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A Review: Optimization of Fungal Laccase Production and their Potential Application in Effluents Treatment

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Abstract: **Due to globalization, urbanization, and industrialization water pollutants and contaminants rise in water bodies which distort an ecosystem and impacting human and animal health. To eliminate various contaminants from water bodies, so many techniques and strategies have been designed. Nowadays laccase enzymes pay attention due to their high potentiality, substrate specificity and atmospherically constitute benign reaction properties and are used to remove environmental and industrial pollutants. Fungal laccases are enzymes with a lot of promise for removing harmful phenolic and non-phenolic chemicals from industrial effluents, as well as for degrading resistant xenobiotics. There have recently been a slew of studies on the advancements in the creation of laccase enzyme by modification of growth and optimization conditions and the discovery of new endophytic strains for the production. The following evaluation of the literature relates to optimising endophytic laccase production and also provides new insights for biotechnological applications in environmental protection, such as wastewater/effluents treatment.**

Index Terms: **Urbanization, Industrialization, Endophytic Laccase, Phenolic compounds.**

I. INTRODUCTION

Phenolic compounds are widespread in nature. Phenol is present in vegetables and fruits. After breakdown, natural organic molecules such as humic substances, lignins, and tannins produce phenols. Phenols are persistent pollutants that enter waterways through the effluents of industrial activities such as petrochemicals, pulp, paper, paints, textiles, coal refineries, medicines, and resin manufacturing, including the formation of phenol (Bollag, *et al.,* 1988; Viswanath, *et al.,* 2008; Shraddha, *et al.,* 2011). Industrial discharges produced by various industries in huge quantities and their disposal create a big problem in the environment. The untreated discharge of phenol and phenolic chemicals may pose substantial health concerns to humans, animals, and aquatic ecosystems. For an imperishable environment, International regulatory authorities such as the EPA have set strict discharge limitations for phenols (Viswanath, *et al.,* 2008). For example, phenol is less than 1 ppb has set an incredible clarity of surface water by the EPA (Shraddha, *et al.,* 2011). The Contagiousness levels usually are in the 9–25 mg/L range for the living form of life (Bollag, *et al.,* 1988). Both acute and chronic kinds of perilous health effects can possess phenol and phenolic compounds. Human exposure to phenol at LD value for Long-term use can cause dyspnea, muscular dizziness, tremor, coma, respiratory malfunction (apnea), skin, eye, and mucous membrane irritation, and more. Chronic consequences of phenol exposure in animals include anorexia, weight loss, diarrhoea, vertigo, salivation, and dark urine colouring, as well as irritation of the gastrointestinal, cardiovascular, liver, renal, and central neurological systems. (Thurston, 1994; Viswanath, *et al.,* 2008; Shi, *et al.,* 2013). Animal studies have revealed that the progeny develop abnormally. To protect the environment from the harmful effects of phenol, wastewater effluents containing phenolic compounds must be treated before release.

To detoxify these industrial wastes effluents and prevention of their harmful effects on the environment, laccase can work as a good remedy to solve it. Laccases have lately gained popularity because to their prospective applications in the detoxification of recalcitrant contaminants and bioremediation of phenolic and non-phenolic substances (Singh, *et al.,* 2009; Desai, & Nityanand, 2011; Singh, *et al.,* 2011). Their ability to act on the diversity of substrates as well as modify a variety of contaminants into nontoxic compounds (reactions with great efficiency, selectivity, and environmental friendliness). Because

their cosubstrate oxygen is usually present in their environment, laccases do not require the inclusion of a low molecular weight cofactor or its production. Because most laccases are extracellular, they are easy to purify; they also have a high level of stability in the extracellular environment; and laccase expression is inducible in most fungal species, contributing to their stability. The development of laccase-based biocatalysts that are highly efficient, long-term, energy-efficient, and biodegradable, as well as industries that is ecologically benign. Laccases promise in biotechnological and environmental applications has sparked a desire to find promising laccases in large quantities, and the need for this enzyme necessitates a cost-effective production procedure (Riva, 2006).

The study's goals were to find out more about optimization of laccase production from endophytes and their use to the total phenol content and chemical oxygen demand in diverse wastewaters release from industries (thus lowering toxicity), raising the pH to a level suitable for further treatment, and lowering the colour. Parellaerly laccase production at a greater concentration, secondary objective was to bioremediate wastewater/ industrial effluents.

II. SOURCES OF LACCASES

The study of laccase (EC 1.10.3.2, p-diphenol, dioxygen oxidoreductase) has been done since the nineteenth century. Laccase enzyme has the potential ability of oxidation. Laccase comes under a small group known the blue multicopper. It belongs to the group of enzymes that create reactive radicals with inherent characteristics (Bertrand, 1985; Ranocha and coworkers, 1999; Battistuzzi, *et al.*, 2003). Laccase was discovered in the exudates of the Japanese lacquer tree, *Rhus vernicifera*, by Yoshida in 1883. Afterward, laccases have been discovered from numerous plants (Johnson, *et al.,* 2003) but plenty of oxidative enzymes presence in crude plant extracts creates difficulties in isolation and purification, which is the reason behind the lack of information about plant laccases. Plant laccases are found in the xylem, where they catalyse a stage of the lignification reaction that occurs earlier (Gavnholt & Larsen, 2002; Hoopes & Dean, 2004). Plant laccase is less common than fungus laccase (Mayer & Staples, 2002; Moin & Omar, 2013).

