Treatment of the textile wastewater through fungi: a sustainable alternative

Tratamento das águas residuais têxteis com fungos: uma alternativa sustentável

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ABSTRACT

The decolorization of textile effluents represents a considerable challenge because it contains certain degradation resistant compounds, such us dyes. Chemical, physical and biological methods are used for the removal of dyes from wastewater; however, conventional treatments of these effluents do not appear effective in removing dyes compounds. It actually has several drawbacks such as the high cost of the chemicals used, the generation of hazardous secondary wastes or its disposal problem and limited applicability. A fungal culture has the capability to acclimate its metabolism to changing environmental conditions. This ability is vital for their existence. Here, intra and extracellular enzymes help in metabolic activity. These enzymes have the capacity to degrade various dyes present in the textile wastewater. Due to these enzymes, fungal cultures seem to be suitable for the degradation of dyes in textile wastewater. For these reasons, the purpose of this interdisciplinary approach review is to provide innovative solutions to environmental problems, particularly to improve the treatment of industrial textile effluents with the use of biomass generated in the agroindustry, like palm tree extraction.

Keywords: Textile Wastewater; Fungi; Agro-Industrial Waste.

RESUMO

A descoloração dos efluentes industriais representa um desafio considerável, pois certos corantes são resistentes à degradação. São utilizados métodos químicos, físicos e biológicos para a remoção de corantes dos efluentes industriais têxteis, no entanto, os tratamentos convencionais desses efluentes não são efetivos na remoção de corantes, na verdade, possuem várias desvantagens, tais como: o alto custo dos produtos químicos usados, a geração de resíduos secundários perigosos, seu problema de descarte e aplicabilidade limitada. Uma cultura de fungos tem a capacidade de aclimatar seu metabolismo frente a mudanças nas condições ambientais. Essa habilidade é vital para sua existência. As enzimas intra e extracelulares ajudam na atividade metabólica e possuem capacidade para degradar vários corantes presentes nas águas residuais têxteis. Devido a elas, as culturas de fungos parecem ser adequadas para a degradação de corantes em águas residuais têxteis. Por estas razões, o propósito desta revisão de abordagem interdisciplinar é fornecer soluções inovadoras para problemas ambientais, em particular, para melhorar o tratamento de efluentes têxteis industriais com o uso de biomassa gerada na agroindústria, como a extração de palmito (Bactris gasipaes).

Palavras-chave: Efluente; Fungos; Resíduos Agroindustriais.

1 INTRODUCTION

Textile industry demands the use of large volumes of water and various types of substances (such as caustic soda, gum, detergents, defamers, sodium hypochlorite, formaldehyde, emulsions, oils and resins, among others), which frequently generates a complex, toxic and recalcitrant wastewater with a high chemical oxygen demand (SWAMI *et al.*, 2012).

Moreover, with the constant search for competitiveness, there is no doubt that, in the coming years, nanotechnology will permeate all areas of the textile industry. The nanotechnology will overcome the limitations of the application of conventional methods to give more properties to the textile materials. Currently, nanotechnology is already available for the improvement of tissue properties. For example, the water repellent property benefits from the use of hydrocarbons one-thousandth the size of a typical cotton fiber, adding them to the fabric to create a velvety effect without reduced cotton strength. Another known application is the use of zinc oxide and titanium dioxide in “nanoparticle” size particles, which are more efficient in the absorption and dispersion of ultraviolet radiation. Nanotechnology is also used to confer antibacterial, fungicidal, anti-static and anti-wrinkle properties with the application of nano silver particles, titanium dioxide and zinc oxide or silica, for example (CALDEIRA *et al.*, 2015).

The use of conventional industrial wastewater treatments has many shortcomings, as many pollutants can pass through these systems without being satisfactorily degraded. In some cases, these recalcitrant substances are also adsorbed onto the surface of the primary and secondary sludge, causing further problems of accumulation. In addition of its limited efficacy, these procedures are expensive, and produce large quantities of waste that need subsequent treatments (LADE *et al.*, 2015).

Therefore, the interests in studying alternative methods which reduce its toxicity and allow the reuse of the water in the own textile industry, are growing up. In this sense, the developments of environmentally cleaner and low-cost technologies using microorganisms are considered an attractive option for the decontamination of these wastewaters (MANSOUR *et al.*, 2016). The biodegradation process can be carried out by different microorganisms which, throughout its enzymatic action, hydrolyze the pollutant compounds to smaller size molecules with lower toxicity.

Among the great diversity of microorganisms that can be used for the wastewater treatment (fungi, bacteria and algae), macromycetes are highlighted due to its ability of degradation of toxic substances, such us phenols, organochlorine compounds, aromatic hydrocarbons, pesticides, synthetic dyes, polymers, leading in some cases to its complete mineralization. Several factors such the type of the cultivation, submerged fermentation (SmF), solid state fermentation (SSF) and nutricional supplementation like the agro-industrial wastes, can influence the level of the enzymes productions (DAS *et al.*, 2016). Different lignocellulosic wastes have been used as raw materials to increase the productions of this enzymes (Li *et al.*, 2015).

