. The

test-tubes were placed in an oven at 30°C for 0 min. Control tests were also performed by mixing 0.8 mL ABTS to 0.1 mL acetate buffer. The oxidation of ABTS and control samples were monitored by measuring the absorbance at 420 nm (ε = 36 mM^{-1} cm^{-1}) every 15 s for 2 min. The activity of manganese peroxidase (MnP) was performed by mixing 0.4 mL of sample with 0.4 mL of hydrogen peroxide [0.5 mM], 2.8 mL of sodium malonate buffer [50 mM] pH 4.5 and 0.4 mL [10 mM] of manganese sulfate in a test tube, as described by Wariishi, Valli, and Gold (1992). The oxidation reaction was followed by measuring the absorbance of the samples at 270 nm (ε = 11.59 mM^{-1} cm^{-1}). The enzyme activity is expressed in U mL^{-1}, which represents the amount of enzyme that oxidizes one μmol of substrate to product per min. All experiments were performed in triplicate.

Concentration of total phenolic compounds

The concentration of total phenolic compounds was determined by the Folin-Ciocalteu method, as described by Anagnostopoulou, Kefalas, Papageorgiou, Assimopoulou, and Boskou (2006). Briefly, 0.5 mL of sample, 5 mL of distilled water and 0.25 mL of Folin-Ciocalteu's reagent were mixed in a test tube. After 3 min, 1 mL of saturated Na_2CO_3 was transferred to the tubes and the mixture was left to stand for 1 hour in the dark. The absorbance of the samples was measured at 725 nm. A blank with distilled water was also analyzed. The determination of total phenols was performed from a standard curve constructed with solutions of gallic acid (0 and 500 μg mL^{-1}).

Total organic carbon concentration

The concentration of total organic carbon (TOC) was obtained by determining the total carbon (TC) and total inorganic carbon (TIC) contents separately in a TOC analyzer, model TOC-V CHS (Shimadzu, Kyoto, Japan). The measurements were carried out at a least three times.

Moisture content and pH

The moisture content (Equation 1) of the cultured samples was determined by the gravimetric method described by Hermann, Vegini, Costa, Tavares, and Guedes (2013). Briefly, three samples (5 g each) taken from the flasks after 14 days of the solid-state cultivation were dried at 60ºC until constant weight. The moisture content (MC) was calculated using the following equation:

$$MC(\%) = \frac{MC_i - MC_f}{MC_i} \cdot 100 \quad (1)$$

where:
MC_i and MC_f correspond to the values for the initial and final moisture content of the samples. The pH values were measured at time zero and at the end of fermentations. The liquid extracts were prepared as described in the solid-state fermentation section.

Results and discussion

The physicochemical compositions of the industrial wastewaters are shown in Table 2. The two effluents were obtained from different locations of an industrial plant. The residual dye bath effluent (RDB) was collected from the location where the dyed material is washed. The final effluent (FE) was collected at the end of the primary physicochemical treatment and prior to biological treatment at the treatment plant for the entire industrial process. Thus, the two effluents are very distinct with different compositions in terms of organic compounds, metals, salts, dyes, chemical and biochemical oxygen demand (COD/BOD), total dissolved solid (TDS), total suspended solid (TSS), and pH (Kabra, Khandare, & Govindwar, 2013). Furthermore, the final effluent originates from all areas involved in the industrial process where water is used, and it is therefore much more dilute than the residual dye bath effluent.

To study the influence of the industrial wastewater concentration on the decolorization efficiency and laccase production, SSF experiments were carried with *G. lucidum* EF31 using several dilutions of the FE and RDB effluents (0, 25, 50, 75 and 100%). The corresponding results are shown in Figure 1 and 2. Independently of the initial pH, no significant differences were found in the pH values at end of tests (4.8±0.1, at 14 days) conducted with FE and RDB.