Bertrand and Laborde in 1896 searched firstly laccase was a fungal enzyme. Laccases are glycoproteins present in a wide range of organisms, including plants, fungus, bacteria, and insects. A typical fungal laccase is a 60-70 kDa protein with an acidic isoelectric point of roughly 4.0 (Johnson *et al.,* 2003). Laccase activity has been found in several ascomycetes and basidiomycetes fungus species, and the enzyme has been isolated from many of them, including *Melanocarpus albomyces* (Kiiskinen, & coworkers; 2002), *Cerrena unicolor* (Kim *et al.,* 2002), *Magnaporthe grisea* (Iyer & Chattoo, 2003), *Trametes versicolor* (Minussi & coworkers; 2007), *Trichoderma reesei* (Levasseur, & coworkers; 2010) and *Xylaria polymorpha* (Nghi & coworkers; 2012). Laccase synthesis has also been documented for several soil ascomycete species belonging to the genera *Aspergillus*, *Curvularia*, and *Penicillium* (Scherer & Fischer, 1998) as well as some freshwater ascomycetes (Junghanns, *et al.,* 2005). Yeasts are able to produce true laccase which can oxidise phenols and derivative of phenols, but can't oxidise tyrosine (De Jesus, *et al.,* 2009) and provided resistance from fungicides (Ikeda, *et al.,* 2001). Laccase has already been found in varying amounts in all white-rot fungi species (Hatakka, 2001), and most of them are efficient lignin degraders (Kiiskinen, *et al.,* 2004). Laccase producing basidiomycetes were *Agaricus bisporus* (Wood, 1980), *Botrytis cinerea* (Marbach *et al.,* 1984), *Phlebia radiata* (Niku-Paavola, *et al.,* 1988), *Pleurotus ostreatus* (Sannia *et al.,* 1986), *Trametes versicolor* (Rogalski, *et al.,* 1991) and *Coprinus cinereus* (Schneider, *et al.,* 1999). Laccases have not only been found in plants, bacteria, and fungi, as well as in insects, where they are involved in cuticle sclerotization (Dittmer *et al.,* 2004). Laccases are now used by termites to make lignin modifying enzymes (lignases). The fungi isolated from the nests of three taxa of fungus-eating termites (fungus combs), Macrotermes, Odontotermes, and Microtermes (fungus combs), had high laccase activity against DMP (2, 6-Dimethoxyphenol) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (Taprab & coworkers; 2005; Scharf *et al.,* 2011; Ni & Tokuda, 2013). 127 endophytic fungal strains have been isolated from eucalyptus trees and, out of them, 21 fungal strains have been screened for ligninolytic enzyme production (Brijwani, *et al.,* 2010).

Laccases have a role in lignification in plants, and they've been linked to a variety of cellular activities in fungi, including delignification, sporulation, pigment generation, fruiting body development, and plant disease. Laccases are capable of enhancing the quality of pulp either by functionalizing lignocellulosic fibers or by forming reactive radicals with lignin. Laccases can also use their polymerization and depolymerization activities to remove colourful and hazardous substances generated as effluents from various industries and render them benign (Mayer, & Staples, 2002).

Laccases have been found in only a few bacterial species. "*Azospirillum lipoferum*" was the first bacterial laccase isolated from plant root (Givaudan, *et al.,* 1993) which is involved in the synthesis of melanin (Faure, & coworkers, 1994). Laccases have also been found from *Marinomonas mediterranea* which contain six putative copper-binding sites (Sanchez-Amat, *et al.,* 2001). Laccase from *Bacillus subtilis* CotA is a thermostable laccase that plays a role in pigment formation in the endospore coat (Martins & coworkers, 2002). *Streptomyces cyaneus* (Arias *et al.,* 2003) and *Streptomyces lavendulae* (Suzuki *et al.,* 2003), and some *Bacillus* sp. laccases produced from endospores were involved in phenol degradation (Naclerio, *et al.,* 2010; Singh, *et al.,* 2011) whereas Laccases from *Bacillus licheniformis* are

involved in phenolic acid dimerization (Koschorreck, *et al.*, 2008). In this way, bacterial laccases are intracellular or periplasmic proteins that showed different kinds of activity in different bacterial sources.

III. MECHANISM ACTION OF LACCASE

A wide spectrum of aromatic chemicals, including polyphenolic compounds, are catalysed by the laccase enzyme (Bourbonnais, & Paice, 1990), methoxy-substituted monophenols, and aromatic hydrocarbon amines, by reducing one molecule of oxygen to water, followed by one-electron oxidation (Bourbonnais, *et al.,* 1995). An oxygen-centered free radical is produced during the oxidation process, which can subsequently be converted to quinone utilising an enzyme-catalyzed reaction. Using UV/visible and electron paramagnetic resonance (EPR) spectroscopy, monomeric laccase molecules containing four copper atoms can be divided into three groups (Palmieri, *et al.,* 1998). Type I copper (T1) provides the enzymes a bright blue colour at 600 nm and is EPR-detectable, whereas type II copper (T2) appears uncolored but is EPR-detectable, and type III copper (T3) is made up of two copper atoms with a weak UV absorbance but no EPR signal (Bourbonnais, & Paice, 1996). The copper locations T2 and T3 are close together, forming a trinuclear core (Palmieri, *et al.,* 1998) that is crucial in the enzyme's catalytic mechanism (Bourbonnais, & Paice, 1996).