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 *et al.*, 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 (IBGE, 2015). These residues represent loss of biomass and nutrients, as well as increasing the pollutant potential associated with the inadequate disposal, often accumulated in the area under cultivation, which, in addition to contamination of soils and water bodies when leaching the compounds, leads to problems of public health due to the presence of animals (TOLLER, 2016).

This paper presents a review focused on effluent treatment issues in the textile industry and on how White-Rot-Fungi (WRF) can mineralize the dyeing molecules from these effluents. The article also intends to raise the question about the use of agro-industrial residues as low-cost substrate and sources of carbon and nitrogen as inducers of enzymes improving the treatment of industrial textile effluents with the use of fungi for a real possibility of using this technique in a large scale.

2 THE TEXTILE INDUSTRY

The textile industry has great relevance worldwide. In 2014, Brazil occupied the sixth position. In the world textile production, earning US $ 55.4 billion and generated 1.6 million jobs, with an estimated textile production at 2.1 million tons (ABIT, 2014). This sector is the second largest employer in the Brazilian manufacturing industry, providing 16.4% of jobs, just behind food and beverage industry (TEXBRASIL, 2014).

The state of Santa Catarina (Brazil) has one of the most advanced textile manufacturing facilities in Latin America and the second largest in the country, behind only to the state of São Paulo. The industrial complex in Santa Catarina state is located mainly in the "*Vale do Itajaí*". The city of Blumenau stands out for being the largest center of Santa Catarina's textile industries (GAZZONI, 2013), having 9.264 textile and clothing industries, and being responsible for 1.9% of exportations, reaching in 2011, US $ 176 million (FIESC, 2013).

However, the major environmental problem associated with the textile sector, which is the contamination of natural waters, is not a regional but rather global concern. A significant part of the synthetic dyes and other chemicals products, called auxiliary in the activities of processing and finishing of fabrics, unfixed on the fibers during the dyeing process are found in the wastewaters generated (BARCELLOS *et al.*, 2009).

In the period prior to the half of XIX century, the dyes were often extracted from natural sources, mainly of animal or vegetable origins. Naturally, the properties of many of these substances were far from ideal (poor fixing, high biodegradability, etc.) and this fact, together with the limited commercial availability of sources of supply, encouraged the search for synthetic dyes with superior properties (HOLKAR et al., 2016). Viable discoveries came quickly and the natural dyes have been almost completely replaced by synthetic in the early twentieth century. The first synthetic dye was discovered only in 1856 in England, and the monopoly of synthetic dye production belonged to Germany from 1915 until the Second World War (ISENMANN, 2013).

Nowadays, except of some important inorganic pigments, all the dyes and pigments commercially available are synthetic substances. According to Guarantini; Zanoni (2000), due to the increasingly demanding market, millions of colorful chemical compounds have been synthesized in the last 100 years. About 10.000 different dyes are used industrially, representing an annual consumption of approximately 8x10^{5} tons on the planet, with 26.500 tons only in Brazil (SILVEIRA-NETA *et al.*, 2012).

The wide number of colorants commercially available is justified by the diversity of fibers, which requires well defined dyeing characteristics, and to the great demand of new colors and dyes with greater binding capacity and specificity related to the fibers (ISENMANN, 2013).

The dyes have large structural diversity that comes from different chromophore groups and different application technologies. They are aromatic and heterocyclic compounds, being in most of cases are difficult in degradation (BARCELLOS *et al.*, 2009; RODRÍGUEZ, 2013). They can be classified according to their chemical structure or fixing method in textile fiber (GUARANTINI; ZANONI, 2000).

In addition to the dyes, the textile effluents present extremely heterogeneous composition and large amounts of toxic and recalcitrant material which makes its treatment a complex task. Besides the strong coloring, large amounts of suspended solids, highly fluctuating pH, temperature, and concentrations of chemical oxygen demand (COD) and trace elements (Cr, Ni and / or Cu), as well as chlorinated organic compounds and surfactants (JERÔNIMO, 2012).

According Dellamatrice *et al.* (2008), given the physicochemical characteristics of the textile effluent highlighted to pH typically between 8 and 11, total solids between 1.000 and 1.600 mg.L^{-1} and solids content of the suspension between 30 - 50 mg.L^{-1}. Such characteristics are subject to variation according to the type and stage of the process in progress within each industry. The characteristics of industrial effluents are variable about the color tones and concentrations, which makes it difficult to quantify the color of an industrial effluent.

Several environment protection agencies worldwide have imposed rules entrusted with the protection of human health and guarding the environment from pollution caused by the textile industry. These agencies imposed certain limits on the disposal of effluents into the environment. The disposal limits are found to differ from country to country. However, a constant check is to be kept on these discharge limits every now and then to maintain a safe and a healthy environment (GHALY et al., 2014).