As can be observed in Figure 1, an increase in the RDB concentration negatively affected the color removal efficiency, which varied from 52.1% (25% effluent) to 10.4% (100% effluent). Thus, the experimental data clearly indicate an inhibitory effect of this effluent on the fungus metabolism, which varies according to the RDB concentration. Similarly, the laccase production was negatively influenced by increases in the RDB concentration (Figure 2).

Table 2. Physicochemical characterization of the two textile effluents.

Parameter	Residual dye bath effluent	Final effluent
pH	11.34	10.19
BOD (mg L^{-1})	992.00	239.00
COD (mg L^{-1})	2600.00	789.00
Turbidity (FTU)	58.20	113.00
Color (Pt Co)	5500.0	903.0
Total solids (mg L^{-1})	30456.00	1368.00
Suspended solids (mg L^{-1})	153.33	227.50
Volatile solids (mg L^{-1})	123.33	2.69
Nitrogen(mg L^{-1})	88.60	<0.01
Total phenols (mg L^{-1})	0.01	0.020
Cu (mg L^{-1})	0.367	0.024
Fe (mg L^{-1})	0.19	0.10
Ni (mg L^{-1})	<0.01	<0.01
Cd (mg L^{-1})	<0.001	<0.001
As (mg L^{-1})	0.02	<0.01
Ba (mg L^{-1})	<0.20	<0.20
Pb (mg L^{-1})	<0.01	<0.01
Cr (mg L^{-1})	<0.01	0.01
P (mg L^{-1})	7.46	2.54
Mn (mg L^{-1})	<0.05	<0.05
Hg (mg L^{-1})	<0.0002	<0.0002
Ni (mg L^{-1})	<0.01	<0.01
Zn (mg L^{-1})	0.05	0.05
Sulfides (mg L^{-1})	0.81	0.14

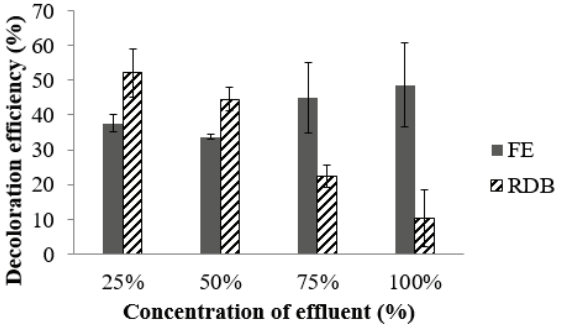

Figure 1. Decolorization efficiency observed in the SSF assays carried out with 60 mL of FE or RDB.

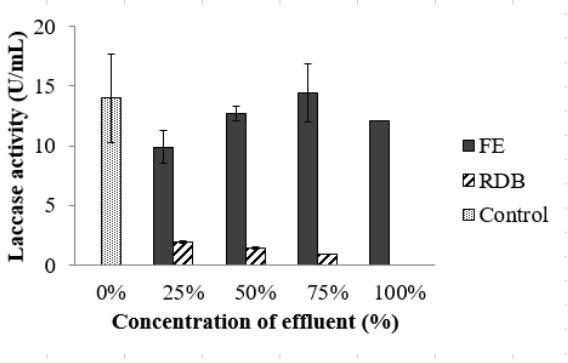

Figure 2. Laccase activity found in SSF assays carried out with FE and RDB.

On the other hand, these findings were not observed in the assays performed with the final effluent. In this case, the decolorization efficiency and laccase production tended to increase with increasing FE concentration. In addition, the values for the laccase activity obtained with the final effluent and the control are nearly the same. Regarding the manganese peroxidase, its production was negligible under all experimental conditions assayed. Similar results have been reported by Mota et al. (2015) who observed that *G. lucidum* did not produce MnP.

It is well known that some industrial effluents are toxic toward white-rot fungi and in these cases the enzyme production and decolorization process are inhibited (Younes, Ellouze, & Sayadi). The differences in the results obtained with EF and RDB can be attributed to the compositions of the two wastewaters, which differ particularly in terms of the dye concentration (Table 2). Under the experimental conditions, it was observed that on diluting the RDB effluent to at least 50% the E_D values were similar to those obtained with FE. However, since the E_D values are still low (around 50%), it is necessary to optimize the SSF conditions to enhance the decolorization process.