The reaction is catalysed by laccase in three steps: (1) type I Cu reduction by the substrate (2) type I Cu to type II Cu and type III Cu trinuclear clusters electron transfer (3) At the trinuclear core, oxygen is reduced to water (Gianfreda, & coworkers 1999) and catalyses a wide variety of aromatic compounds (Couto & Toca-Herrera, 2007). The mediators such Low molecular weight chemical compounds such as1-hydro-xybenzotriazole (HOBT), N-hydro-xyphthalimide (NHPI), and 2, 2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) can be used to broaden the laccase substrate range to include non-phenolic substances. Laccase can be oxidized mediators and firstly form very reactive radicals of cation oxidising non-phenolic chemicals that laccase alone cannot oxidise (Gochev & Krastanov, 2007). Only laccase binds to the phenolic components of lignin, causing Cα oxidation, Cα -Cβ, and aryl-alkyl bond breakage.

IV. SCREENING OF LACCASE PRODUCING ORGANISMS

It is critical to screen laccase-producing fungal species and their variants in order to choose laccase-producing fungal strains that will work in industrial applications (Monteiro, & De Carvalho, 1998). Novel laccases with varied substrate specificities and enhanced stabilities must be discovered for industrial uses. Qualitative screening of laccase production has been done by plate method on solid selective media that carries coloured indicator chemicals can be detected by visualization (Nishida, *et al.,* 1988) whereas liquid culturing has also been subjected to quantitative investigation via enzyme activity assays (Luterek, and coworkers, 1997). Gallic and tannic acid (Harkin & Obst, 1973) are screening reagents used in old days. Nishida *et al.* (1988) used synthetic phenolic reagents like guaiacol and syringaldazine, whereas Raghukumar, *et al.* (1999) applied the polymeric dyes Remazol Brilliant Blue R (RBRR) and Poly R-478 for screening purposes. A favourable reaction using guaiacol is shown by the production of a red - brown zone (Nishida, *et al.,* 1988), whereas a significant result using tannic and gallic acid is indicated by the formation of a dark-brown coloured zone (Harkin & Obst, 1973).

V. LACCASE PRODUCTION OPTIMIZATION PARAMETERS

Laccase is enzyme produced during secondary metabolism and released into the medium extracellularly by filamentous fungi (Dong, *et al.,* 2005). Enzyme expression is co-related with Culture conditions and medium composition. Several fermentation parameters like, sources of carbon and nitrogen, pH, temperature, medium, incubation duration, enhancer concentration (Palmieri, & coworkers, 2000), aeration (Dekker & Barbosa, 2001), and other factors, such as the kind of cultivation (submerged or solid-state), can influence laccase production (Monteiro, & De Carvalho, 1998).

A. Effect of Carbon & Nitrogen Source on Laccase Production

Carbon is the primary source that liberates energy for the growth and development of an organism. The most readily usable carbon source is glucose reported for laccase production in various fungal cultures. Various concentration of glucose has been described for maximum laccase production such as *Coriolus versicolor* at (10 g/L) (Collins, & Dobson, 1995), *Trametes versicolor* (20 g/L) (Battistuzzi, *et al.,* 2003). *Ganoderma lucidum*, (10 g/L) (Perumal, 1997), *Lentinula edodes* and *Grifola frondosa* (10 g/L) (Arora, & Rampal, 2002; Cavallazzi, & coworkers, 2005), *Trametes gallica* (5 g/L) and using response surface methodology *Pleurotus florida* NCIM 1243 at (15.21 g/L) (Palvannan, & Sathishkumar, 2010). In preference to glucose some other carbon sources also have been screened for increased laccase production, by malt extract in *Phlebia floridensis*, *P. brevispora*, *P. radiata*, and *P. fascicularia* (Da Cunha, *et al.,* 2003); by glucose, fructose, galactose, galacturonic acid, xylose, lactose, sucrose, mannitol, pectin, and inulin in *Botryosphaeria* sp. (D'Souza-Ticlo, *et al.,* 2006). In case of *Trametes versicolor* MTCC 138 using glucose, fructose, lactose, sucrose, glycerol and starch as carbon sources and obtained highest laccase activities (Revankar & Lele, 2006); and mannitol boosted laccase enzymatic activity in strain of *Ganoderma lucidum* 7071-9 and in *Pichia pastoris* till 115.62% (Sun, & coworkers, 2012). *Kluyveromyces* sp. Dw1 prefers

glucose (10g/L) while *Pichia* sp.Dw2 prefers maltose to yield maximum laccase (Wakil, *et al.,* 2017). In *P. ostreatus*98, the medium with CMC had the highest percent of laccase activity (18 U/g biomass), which was 2 times higher than the medium with sodium gluconate (9.3 U/g biomass) (Mikiashvili, *et al.*, 2006). Laccase production in many fungal strains is suppressed by higher glucose concentrations (Lee, *et al.,* 2004).