Table 1 shows the physical and chemical characteristics of the effluent from a local textile industry. The residual wastewater from the dyebath used in the table below is derived from cotton dyeing process and has as a component only, yellow dye, Remazol red and blue R, calcium carbonate, caustic soda and neutralizer. The final effluent is composed of the entire effluent collected at the treatment station from the company after the physical and chemical process and prior to biological treatment. For this reason, the effluents cited cannot be compared to Brazilian legislation because they were collected before the final treatment process. The table only presents the CONAMA / 2011 legislation data as a form of information in comparison to an effluent not treated yet.

Table 1- Physical and chemical characteristic of the effluent from the textile industry.

Characterization	**CONAMA 430/2011**	**Residual dyebath effluents**	**Final effluent**
pH	5,0 a 9,0	11.34	10.19
DBO	< 120 mg/L or > 60% of removal	992.00 mg/L	239.00 mg/L
DQO	-	2600.00 mg/L	789.00 mg/L
Turbidity	-	58.20 FTU	113.00 FTU
Color	no color	5500.00 Pt Co	903 Pt Co
Total solids	-	30.456,00 mg/L	1368.00 mg/L
Suspended solids	Removal efficiency of > 20%	153.33 mg/L	227.50 mg/L
Volatile solids	-	123.33 mg/L	2.69 mg/L
Nitrogen	-	88.60 mg/L	<0.01 mg/L
Total phenols		0.01 mg/L	0,020 mg/L
Cu	-	0.367 mg/L	0.024 mg/L
Fe	-	0.19 mg/L	0.10 mg/L
Ni	-	<0.01 mg/L	<0.01 mg/L
Cd	-	<0.001 mg/L	<0.001 mg/L
As	-	0.02 mg/L	<0.01 mg/L
Ba	-	<0.20 mg/L	<0.20 mg/L
B	-	<0.20 mg/L	<0.20 mg/L
Pb	-	<0.01 mg/L	<0.01 mg/L
Cr	-	<0.01 mg/L	0.01 mg/L
Sn	-	<0.20 mg/L	<0.20 mg/L
P	-	7.46 mg/L	2.54 mg/L
Mn	-	<0.05 mg/L	<0.05 mg/L
Hg	-	<0.0002 mg/L	<0.0002 mg/L
Ni	-	<0.01 mg/L	<0.01 mg/L
Ag	-	<0.01 mg/L	<0.01 mg/L
Se	-	<0.01 mg/L	<0.01 mg/L
Zn	-	0.05 mg/L	0.05 mg/L
Sulfetos	-	0.81 mg/L	0.14 mg/L

Source: Prepared by the authors.

Since the formation of the dye to its deposition in water course, the contaminants may be associated with some particles becoming bioavailable to the ecosystem; suffer biotransformation, causing toxic substances or migrate from sediment to other environmental compartments via trophic chain (ZAGATTO; BERTOLETTI, 2006). They can also be assimilated and retained in the organisms, both directly, by direct contact in the environment, or indirectly, through predation contaminated organisms. In the indirect way, the metals are accumulated faster than excreted or detoxified, which may lead to bio-magnification, i.e., toxic substances are passed from a trophic level to another, leading to increased concentration along the trophic chain (KHAN *et al.*, 2012).

Many of the substances present in these effluents, such as phenolic compounds, have not yet established a suitable treatment method, and are sometimes not efficiently handled (DELLAMATRICE *et al.*, 2008). Thus, the development of appropriate treatment technologies constitutes an important task. The improvement and integration of different treatment methods are needed convert the treatment wastewater a sustainable process (MANAVALAN *et al.*, 2013).

2.1 TREATMENT OF THE EFFLUENT FROM TEXTILES INDUSTRY

In a general way, after a pollution event, the balance between the different ecosystem communities is firstly affected, resulting in an initial disorganization. However, after certain adaptation time and under determinate conditions (balance of organisms), these systems have a tendency to further reorganize themselves (BARBIER, 2017). Besides of that, there is a limit from which the aquatic ecosystem become saturated and cannot be restored.

Therefore, the low efficacy on the elimination of toxic products has forced government agencies to establish restrict environmental regulations to protect the natural ecosystems (MANSOUR *et al.*, 2016). Some of the measurements proposed include strategies for the reuse of water and the disposal of effluents, changes on the limits of emission standards in the course of water, as well as increasing the costs associates with the treatment and disposal of waste and by products from the wastewater (FARIA, 2004). All of these practices stimulate the use of cleaner production technologies (PEIXOTO, 2011).

For example, in Brazil, the Resolution of "*Conselho Nacional do Meio Ambiente* (CONAMA)" no. 430 of 13 May 2011 brings the conditions of effluent standards release, which supplements the amends no. 357 of the Resolution of March, 2005. Establishing in its Article 3, that the effluent from any source of pollution can only be discarded directly into water body after proper treatment and if they satisfy the conditions standards and requirements laid out in this resolution and other applicable standards (BRAZIL, 2011). Some of these requirements are: the effluent must have a pH between 5-9, the temperature should be less than 40ºC, with no particulate materials and dyes. In addition to not causing intoxication or having toxic effects to aquatic organisms and cannot modify the chemical characteristics of the water body and derail supply to the water network. The treatment of textile effluents should be carried out on site, prior to discharge into the water body to mitigate possible environmental impacts. In addition, in this Brazilian legislation there are sections that deal with domestic and industrial sewage separately.