Regarding the laccase activity, there were no significant differences between the results obtained with FE and the control. In contrast, in the tests performed with RDB, the laccase activity was at least 5 times lower than that obtained at different concentrations of FE.

Regardless of the phenolic compounds contents of the liquid extracts carried out with 100% of FE and RDB, the values decreased over the 14 days of fermentation to 0.02 and 0.09 μg mL^{-1}, respectively. These values represent reductions in the phenolic compounds content of 66.4 and 53.3%, respectively. Thus, the treatment process which provides the greatest reductions in both the phenolic compounds content and the laccase production was SSF carried out with FE.

With the aim to improving the efficacy of the process, new SSF assays were carried out with lower moisture content and also with another two strains of WRF, *G. lucidum* DSM9621 and *Trametes versicolor* CECT 20817. Figure 3 shows the decolorization efficacy and Figure 4 the laccase production during these experiments. Although the highest decolorization percentage (80%) was attained after 10 days of fermentation with *G. lucidum* EF 31, no significant differences were found in relation to the other two fungi. Furthermore, except for *T. versicolor*, the decolorization efficiency remained constant ($p > 0.05$) throughout 30 days of fermentation.

Interestingly, independently of the WRF used, the laccase activity decreased over time during the solid cultivation tests (Figure 4). The values for the laccase activity obtained in the assays conducted

with the final effluent are higher than those reported by Elisashvili, Kachlishvili, and Penninckx (2008). The cited authors performed SF assays with *T. versicolor*using a culture medium supplemented with 4 g L^{-1} of yeast extract and 50 g L^{-1} of different lignocellulosic biomasses and the laccase activity varied from 0.54 to 3.01 U mL^{-1}.

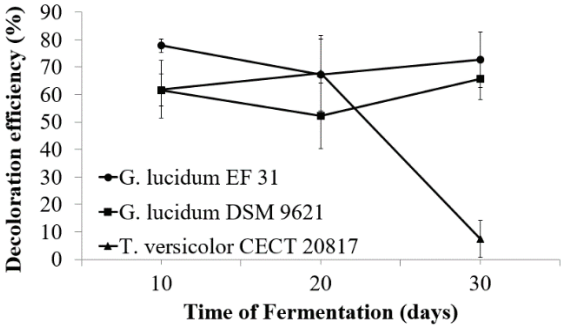

Figure 3. Time course in SSF experiments carried out with 40 mL of final effluent (100%) and three different WRF for decolorization efficiency^{-1}).

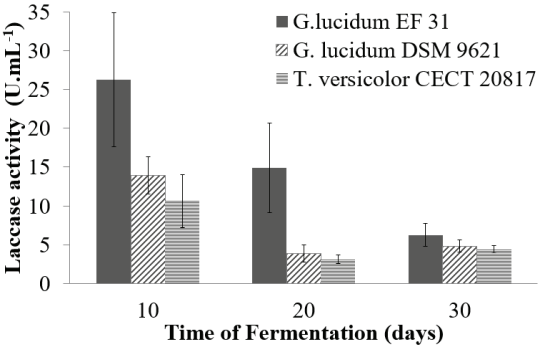

Figure 4. Time course in SSF experiments carried out with 40 mL of final effluent (100%) and three different WRF for Laccase activity.

The reduction in the total organic carbon (TOCr) in the liquid extracts was also evaluated as a function of the fermentation time. The highest TOCr values were obtained with *G. lucidum* EF 31. *Trametes versicolor* also demonstrated good potential for reducing the TOC, presenting values close to those observed with *G. lucidum* EF 31. Regarding the efficacy of *G. lucidum* DSM 9621, its ability to degrade the FE presented a linear increase over time. Remarkably, under all assay conditions, it was found that the concentration of inorganic carbon in the samples was negligible. On comparing the data on the decolorization efficacy with the TOC_r values, it can be verified that TOC_r is not directly related to the color removal. This finding could be attributed to the complex composition of the final effluent, the dyes being only one of the components.