In the case of nitrogen source found contradictory observations, in the case of some fungi, laccase production is often triggered by nitrogen depletion (Leatham, & Kirk, 1983) whereas it also found that did not affect laccase activity (Janusz, *et al.,* 2006). Buswell *et al.* (1995) reported a conflicting result *in Phanerochaete chrysosporium* and *Lentinus edodes* strains produced laccase at increased nitrogen levels, and these alterations did not correspond to biomass differences. The optimum concentration of nitrogen requires obtaining the highest laccase production; the level of laccase production is varied with different fungal species due to various concentrations and sources of nitrogen (Eugenio, *et al.,* 2009). Laccase production enhances with higher nitrogen levels (Baldrin, & Gabriel, 2002; Chen, *et al.,* 2003) but certain fungi stimulate the formation of laccase enzyme in nitrogen-limited culture conditions whereas in some of the cases activation of oxidoreductase is generally done in nitrogen-limited medium and inhibited laccase production (Heinzkill, *et al.,* 1998; Lo, & coworkers, 2002; Lee, *et al.*, 2004). *Pleurotus ostreatus* laccase activities were reduced when inorganic nitrogen sources were supplied to a specified medium. The optimum nitrogen source for laccase production by *P. ostreatus* appeared to be peptone, next by casein hydrolysate. However, there is a positive correlation between enzyme accumulation and higher biomass production (Mikiashvili, *et al.,* 2006). Laccase activities were discovered in a medium that was enhanced with by DL-tryptophan in *Grammothele fuligo* (Chauhan, 2019).

The maximum laccase activity of P. ostreatus was tested using various nitrogen sources, and it was discovered that malt extract had the greatest laccase activity when compared to yeast extract and tryptone. Wheat bran and malt extract, on the other hand, were both used to help with growth (Nora, & coworkers, 2015). Sodium nitrate (3g/L) is the optimal nitrogen source, for *Pichia* sp.Dw2 and *Kluyveromyces* sp.Dw1 respectively (Wakil, *et al.,* 2017). The best production of laccase was at 1 g NH_4Cl and 0.5 g malt extract concentration (Sharma, & Arora, 2010). Using a complex nitrogen supply, the greatest laccase activity in Trametes versicolor MTCC 138 was achieved (yeast extract) (Strong, 2011). Variety of nitrogen sources provided increased levels of laccase, including potassium nitrate, glycine, beef extract, corn steep liquor, and glutamate at minute quantity (Lee, *et al.*, 2004). Peptone was the most effective source of nitrogen for increasing laccase synthesis (1.8-fold increase) (Strong, 2011). *P. sanguineus* (820 mU) had 2.5 times higher laccase activity than sucrose-asparagine medium, which contains 5 times as much asparagine (Buswell *et al.* 1995). In *Scytalidium lignicola* laccase synthesis was most aided by sucrose and sodium nitrates as carbon and nitrogen sources (Sidhu, *et al.,* 2017). Among the numerous carbon sources used for laccase production in *Aspergillus* sp. HB RZ4, glucose boosted laccase production by 12.45 times whereas other carbon sources were contributing laccase production in order of glucose> sucrose> starch> maltose> lactose> fructose> glycerol. Yeast extract (6.581 U/mL, an 11.7-fold increase) is an organic nitrogen source and in inorganic NH_4NO_3 (3.97 U/mL), was obtained maximum laccase activity (Sayyed, *et al.,* 2020).

B. pH Effect on Laccase Production

When the ideal pH is acidic (pH 3–5), most laccase production will be excessive. Some applications necessitate a closer match to physiological circumstances, such as pH-7 or even basic medium (Collins, & Dobson, 1995). The ideal pH for laccase synthesis, according to many fungi, is between 5.0 and 6.0 (Papinutti, *et al.,* 2003; Minussi, *et al.,* 2007; Thiruchelvam, & Ramsay, 2007). *Fomes sclerodermeus*, *Kluyveromyces* sp. Dw1, *Pichia* sp. Dw2 and white-rot basidiomycetes, produced maximum titers laccase and biomass on a condition set to pH 6.0 respectively (Wakil *et al.,* 2017). Laccases from *T. versicolor*, *P. cinnabarinus*, *C. gallica*, and *P. ostreatus* are examples of fungal enzymes. Surprisingly, the optimal pH has shifted from 4 to 5, with variety R2 retaining 70% reactivity at pH 6 (Yaver, *et al.,* 1996). The laccase isoforms released by *Trametes pubescens* fungus strain have been found to work best between pH 3.0 and 4.5 (Strong, 2011). In a medium containing glucose and yeast extract, *Aspergillus* sp. HB RZ4 grew under mesoacidophilic shaking conditions, it produced a high amount of laccase. A low pH condition is preferable for fungal laccase production and its functioning (Sayyed, *et al.,* 2020).