Removal of dyes can be achieved through different physicochemical and/or biological processes. The applied physicochemical methods include membrane separations, photocatalysis, sonication, irradiation, photochemical process, electrochemical oxidation, ion exchange, adsorption, coagulation/flocculation, ozonation and Fenton processes. A widely used commercial chemical method of dye removal is coagulation which rapidly transfers dyes from the liquid to the solid phase but has several drawbacks such the inability to remove dyes completely, the high cost of the chemicals used, generation of hazardous secondary wastes and its disposal problem (SARATELE *et al.*, 2009).

Due to these drawbacks, there is a certain predilection for the use of processes that can actually degrade the species of interest. Within the destructive processes context, it is for biological processes a prominent place, mainly due to the relative ease encountered in the implementation of systems that operate on a large scale. The most frequently used biological processes are represented by activated sludge systems (Figure 1). This process consists in mixing the effluent in the presence of microorganisms and oxygen during the time required to metabolize a large part of the organic matter (DEZOTTI *et al.*, 2011). Unfortunately, there is a major downside which is being susceptible to the effluent composition (shock loads), and produces a large volume of sludge.

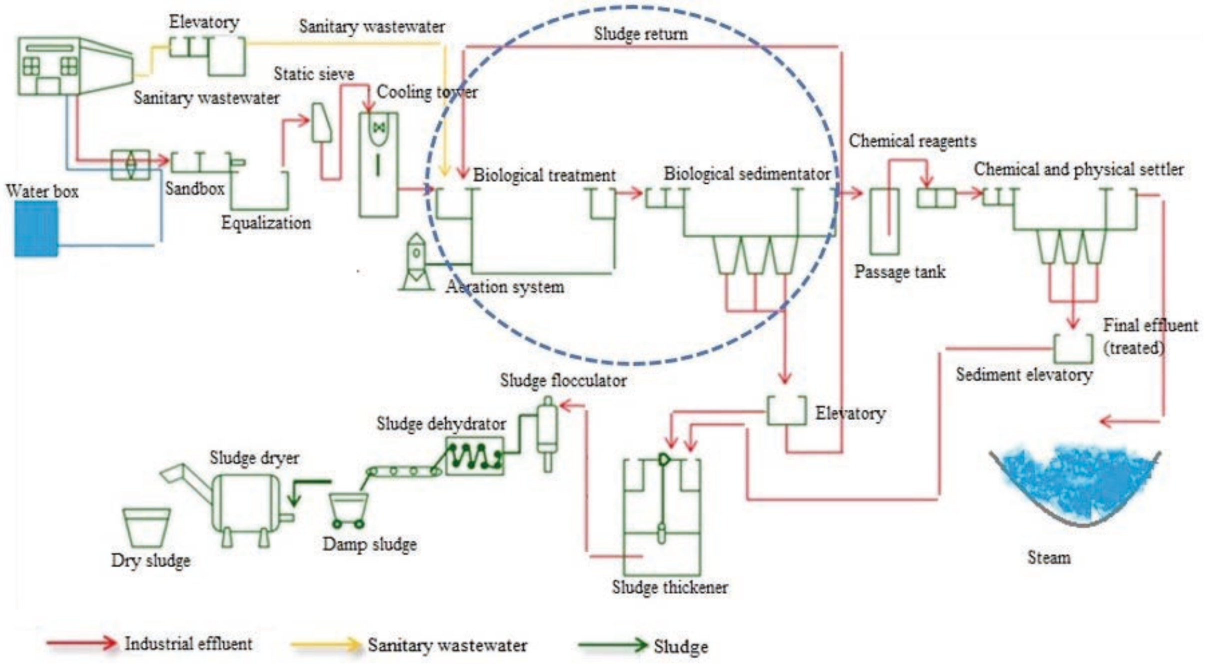

Figure 1 - Diagram of effluent treatment plant using activated sludge in secondary settler, as show in the circle, typically used for the treatment of textile effluent.

Source: Prepared by the authors.

Frequently, the industrial textile wastewater treatment starts with use of the precipitation-coagulation process, followed by activated sludge system. The combination of the physicochemical and biological operations presents a relatively high efficiency, enabling the removal of about 80% of dyes load. Unfortunately, one important inconvenient of this process is the accumulation of dye into the sludge, which is frequently quite high, preventing any possibility of reutilization (KUNZ *et al.*, 2002).

3 THE FUNGI AS MICROORGANISMS DECOMPOSERS

All fungi are chemoheterotrophic, and adsorption of nutrients occurs due to enzyme secreted extracellularly. Some fungi can obtain energy by fermentation, such as yeast. Fungi are present in all continents, occupying different niches and are predominantly saprophytes. Decomposition is the main ecological function exercised by them, being fundamental in the equilibrium of the different ecosystems. There are two forms of growth, multicellular filamentous (filamentous fungi) and unicellular. The filaments are called hyphae, and hyphae set are called mycelium (RAVEN *et al.*, 2007). These are the unique microorganisms having exclusive complex enzymatic machinery for the degradation of as lignin and holocellulose components as a source of carbon and energy along with the removal of polysaccharides and hence total biomass breakdown usually occurs (MADHAVI *et al.*, 2009).