The TOCr values for the SSF assays carried out with *G. lucidum* EF 31 and different volumes of final effluent (20 and 60 mL). Interestingly, when the moisture content was low (20 mL), the TOC reduction decreased over time from 62.3 (10 days) to 10.9% (30 days). In contrast, at a volume of 60 mL of FE, the TOC reduction increased over time, reaching a maximum of 65.4% after 30 days.

Regarding to the pH of the liquid extracts, it was verified that with the *Ganoderma lucidum* strains the pH was slightly higher than that observed in the assays conducted with *T. versicolor*, i. e., 5.1±0.1 and 4.9±0.1, respectively. This pH behavior has been previously reported in the literature (Zadrazil & Brunnet, 1981, Murugesan, Nam, Kim, & Chang, 2007) and it is associated to the capacity of some white rot fungi to establish the optimum pH of the substrate for growth.

Table 3 summarizes the values obtained for the decolorization efficiency, laccase activity, pH and surface tension of the solid-free supernatant after 14 days of submerged fermentation. No statistical differences were found between the values for the pH, ST and phenolic compounds concentration obtained in assays performed with the final effluent and the control (distilled water). It can be observed that the decolorization efficacy values obtained in these tests were much lower than those observed in the SSF assays. Additionally, although the presence of FE in the culture medium improved the laccase activity (from 0.5 to 1.4 U mL^{-1}), the values obtained are considered low when compared to data published in the literature. Elisashvili and Kachlishvili (2009) reported values for laccase activity of 20.8 to 75.4 U mL^{-1} in submerged cultivation tests with strains of *G. lucidum* using mandarin peelings in the medium. No MnP production was detected. Hence, under our experimental conditions, SF did not represent an appropriate alternative to treat these effluents. Compared to SSF, the decolorization process and laccase production are not favored in the SF process.

Table 3. Experimental results for the SF assays carried out with *G. lucidum* EF 31.

	pH		TS (mN m^{-1})		E_D (%)		A_{la} (U mL)		Phenolic compounds	
	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
Final effluent	3.82	0.07	52.0	1.56	40.97	5.11	1.39	0.35	0.02	0.00
Control	3.81	0.05	57.65	3.18	---	---	0.55	0.05	0.02	0.00

The adsorption experiments (Figure 5) were performed under the same conditions applied in the SSF assays. The efficacy of the decolorization

process was 67.2±3.6% in the tests carried out with the final effluent at a concentration of 75%. In the solid-state fermentation experiments carried out with *G. lucidum* EF 31, the highest decolorization percentage was 80 with 100% of final effluent. Waghmare, Kadam, Saratale, and Govindwar (2014) obtained an absorption of 60% for Reactive Blue 172 onto a residue of sugar cane bagasse and *Providensia staurti* in solid-state fermentation with bagasse as a dye adsorbent they achieved more than 99% of decolorization. Concerning the experiments with RDB, there was clearly no relationship between the adsorption and the dye concentration, the decolorization efficiency being 17.73±8.2 with 25% of effluent.

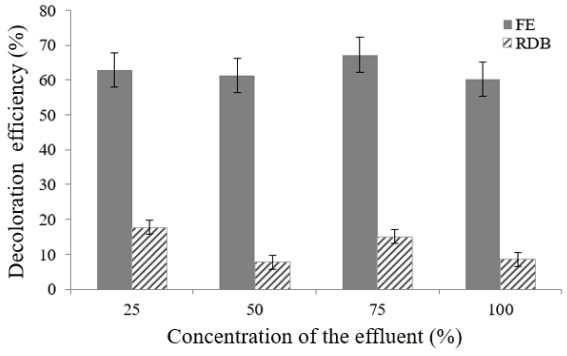

Figure 5. Decolorization efficiency obtained in the adsorption assays carried out with 60 mL of FE and RDB.