C. Temperature Effects on Laccase Production

In the organism's development and laccase production, temperature plays a very important role. Results reveal that an average temperature of 25-35°C is best for fungal biomass growth and laccase production, variations occurs due to being incubated in the dark or light (Minussi, & coworkers, 2002). The highest laccase output is reported in P. ostreatus prefers temperatures of 25-30°C, while T. versicolor prefers temperatures of 35°C (Snajdr & Baldrian, 2007) and *T. harzianum* after 6 days at 35°C and pH 5, (Abd *et al.,* 2016). Kluyveromyces sp. Dw1 and Pichia sp. Dw2 have suitable temperatures of 30- 35°C, accordingly (Wakil *et al.,* 2017). In this study, three extremely thermostable laccase isoforms with the highest activities were generated in *Steccherinum ochraceum* isolate 1833 in the range 75–80°C (Chernykh, & coworker, 2008; Hilden, 2009). *A. flavus* NG85 showed maximum production of laccase at 36.7ºC (Sayyed, *et*

al., 2020). As a result, it's clear that the optimal laccase production varies significantly from one species to next species.

D. Effect of Inoculum Time & Size

Cold and pH tolerant *Penicillium pinophilum* strain is already recorded for laccase production up to 35 days of incubation under different cultural conditions, whereas maximum production was recorded on day 28 and steadily decline until day 35 of incubation (Dhakar, & coworker, 2014). *Pleurotus* species on the tenth day of incubation, at temperature and pH 28°C and 5.5 were optimal for laccase production (0.292 U/mL), respectively (Edae, & Alemu, 2017). The greatest laccase activity was discovered to be (43,761.33 ± 3845U/L) by *P. eryngi* on the 20th day (Akpinar, & Urek, 2017) and by *A. flavus* NG85 (8.422 U/mL) on the eighth day of incubation (Sayyed, *et al.,* 2020). The gradual increase in the incubation period resulting in a concomitant rise in laccase amount over the optimal led to a decrease in enzyme production (Ali, *et al.,* 2015).

A lower inoculant quantity is not adequate to initiate proliferation, and a higher inoculant amount inhibits growth (Sabu, *et al.,* 2005). Increased inoculum size reduces laccase production due to rapid nutrient depletion, resulting in lower metabolic activity (Patel, & coworkers, 2009). The best inoculum size for laccase production from *P. martensii* NRC 345 was five discs (Elshafei, *et al.,* 2012). Laccase production employing Myrothecium gramineum LCJ177 in solid form was shown to favour highest laccase production (17.56 U/g ds) with an initial inoculum size of 4 g/kg (Daphne, & coworkers, 2019). Results of whole studies show that laccase production increases to an optimal level with gradually increasing inoculum size for various fungal species, and that optimal level occurs after high inoculum levels decline synthesis of laccase.

E. Effect of Inducer & Inhibitor on Laccase Production

A significant correlation has been discovered between fungal hyphal branching and expression of laccase (Garzillo, *et al.,* 1998). Various recognition sites specialised for heavy metals and xenobiotics are found in the promoter regions of laccase genes, which trigger laccase synthesis (Robene-Soustrade, & Lung-Escarmant, 1997). The responses of white-rot fungus could cause a wide range of laccase production, and some inducers were also able to produce new isoforms of the enzyme (Eggert, *et al.,* 1996). *Trametes villosa* and *Pleurotus sajor-caju*, on the other hand, have been discovered to contain constitutively expressed laccase genes, which could be linked to a variety of laccase physiological activities in fungi (Marbach, & coworkers, 1985; Da Cunha, *et al.,* 2003), whereas in some cases, a complex cocktail of inducers may be required instead of a single inducer (Grotewold, *et al.,* 1989). Due to inducers uses production suffers from their toxicity, as well as the additional cost, both are negatives.

Copper has been found to be a potent laccase inducer in a variety of species, including *Neurospora crassa* (Dittmer *et al.,* 1997), *Pleurotus sajor-caju* (Sethuraman *et al.,* 1998), *Panus osteratus* (Palmieri *et al.,* 2000), and *Trametes versicolor* (Soden, & Dobson, 2001), *Grifola frondosa* (Arora, & Rampal, 2002), *Trametes trogii* (Levin, & coworkers, 2002), *Phanerochaete chrysosporium* (Chen, & coworkers, 2004), *Lentinula edodes* (Cavallazzi, & coworkers, 2005), *Volvariella volvacea* (Xing *et al.,* 2006), *Paecilomyces* sp. WSH-L07 (Liu, *et al.,* 2009), *Pleurotus florida* NCIM 1243 (Palvannan, & Sathishkumar, 2010), *Shiraia bambusicola* strain GZ11K2 (Du, & coworkers, 2012), *Trametes trogii* TEM H*2* (Kocyigit, *et al.,* 2012), *Peniophora* sp. (Shankar, & Shikha, 2012). Copper (Soden, & Dobson, 2001; Baldrian, & Gabriel, 2002) and $CuSO_4$ (Palmieri, *et al.,* 2000) significantly boost production in *Trametes pubescens*, by acting as a potent inducer of laccase gene transcription in yeast and other fungal species (Akpinar, & Urek, 2017). In place of copper, other metalic ions such as Mg^{2+} (Palvannan, & Sathishkumar, 2010), Mo^{2+}, Zn^{2+}, Mn^{2+}, Fe^{2+} (Akpinar, & Urek, 2017), enhanced the enzyme activity can also stimulate laccase expression significantly. The optimum production of laccase in *P. feryngi* (43,761.33 ± 3845 U L−1) was induced by the inducers Cu^{2+} 70 mM, Fe^{2+} 18 mM, 0.025 percent (v/v) Tween-80, 4.0 g/L ammonium nitrate 750 µM Mn^{2+} (Akpinar, & Urek, 2017).