It is well known that, in any ecosystem, the fungi are among the main microorganisms decomposing organic matter such as cellulose, hemicellulose and lignin. Fungi can mineralize and bio accumulate toxic materials as well as storing and releasing elements and ions (SINGH, 2006). The WRF are the best organisms to degrade lignin, cellulose and hemicellulose into smaller molecules to CO_2 and water (so they are called lignocellulolytic fungi), and are consequently used in bioremediation of pollutants.

The lignin macromolecule is responsible for the rigidity of the cell wall of plants and trunk thickening (Figure 2). Furthermore, it is a recalcitrant and chemically complex polymer, considering the heterogeneity of functional groups present in structure (COHEN *et al.*, 2002). The WRF are the only micro-organisms able to hydrolyze lignin to CO_2 and H_2O. These micro-organisms have been widely studied since the last century to take advantage of their degrading ability and find biotechnological applications, especially in the treatment of emerging contaminants (RODRÍGUEZ, 2013).

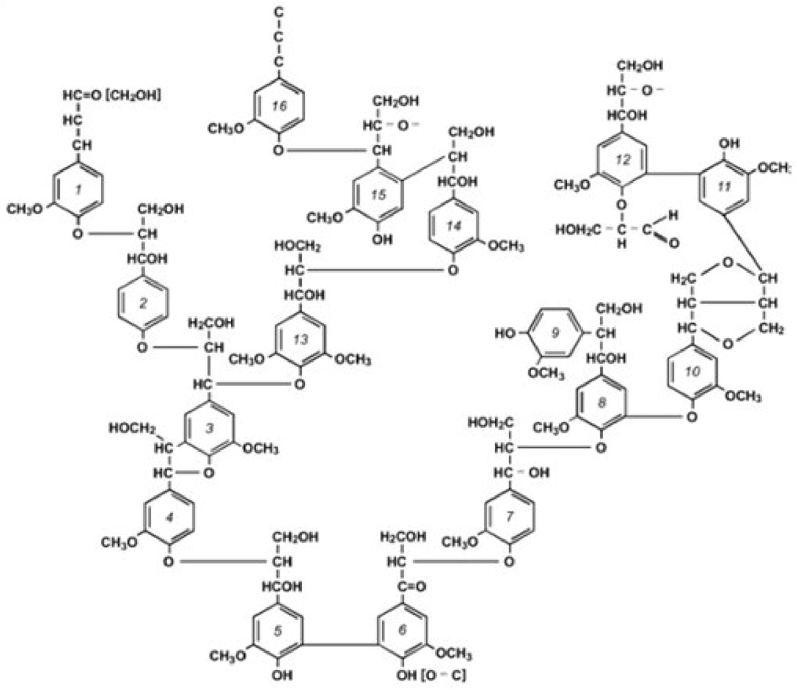

Figure 2. Fragment of lignin.

Source: Rodríguez, 2013.

The capacity of the microorganisms to degrade organic compounds is scientifically recognized and has been explored in biological treatment processes for wastewater, as well as processes involving decoloration and metabolism of recalcitrant compounds. No doubt, basidiomycetes fungi with their large batteries of ligninolytic enzymes, among the different types of phenol oxidases with their different broad substrate ranges, and with their expanded but barely exploited genomes present an excellent “green” potential for handling of many problematical types of pollution (KÜES, 2015).

Enzymes in lignocellulose degradation are commonly extracellular, which is compulsory by the large molecule sizes of the envisaged substrates. Larger polymers are broken down into smaller fragments and finally into individual molecule units that might be taken up into the cells for eventual metabolic use or for further detoxification by the xenome, that is the protein machineries for detection, transport and metabolism of xenobiotics (MOREL *et al.*, 2013).

There are four main means of usage of ligninolytic enzymes in environmental management with partial overlaps: (i) Enzymes might be used to purify pollutions in contaminated water or solid materials prior to release into an environment; (ii) Enzymes might be used in bioremediation within environments; (iii) The environment might be manipulated in favor of organisms producing enzymes of environmental benefit; (iv) Enzymes might be used in biosensors and as bioindicators to monitor pollution in the environment (RAO *et al.*, 2014).

The ligninolytic enzymes have very low substrate specificity, enabling them to mineralize a wide variety of recalcitrant xenobiotic compounds and organopollutants having structural similarity with the lignin (HOFRICHTER *et al.*, 2002). Lignin-modifying enzymes are potential industrial enzymes for several applications. These include bio-bleaching, bio-pulping, the functionalization of lignocellulosic materials, the modification of wood fibers, the remediation of contaminated soil and effluents, as well as improvement of the enzymatic hydrolysis of lignocellulosic substrates (MOILANEN *et al.*, 2011).