The interactions between the dyes and these fibers have received considerable interest. The structure of peach palm sheaths is comprised of 21.65 lignin and 73.51% holocellulose (hemicellulose and cellulose). Cationic dyes clearly have a higher affinity for lignin-containing fibers, and the presence of a positive charge plays an important role in the dye affinity for lignin (Drnovsek & Perdih, 2005).

Agricultural wastes are known to be the best low cost adsorbents for textile dyes and adsorption is an economically viable approach to the treatment for effluents containing dyes (Gupta & Suhas, 2009). On the other hand, the removal of dyes from textile effluent using exclusively the adsorption technique does not ensure the complete removal of the dye from the environment (Nigam, Armour, Banat, Singh, & Marchant, 2000), which leads to other serious environmental challenges. However, after the removal of the textile dyes, adsorbed onto agricultural wastes, the solid-state fermentation ensures the complete removal of the textile dye (Sarkar, Pal, Ghorai, Mandre, & Pal, 2014). In addition, the biomass generated after the bioremediation applying solid-state fermentation could be used as agricultural manure.

Conclusion

This study on the decolorization of textile dyes using white-rot fungi and peach-palms heaths opens new perspectives for up-scaling. Solid-state fermentation was found to be a suitable system for treating the final effluent, comprised of waste waters from all stages of the industrial process. In addition, it was verified that peach-palm sheath is a very useful agent offering support to the system, stimulating the development of fungal hyphae and the production of laccases. All three fungi studied degraded the effluent by producing enzymes. In particular, *G. lucidum* EF 31 was found to be able to grow under restrictive conditions and proved to be more effective in the decolorization of the final effluent.

Acknowledgements

This research was supported by the Brazilian Ministry of Science, Technology and Innovation (MCTI) (Grant 402593/2013-8). The authors are grateful to the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* (Capes) and *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) for scholarships. The author L. B. B. Tavares is the holder of a CNPq fellowship.

References

Anagnostopoulou, M. A., Kefalas, P., Papageorgiou, V. P., Assimopoulou, N., & Boskou, D. (2006). Radical scavenging activity of various extracts and fractions of sweet orange peel (*Citrus sinensis*). *Food Chemistry, 94*(1), 19-25. doi 10.1016/j.foodchem.2004.09.047

Banat, I. M., Nigam, P., Singh, D., & Marchant, R. (1996). Microbial decolourization of textile dyes containing effluents: a review. *Bioresource Technology, 58*(1), 217-227. doi 10.1016/S0960-8524(96)00113-7

Clarke, E. A., & Anliker, R. (1980). *Organic dyes and pigments*. In: Anthropogenic Compounds. The Handbook of Environmental Chemistry. *Anthropogenic compounds, the handbook of environmental chemistry. Part A (p. 181-215).* Berlim: DE: Springer-Verlag. doi: 10.1007/978-3-540-38522-6.

Drnovsek, T., & Perdih, A. (2005). Selective staining as a tool for wood fiber characterization. *Dyes Pigment, 67*(1), 197-206. doi 10.1016/j.dyepig.2004.10.013

Elisashvili, V., & Kachlishvili, E. (2009). Physiological regulation of laccase and manganese peroxidase production by white-rot Basidiomycetes. *Journal of Biotechnology, 144*(1), 37-42. doi 10.1016/j.jbiotec.b2009.06.020

Elisashvili, V., Kachlishvili, E., & Penninckx, M. (2008). Effect of growth substrate, method of fermentation, and nitrogen source on lignocellulose-degrading enzymes production by white-rot basidiomycetes. *Journal of Industrial Microbiology and Biotechnology, 35*(1), 1531-1538. doi 10.1007/s10295-008-0454-2

Guiza, S., Ghiloufi, K., & Bagane, F. M. (2014). Utilization of waste Tunisian palm tree date as low-cost adsorbent for the removal of dyes from textile wastewater. *Mediterranean Journal of Chemistry, 3*(5), 1044-1052. doi: http://dx.doi.org/