The addition of xylidine acting as an inducer had the most fantastic addition to laccase production (Rogalski, *et al.,* 1991; Lu, *et al.,* 1996; Pickeard *et al.,* 1999) in *Trametes villosa*, *T. versicolor*, and *Pleurotus sajor-caju*, (Da Cunha, *et al.,* 2003), *Cariolopsis polyzona* (Jaouani, & coworkers, 2006), *Cariolopsis caperata* RCR2011 (Nandal, & coworkers, 2013). Alcohol, such as ethanol, was used to increase laccase activity in *Pycnoporus cinnabarinus* (Blaich, & Esser, 1975), *Trametes versicolor* (Dhawan, & Kuhad, 2001), and veratryl alcohol in *Peniophora* sp. (Mansur, *et al.,* 1997; Fenice, *et al.,* 2003). As a result, adding cellobiose to some *Trametes* sp. AH28-2 (Dosoretz, *et al.,* 1990), *Pycnoporus* species (Garzillo, *et al.,* 1998) significantly increased laccase activity. Lignin (Gianfreda, & coworkers, 1999) and cycloheximide (Leonowicz, & Trojanowski, 1975) Tween 20 or 80, (Dombrovskaya, & Kostyshin, 1996) and ammonium nitrate (Akpinar, & Urek, 2017) in plenty of fungi, this has resulted in larger production of ligninolytic enzymes. There has been evidence of anionic and cationic surfactants as an effective inducer of laccase from *Pleurotus florida* (Lomascolo, & coworkers, 2003).

By the addition of inducer tannic acid, the laccase gene's expression rises and increases laccase production in the growth medium (Rothschild, & coworkers, 1995). At 1 mM, quantity of EDTA produced considerable laccase secretion. Tested sodium azide at all doses (0.5-2 mM) induced laccase secretion in *Pestalotiopsis* CDBT-F-G1 to isolate colonies (Yadav, et al., 2019). Laccase production was stimulated by Cu^{2+} (0.1mM),

tannic acid (0.1mM), Mn^{2+} (10mM), Mg^{2+} (10mM), and ethanol (0.5 M) in *Abortiporus biennis* J2 and hindered by Ag^{2+}, Cu^{2+}, Cd^{2+}, Fe^{2+}, Hg^{2+}, and Zn^{2+} (Liang *et al.*, 2017).

Sodium azide (Sayyed, *et al.*, 2020), SDS (Arora, & Rampal, 2002), and other metal ions, such as Al^{3+}, As^{2+}, Cd^{2+}, Co^{2+}, and Li^{2+}, considerably decreased the activity of an enzyme (Baldrian, & Gabriel, 2002), whereas halides (F-> Cl-> Br-> I-), Ag^{2+}, Hg, $FeSO_4$, $HgCl_2$, $MnCl_2$, and $FeCl_3$ reported as an inhibitor respectively (Bhamare, *et al.*, 2020). Chlorides of metal ions like Ba^{2+}, Mg^{2+}, Fe^{2+}, Zn^{2+}, and other compounds such as L-cysteine, vanillin, ammonium tartrate, gallic acid, urea, PCMB (p-chloromercuribenzoic acid), DDT (Dichlorodiphenyltrichloroethane), and mercaptoethanol do not affect enzyme activity (Arora, & Rampal, 2002). The xylidine exhibited a diminished effect at greater concentrations, most likely due to toxicity (Lu, *et al.*, 1996).

VI. MOLECULAR BIOLOGY OF LACCASE

The SDS-PAGE of purified proteins of *Ganoderma lucidum* MDU-7 laccase isozymes' multimeric nature was established. The molecular mass of isozymes was discovered to be between 40 and 66 kDa (Perry, *et al.*, 1993). SDS-PAGE investigation of pure *Aspergillus nidulans* laccase (KF974331) revealed a band with a molecular mass of 66 kDa (Sethuraman, *et al.*, 1998). Laccase from *Trametes* sp. strain AH28-2 has a molecular mass of 62 kDa, according to SDS-PAGE (Hong, & coworkers, 2002). SDS-PAGE examination of *Agaricus bisporus* extracellular laccase protein extracted from compost extract revealed a prominent band with molecular weights of 65 kDa, as well as smaller amounts of polypeptides (More, *et al.*, 2011). The purified laccase of *Pleurotus* sp. SDS-PAGE revealed that it was a monomer with a molecular mass of 40$\pm$1kDa (Edae, & Alemu, 2017). The laccase molecular mass is assessed by SDS-PAGE and is normally in the range of 60 to 90 kDa, coding for 500–600 amino acids in the laccase protein. The research found that about 10–20% of the total molecular weight of laccase protein obtain by glycosylation which causes variation in molecular weight and peptide sequence of laccases. Microbial laccases isoelectric points are generally around 3.6. Numerous fungal genomes have more than one laccase gene (Xiao, *et al.*, 2003). Cultivation conditions extremely correlate with different laccase gene expression levels. For example, when nitrogen concentration enhances in cultivation medium laccase gene transcription is stimulated in the *Pleurotus* sajor-caju and Basidiomycete I-62 (CECT 20197) (Patel, & coworkers, 2009). Laccase closely resembles the ascorbate oxidase subunit and has shown significant homology with the mammalian plasma ceruloplasmin (Gerrnann, & Lerch, 1986).