One of the main challenges in the development of industrially relevant applications is to produce these enzymes cost-effectively in sufficient amounts to prove the attractiveness of the biochemical approach as an alternative to the more traditional processes. One solution for the feasible commercial production of lignin-modifying enzymes could be the use of solid-state fermentation (SSF) techniques in the production process (MANSOUR *et al.*, 2016).

Laccases belong to the multicopper oxidase family of enzymes that catalyze the oxidation of various substrates with the simultaneous reduction of molecular oxygen to water, through a radical-catalyzed reaction mechanism. They are mainly of fungal or plant origin, although a few representatives have been identified and isolated in bacteria and insects. The most studied laccases are fungal in origin, mainly in phyla Ascomycota, Zygomycota, and Basidiomycota. The most biotechnologically useful laccases are also of fungal origin (GIARDINA *et al*., 2010).

Physiologically, the functions of laccases are diverse, ranging from lignolysis, pigment formation, detoxification, to pathogenesis. All these functions are attributed to the enzymes ability to oxidize a wide range of aromatic substrates such as polyphenols and diamines and even some inorganic compounds. Compared with fungal laccases, bacterial laccases are generally more stable at high pH and temperatures. Although fungal laccases can be both intra and extracellular, bacterial laccases are predominantly intracellular (CHO *et al.*, 2011). Laccase produced using agroindustry wastes are proved as an effective synthetic dye degrader (DAS *et al.*, 2016). Most basidiomycetes produce laccase and manganese peroxidase, while lignin peroxidase seems to be rare distribution (SILVA *et al.*, 2008).

The manganese peroxidase (hydrogen peroxide oxidoreductase, EC 1.11.1.13), is the most common ligninolytic peroxidase produced by almost all basidiomycetes (HOFRICHTER *et al.*, 2010). Manganese peroxidase is a glycoprotein with a heme (ferric protoporphyrin) group that shares the mechanistic properties of other peroxidases and the formation of oxidized intermediates, compound I and compound II, in the presence of H_2O_2 for aromatic and nonphenolic substrates oxidation (KÜES, 2015).

The biodegradation process can be defined as the biological decomposition or breakdown of a chemical compound which occurs by the action of an enzyme system consisting of different enzymes and mediator compound. It is process known as mineralization and uses microorganisms to metabolize toxic waste in the environment, degrading and transforming it into little toxic or non-toxic elements, such as carbon dioxide (CO_2), water (H_2O) and inorganic salts (BURATINI, 2008).

The breakdown of synthetic dyes using different fungi is becoming a promising in the treatment of effluents with dyes approach. The biodegradability of these micro-organisms can be gradually increased by exposure to higher concentrations of organic or synthetic chemicals. The adaptation of a microbial community by toxic and recalcitrant components is very favorable for the biological process of decolorization. This process has been suggested as a promising method which not only potentially mineralizes dye molecules into CO_2 and H_2O, but also generates low amounts of sludge. A wide variety of basidiomycetes, particularly WRF, have been used in experimental works of bio-treatment of wastewater dyes, such as strategies to decolorization, mineralization, processing or degradation of various natural or synthetic compounds. Table 2 shows some processes and organisms used by various authors.

Table 2. Application of fungi degradation in experimental trials dye bleaching bio-treatment and wastewater.

Fungal species	Application	Reference
Agaricus blazei	Decolorization of reactive dyes	Santos et al. (2004)
Bjerkandera sp.	Decolorization of textile dyes	Anastasi et al. (2011)
Capinus plicatilis	Decolorization of reactive dyes	Akdogan; Canpogat (2014)
Cerrena unicolor	Decolorization of textile dyes	Michniewcz et al. (2008)
Coriolopsis sp. (1c3)	Decoloration of Triphenylmethane dyes	Chen; Yien Ting 2015)
Coriolus rigida	Decolorization of textile dyes	Saparrat et al. (2010)
Coriolus versicolor	Decolorization of textile dyes	Asgher et al. (2009)
Dichomitus squalens	Decolorization of dyes	Susla et al. (2008)
Ganoderma sp.	Decolorization of synthetic dyes	Sadaf et al. (2013)