Gupta, V., & Suhas, S. (2009). Application of low-cost adsorbents for dye removal-a review. *Journal of Environmental Management, 90*(8), 2313-2342. doi 10.1016/j.jenvman.2008.11.017

Helm, C. V., Raupp, D. S., & Santos, A. F. (2014). Development of peach palm fibrous flour from the waste generated by the heart of palm agribusiness. *Acta Scientiarum. Technology, 36*(1), 171-177. doi 10.4025/actascitechnol.v36i1.17165

Hermann, K. L., Vegini, A. A., Costa, A., Tavares, L. B. B., & Guedes, F. F. (2013). Expression of manganese peroxidase by *Lentinula edodes* and *Lentinula boryana* in solid state and submerged system fermentation. *Anais da Academia Brasileira de Ciências, 85*(1), 965-973. doi 10.1590/S0001-37652013000300009

Hou, H., Zhou, J., Wang, J., Du, C., & Yan, B. (2004). Enhancement of laccase production by *Pleurotusostreatus* and its use for the decolorization of anthraquinone dye. *Process Biochemistry, 39*(1), 1415-1419. doi 10.1016/S0032-9592(03)00267-X

Instituto Brasileiro de Geografia e Estatística [IBGE]. (2015). Censo Agropecuário 2015. Retrieved from https://www.ibge.gov.br/home/estatistica/economia/forum_questionario_censoagro2015/Censo_Agropecuario_2015. Pdf

Kabra, A. N., Khandare, R. V., & Govindwar, S. P. (2013). Development of a bioreactor for remediation of textile effluent and dye mixture: a plant-bacterial synergistic strategy. *Water resources, 47*(1), 1035-1048. doi 10.1016/j.watres.2012.11.007

Kadam, A. A., Kamatkar, J. D., Khandare, R. V., Jadhav, J. P., & Govindwar, S. P. (2013). Solid-state fermentation: tool for bioremediation of adsorbed textile dyestuff on distillery industry waste-yeast biomass using isolated *Bacillus cereus* strain EBT1. *Environmental Science and Pollution Research, 20*(2), 1009-1020. doi 10.1007/s11356-012-0929-6

Kadam, A. A., Lade, H. S., Patil, S. M., & Govindwar, S. P. (2013). Low cost $CaCl_2$ pretreatment of sugarcane bagasse for enhancement of textile dyes adsorption and subsequent biodegradation of adsorbed dyes under solid state fermentation. *Bioresource Technology, 132*, 276-284. doi 10.1016/j.biortech.2013.01.059

Kadam, A. A., Telke, A. A., Jagtap, S. S., & Govindwar, S. P. (2011). Decolorization of adsorbed textile dyes by developed consortium of Pseudomonas sp. SUK1 and *Aspergillus ochraceus* NCIM-1146 under solid state fermentation. *Journal of Hazardous Materials, 189*(1-2), 486-494. doi 10.1016/j.jhazmat.2011.02.066

Kanu, O. K., Ijeoma, O. K., & Achi, O. K. (2011). Industrial effluents and their impact on water quality of receiving rivers in Nigeria. *Journal of Applied Sciences in Environmental Sanitation, 1*(1), 75-86.

Kües, U. (2015). Fungal enzymes for environmental management. *Current Opinion in Biotechnology, 33*(1), 268-278. doi 10.1016/j.copbio.2015.03.006

Mota, T. R., Kato, C. G., Peralta, R. A., Bracht, A., Morais, G. R., Baesso, M. L., … Peralta, R. M. (2015). Decolourization of Congo red by *Ganoderma lucidum* Laccase: Evaluation of degradation products and toxicity. *Water Air and Soil Polluttion, 226*(1), 350-361. doi 10.1007/s11270-015-2612-2