VII. ISOZYMES OF LACCASE

Extracellular laccases in white-rot fungus appear in isozymes that may be inducible or intrinsic. Basidiomycetes, including *A. bisporus* (Wood, 1980), *P. ostreatus* (Sannia & coworkers, 1986), *T. versicolor* (Rogalski, *et al.*, 1991), *C. cinereus* (Schneider, & coworkers, 1999), and *P. chrysosporium* (Rodriguez, *et al.*) were able to produce several isozymes. Various laccase isoforms were produced by *Coprinus plicatilis, Fomes fomentarius, Heterobasidion annosum, Hypholoma fasciculare, Kuehneromyces mutabilis, Leptoporus litschaueri, Panus stipticus, Phellinus igniarius, Pleurotus corticatus, Polyporus brumalis, Stereum hirsutum, Trametes gibbosa,* and *T. hirsuta* (Baldrian, 2006). In liquid culture, the *Ganoderma lucidum* (Ko, & coworkers, 2001) and *Pleurotus pulmonarius* (De Souza, *et al.*, 2004) produced more than three laccase isozymes, and the basidiomycete CECT 20197 produced seven laccase isozymes (Mansur, *et al.*, 1997), *Marasmius querocophilus* strain-17 produced four stimulated isozymes and three conservative isozymes (Farnet, *et al.*, 2000). *Pleurotus* sp. has nine constitutive laccase isozymes, six of which have been extracted and identified (Liu, *et al.*, 2000). A report by Courty, *et al.*, (2008) showed that 17 different isolates of fungus after induction with different aromatic compounds were consistent similar isoenzyme arrangement (one of the three laccase bands on SDS PAGE). Isozyme patterns have also been discovered in ectomycorrhiza, Deuteromycetes, and basidiomycetes, among other fungi (Zervakis, & coworkers, 2001; Tanesaka, 2012).

VIII. ROLE OF LACCASES IN EFFLUENT TREATMENT

Today, view that xenobiotic compounds are created a high level of pollution in the world by a chemical which is a dominant cancer and mutation causing elements. Classical treatment techniques are quite expensive and utilise a lot of chemicals and energy, whereas biological treatment appears to be a good option. As a result, using enzymes to bioremediate contaminants is considered an environmentally acceptable, economical, and effective process. The laccases enzyme-based treatment processes are especially interesting because fewer induction conditions are required for laccase production than Lignin peroxidase and Manganese peroxidase (Bettin, *et al.*, 2011). Laccase has shown great potential for the treatment of wastewaters decolorization and detoxifications of effluents discharge from industries (Ikehata *et al.*, 2004; Chandra and Chowdhary, 2015) such as pulp and paper industry (Archibald *et al.*, 1997), winery/alcohol distilleries (Fitzgibbon *et al.*, 1998, Yague *et al.*, 2000), food and beverage industry (Minussi *et al.*, 2002), olive milling (Jaouani *et al.*, 2003) and textile-industry wastewaters containing dyes (Wesenberg *et al.*, 2003).

Presently laccases are applied as a green remedy to treat organochloride of phenol, polynuclear aromatic hydrocarbons, complex organic polymers structure of lignin, compounds of organophosphorus (OPs) are a diverse group of chemicals, including insecticides, benzenol and its derivatives, and colour compounds bound chemically mean dyes (Murugesan *et al.*, 2007; Saratale *et al.*, 2011; Khan *et al.*, 2013; Viswanath

et al., 2014). Laccases can also convert 1, 1'-(2, 2, 2-Trichloroethane-1, 1-diyl) bis (4-chlorobenzene) means (DDT) (Zhao *et al.*, 2010) and 2, 4-DCP a chlorinated derivative of phenol (Bhattacharya *et al.*, 2009) in soil. Researchers reported that laccase produced in greater concentrations during the idiophase (Collins and Dobson, 1997).

Due to their high water solubility and poor biodegradation, textile dyes are by far the most troublesome chemicals found in textile effluents (Khelifi, *et al.*, 2009). Textile dyes considerably reduce the quality of aquatic environment as a result of untreated effluent discharge (Bhatia, 2017). Increases in relatively high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Setiadi, & coworkers 2006) contribute to a decrease in the photosynthesis rate (Imran *et al.*, 2015) and dissolved oxygen concentration influencing the natural aquatic biotic life system (Hassan & Carr, 2018), entering the food chain, providing recalcitrance and biomagnification (Sandhya, 2010), and potentially causing cytotoxicity, mutation, and various types of cancer (Aquino *et al.*, 2014, Khatri *et al.*, 2018). In agriculture, wastewater is frequently used for irrigation in developing countries (Rehman *et al.*, 2018). Azo compounds dye has a deleterious impact on soil microbial populations as well as plant development and reproduction (Imran *et al.*, 2015).