Fungal species	Application	Reference
Ganoderma lucidum	Degradation and decoloration of dyes	Manavalan et al. (2013); Sharma et al. (2015)
Ganoderma australe	Decolorization of dyes	Rigas; Dritsa (2006)
Lentinula edodes	Decolorization of dyes	Boer et al. (2004)
Phanerochaete chrysosporium	Degradation and Decolorization of dyes	Akdogan; Canpogat (2014)
Pleurotus calyptratus	Decolorization of dyes	Eichlerová et al.(2005)
Pleurotus citrinopileatus	Decolorization of dyes	Santos et al. (2004)
Pleurotus cornucopiae	Decolorization of dyes	Eichlerová et al. (2006)
Pleurotus cystidiosus	Decolorization of dyes	Eichlerová et al. (2005 e 2006)
Pleurotus dryinus	Decolorization of dyes	Eichlerová et al. (2006)
Pleurotus eous	Decolorization of reactive dyes	Santos et al. (2004)
Pleurotus eryngii	Degradation and decoloration of dyes	Eichlerová et al. (2006)
Pleurotus flabellatus	Decolorization of textile effluent	Nilsson et al. (2006)
Pleurotus ostreatus	Degradation and decoloration of dyes	Parenti et al. (2013)
Pleurotus sajor-caju	Decolorization of dyes	Munari et al. (2008)
Pycnoporus sp.	Decolorization of textile dyes	Anastasi et al. (2012)
Pycnoporus sanguineus	Decolorization of azo and anthraquinone dyes	Ramirez-Cavazos et al. (2014)
Trametes sp.	Decolorization and detoxification of dyes	Yan et al. (2014)
Trametes trogii	Decolorization and detoxification of dyes and effluents	Pazarbasi et al. (2012)
Trametes versicolor	Degradation and decoloration of dyes	Champagne; Ramsay (2010); Silverio et al. (2013)
Trametes gibbosa	Decolorization of reactive dyes	Adnan et al. (2014)
Trichoderma asperellum	Decolorization of Leucocrystal violet	Shanmugam et al. (2017)

Source: Prepared by the authors.

The literature is replete with reports that show the excellent ability of fungi to degrade dyes. Its potential so far, however, has not found industrial application, mainly due to the difficulty in selecting the organisms able to grow and degrade the widely varying conditions and restrictive of the textile industry effluents.

The textile effluents are one of the most difficult wastes to treat because of the considerable number of suspended solids and the massive presence of dyes, salts, additives, detergents and surfactants in it. They vary widely in terms of quantity and pollution load, pH and temperature, depending on the type of textile materials (VANHULLE *et al.*, 2008).

Furthermore, most studies on dyes degradation is carried out in laboratory scale. However, before an industrial application, it is necessary to scale-up the process using bioreactors that can be operated under industrial conditions. In these sense, there are only a few studies which report the treatment of industrial textile wastewaters by macromycetes in bioreactors operated under continuous mode and under non-sterile conditions.

Blanquez *et al.* (2008) showed that the fungi *Trametes versicolor* was able to promote the decolorization of textile wastewater (40 to 60%) in a bioreactor operated under 15 days in non-sterile conditions. Anastasi *et al.* (2010) also reported the decolorization of effluent from textile dyeing with *Bjerkandera adusta* fungi in a fixed bed bioreactor. The fungus was effective for four cycles of decolorization and remained active for a longer period (70 days) under non-sterile conditions and without addition of nutrients. The conventional activated sludge system has a very low hydraulic detention time, in the range of 6 to 8 hours, and the system of long activated lows (continuous flow) remains in the reactor for 18 to 30 days, taking into account the entire generation of sludge (SPERLING *et al.*, 2001). Furthermore, treatment of fungi has greatly reduced toxicity of the effluent with no sludge. In this case, dilution of the effluent, nutrient addition and control of chemical parameters were not done, however, the experiment showed the applicability of the developed system.

Later, the same authors tested the ability of the same fungus to degrade the effluent of a textile industry after a secondary treatment. They found that yeast treatment caused a 40% of color removal in 24 h of treatment (ANASTASI *et al.*, 2011). The same authors, using wastewater from a dyeing cotton industry, demonstrated that treatment by fungi, especially with the Trametes pubescens fungus tested in led to very good results in terms of decoloration (over 60%) with toxicity removal (ANASTASI *et al.*, 2012).

Selvakumar *et al.* (2012) studied textile effluent in a batch reactor with *Ganoderma lucidum* under optimized conditions of pH (6.6); temperature (26.5ºC); stirring speed (200 rpm); effluent concentrations of colorant (1:2), found the decolorization of 81.4%.

Wastewater discharged by the textile processing industry is a complex mixture of several substances that accompany a huge variety of dyes with diverse chemical structures. Application of fungal to raw textile wastewater can be effective for achieving a large decrease in the dye content of wastewater despite the enormous amounts of salts, metals and other contaminants. However, in most cases, the microorganisms that have been tested for decolorizing dyes have been studied using wastewater with relatively simple chemical compositions under laboratory conditions and with SmF. As this technology goes to scaled up, it will be necessary to evaluate the true potential for use of microorganisms to decolorize real textile wastewaters in bioreactor systems with SSF, built at industrial outlets that receive water directly from the dyeing units.

Also, the metabolic pathways involved in biodecolorization of textile effluent with fungi have not yet been fully elucidated. It is necessary to target the underlying processes and metabolic pathways by identifying genes and metabolites in the decolorization processes.

4 SOLID STATE FERMENTATION AND AGROINDUSTRY'S WASTE

The two main strategies for the cultivation and therefore enzyme production are submerged fermentation (SmF) and solid state fermentation (SSF), which differ about their environmental conditions and driving ways. Unquestionably one of the most exalted parameters in the differentiation of two types of processes is the water content present in the reaction medium (MANSOUR *et al.*, 2016).