Murugesan, K., Nam, I. H., Kim, Y. M., & Chang, Y. S. (2007). Decolorization of reactive dyes by a thermostable laccase produced by *Ganoderma lucidum* in solid state culture. *Enzyme Microbiology and Technology, 40*(1), 1662-1672. doi 10.1016/j.enzmictec. 2006.08.028

Nigam, P., Armour, G., Banat, I. M., Singh, D., & Marchant, R. (2000). Physical removal of textile dyes and solid state fermentation of dye adsorbed agricultural residues. *Bioresource Technology, 72*(3), 219-226. doi 10.1016/S0960-8524(99)00123-6

Palli, L., Gullotto, A., Tilli, S., Gori, R., Caniani, D., & Scozzafava, A. (2015). Enzymatic treatment of petrochemical wastewater containing 2-naphthalene sulfonated polymers by *Pleurotusostreatus*. *Current Biotechnology, 4*(1), 149-156. doi 10.2174/221155 010402150730165528

Pereira, A. R. B., Bueno, F. L., Santos, S. C., Lima, C. A. A., & Dias, A. L. T. (2010). Biodegradation of dyes and textile effluents by fungi. *Holos Environment, 10*(1), 165-179. doi 10.1590/S1517-83822006000400015

Sarkar, A. K., Pal, A., Ghorai, S., Mandre, N. R., & Pal, S. (2014). Efficient removal of malachite green dye using biodegradable graft copolymer derived from amylopectin and poly (acrylic acid). *Carbohydrate Polymers, 111*(1), 108-115. doi 10.1016/j.carbpol. 2014.04.042

Szalinska, E., Dominik, J., Vignati, D. A. L., Bobrowski, A., & Bseasonal, B. A. S. (2010). Transport pattern of chromium (III and VI) in a stream receiving wastewater from tanneries. *Applied Geochemistry, 25*(1), 116-122. doi 10.1016/j.apgeochem.2009.11.002

Waghmare, P. R., Kadam, A. A., Saratale, G. D., & Govindwar, S. P. (2014). Enzymatic hydrolysis and characterization of waste lignocellulosic biomass produced after dye bioremediation under solid state fermentation. *Bioresource Technology, 168*(1), 136-141. doi 10.1016/j.biortech.2014.02.099

Wang, G., Feng, X., & Chu, K. H. (2014). Symbiosis analysis on industrial ecological system Chinese. *Chemical Engineering Journal, 22*(1), 690-698. doi 10.1016/S1004-9541(14)60084-7

Wariishi, H., Valli, K., & Gold, M. H. (1992). Manganese (II) oxidation by manganese peroxidase from the basidiomycete *Phanerochaete chrysosporium*. *Journal of Biological Chemistry, 267*(1), 23688-23695.

Wesenberg, D., Kyriakides, I., & Agathos, S. N. (2003). White-rot fungi and their enzymes for the treatment of industrial dye effluents. *Biotechnology Advances, 22*(1), 161-187.

Younes, S. B., Ellouze, M., & Sayadi, S. (2013). A comparative study of an industrial effluent treatment using enzymatic and alkaline adapted consortium assays. *Journal of Chemical Technology and Biotechnology, 88*(4), 563-571. doi 10.1002/jctb.3862

Zadrazil, F., & Brunnet, H. (1981). Investigation of physical parameters important for the solid state fermentation of straw by white rot fungi. *European Journal of Applied Microbiology and Biotechnology, 11*(1), 183-188.

Zhang, Y., Zheng, H., & Fath, B. D. (2014). Ecological network analysis of an industrial symbiosis system: a case study of the Shandong Lubei eco-industrial park. *Ecological Modelling, 22*(1), 690-698. doi 10.1016/j.ecolmodel.2014.05.005

Zhou, X. W., Su, K. Q., & Zhan, Y. M. G. (2012). Applied modern biotechnology for cultivation of *Ganoderma* and development of their products. *Applied Microbiology and Biotechnology, 93*(1), 941-963. doi 10.1007/s00253-011-3780-7

Received on February 24, 2017.
Accepted on April 7, 2017.