Solid-state fermentation is a process that occurs under complete absence of free-flowing water contents in the growth media. Some of the advantages of solid cultivation compared to SmF are: higher enzyme production, low production costs, extended stability of products, among others. With increasing progress and application of rational methods in engineering, solid cultivation has achieved higher levels in standardization and reproducibility (IQBAL *et al.*, 2011). SSF has a good cost-effective relation since agroindustry waste materials can be used directly as culture media without additional pre-processing.

Bioconversion of lignocellulosic wastes to higher value products through fungal fermentation has economic and ecological benefits. The degradation of methylene blue by SSF of agricultural residues rice straw with *Phanerochaete chrysosporium* was investigated by Zeng *et al.* (2015). A maximum decolorization was found with 84.8% for an initial dye concentration of 0.4 g/L. Li *et al.* (2015) Also used this strategy to stimulated production of manganese peroxidase (MnP) from cassava residue by *Phanerochaete chrysosporium* in SSF. The decolorization *in vitro* of indigo carmine by the crude MnP attaining the ratio of 90.18% after 6 h of incubation. Das *et al.* (2016) used co-substrates of paddy straw and corn husk to produce laccase for decoloration of Congo red dye from *Pleurotus ostreatus* MTCC 142.

Packed-bed bioreactors with solid-state fermentation consists of cylinders' tubes. The first is the dispersal location of the effluent solution. The second cylinder is fixed-bed solid cultivation. This site was established the residue with the fungus previously inoculated and grown. The latter is the site of collection of the effluent when is in the circulating process and storage when is not circulating. In this reactor model the cycle could be continuous or batch. The recirculation of the effluent need to be automatically by a machine and the flow depends on the dimension of the bioreactor and the residue used (HERMANN *et al.*, 2012).

Up to now, there are no studies reporting the use of large-scale reactors operated in a SSF for the treatment of textile effluents. The drawbacks of SSF in larger scale production could be due to some engineering problems, such as moisture and temperature control together with agitation systems to provide a homogenous mixing. While high lignin-modifying enzyme production levels have been reported in many small-scale laboratory experiments (GASSARA *et al.*, 2010), scaling up the process is rather challenging.

Several crop biomasses such as rice bran, sugarcane bagasse, wheat bran, leaf sheath of peach palm, etc. are generated every year in million-ton scale as "agricultural waste", easily available at low cost and they are known to contain high amounts of carbon and nitrogen (KADAM *et al.*, 2011; SINGH *et al.*, 2012). As an example: the peach palm (*Bactris gasipaes*, Kunth) is a native palm tree in the Amazon region, but currently disseminated by Central and South Americas. The peach palm which was domesticated and widespread in these regions by indigenous people is characterized by having an erect stipe, with diameter ranging from 15 to 30 cm, height between 15 and 20 m, with varieties that may or may not be covered by the stem thorns. Some features are considered attractive for palm production such as earliness, tillering, yield and quality of palm (HELM *et al.*, 2014).

Palm trees can be divided into three layers: outer, medium and internal sheaths. The outer layer that surrounds the heart of palm is fibrous and its function is to protect the leaves still to be formed, those are not used in heart of palm processing, and represent on average, 30% of the weight of the plant, depending on the species (TONINI, 2004). The second layer is formed by the median sheath and it is used to protect the heart of palm during transportation through processing, then being discarded thereafter. This layer is 25 to 30% of plant weight. The last layer is formed by the kernel or heart of palm, which contains low-fiber and represents only 2% of the weight of the plant and is the plant's part with the greatest economic value. In the beneficiation process of the heart of palm it is estimated that for every kg of processed heart of palm another 3 kg sheaths that are not used are generated and discarded. It is estimated that during the heart of palm processing, 90% of the plant is useless waste (PUPO, 2012).

According Helm *et al.*, (2014), leaf sheath of peach palm residue has potential as a food supplement in the form of fiber, and also potential as an inducer of the enzymatic activity due to chemical characteristics such as the presence of lignin and cellulose. Along with the increased availability of this residue from the production of palm, it might thus become a source of unexplored resources as well (PUPO, 2012).

5 CONCLUSIONS

The increasing complexity and difficulty for treating textile wastewater lead to a constant search for new treatment methods. Nowadays, a great variety of physical, chemical and biological methods are available, and the choice of the best methods surely must be made considering the objectives to be achieved in such treatment. The coagulation, widely used commercial chemical method of dye removal and the biological treatment of active sludge, has several drawbacks such the inability to remove dyes completely and the generation of hazardous secondary wastes and its disposal problem.

The scarcity of natural resources and the possibility of agro-industrial wastes reuse are key aspects which contribute to the modernization and conservation of the environment. Undoubtedly, the treatment of industrial wastewaters has great importance as these effluents not only have a high environmental impact, but also can damage human, animal and plant health.

It will be necessary to evaluate the true potential of microorganisms' use to decolorize real textile wastewaters in bioreactor systems at industrial plants that receive water directly from the dyeing units. Unfortunately, up to now, the possibility of large-scale for the treatment of textile wastewaters is not fully explored. Thus, it is of great interest to carry out new studies on the application of SSF under practical conditions.

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