Dye wastewater treatment methods that have been used in the past unproductive and uneconomical. Consequently, laccases based processes appear to be an appealing alternative along with its ability as eco-friendly diverse degrading dyes biocatalysts (Yang, & Yu, 1996; Kalsoom, & coworkers, 2015). The decolorization of dyes by using aerobic bacteria with limited ability to target a specific chemical structure and anaerobic bacteria produced amines that are potentially mutagenic and/or carcinogenic (Wong, & Yu, 1999). Bacterial laccases actions are less specific to the substrate (Thurston, 1994; Wong, 2009). The action of fungal laccase on chromophore molecules such as polymeric dyes, remazol brilliant blue R, triarylmethane, triphenylmethane azo, anthraquinone, heterocyclic, and indigoid dyes has been examined (Abadulla *et al.*, 2000). The black liquor cause altered chemical oxygen demand (COD), biochemical oxygen demand (BOD), and chlorophenol content released into water bodies, as well as raised colour and pH, had a severe influence on the ecosystem (Claudia, *et al.*, 2018).

Table I. The use of certain fascinating fungal laccases which decolorize and destroy dyes in waste waters

Fungal laccases	Decolorized and degraded Dye	References
Pycnoporus sanguineus	Triphenylmethane dyes (bromophenol blue and malachite green)	Rodrıguez, & coworkers, 1999
Flavodon flavus	Azure B and Brilliant Blue R	Abadulla *et al.*, 2000
Thelephora sp.	Azo dyes- *Orange* G and *Congo Red*	Selvam, *et al.*, 2003
Trametes hirsuta	Triarylmethane, indigoid, azo, and athraquinonic -textile dyes and 23 industrial dyes Bromophenol Blue and Indigo Carmine	Setti, *et al.*, 1999 Rodrıguez, & coworkers, 2005; Rodrıguez Couto *et al.* 2004
Trametes versicolor	Degradation dye brilliant green1 and acid green 16 Amaranth, Tropaeolin O, Reactive Blue 15, Congo Red, and Reactive Black 5 with no dye sorption; partially decolorizes Brilliant Red 3G-P, Brilliant Yellow 3B-A, and Remazol Brilliant Blue R with some dye sorption	Casas *et al.*, 2007
Trametes trogii BAFC 463	85% of Indigo carmine, xylidine, Malachite green, Gentian violet, Bromophenol blue, 65% of fast blue RR, and 30% of Azure B and Methylene Blue	Blanquez & coworkers, 2004; Grassi, *et al.*, 2011
Marasmius sp.	Violet, red, orange, and yellow dyes, blue dyes	Schückel *et al.*, 2011
Pleurotus ostreatus URM 4809	86% of the anthraquinone dye remazol brilliant blue R	Simoes, *et al.*, 2019
Ganoderma lucidum E47	Xanthene, azo and triarylmethane dyes organic dyes: Bengal rose; blue black naphthol; congo red; methyl orange; bromo- cresol green; bromo- cresol purple; bromo- phenol blue; and phenol red,	Palazzolo, & coworkers, 2019
Oudemansiella canarii	Congo red	Iark, *et al.*, 2019
Pleurotus sajor-caju	Acid Blue 80, Acid Green 28, Brilliant Green, Bromocresol Green, Coomassie Brilliant Blue G-250, Disperse Blue 79, Reactive Red 198, Reactive Blue 220, Congo Red, Gentian Violet, Malachite Green, Methyl Violet, Disperse Red 324, Levafix Brilliant Red E-4BA, Acid Red 315, Disperse Orange 30	Fernanda Bettin, *et al.*, 2019
Aspergillus sp. HB_RZ4	88% Bromothymol blue, 96% Bromocresol purple, and 99% Bromophenol blue dyes	Sayyed, *et al.*, 2020

Genetically engineered fungal laccases for dyes degradation and decolorization.		
Phanerochaete chrysosporium, T. trogii, Pleurotus ostreatus, and T. Versicolor	Amaranth, Remazol Black B, Remazol Orange, Remazol Brilliant Blue, Reactive Blue, and Tropaeolin O	Swamy & Ramsay, 1999
Recombinant lcc1 gene from *Trametes trogii* in *Pichia pastoris* F	Amaranth, Carmoisine, Cochineal red, Sunset yellow, Patented blue, Blue indigo, and Alizarin red	Colao, *et al.*, 2006
Aspergillus expressing a laccase from *Myceliophthora thermophila*	Anthraquinonic dyes-Acid blue 25 and Acid green 27	Kunamneni, *et al.*, 2008
Recombinant LCC3 from *Trametes trogii* BAFC 463 in *Pichia pastoris*	50–100% decolorizing ability of azoic, indigoid, triarylmethane, and anthraquinonic	Campos, & coworkers, 2016
Recombinant laccase (Lcc IIIb) from *Trametes versicolor* expressed in *Yarrowia lipolytica* C	43% Bromocresol purple, 54% Safranin, 55% Malachite green, 49% Crystal violet, 56% Bromothymol blue, 53% Nigrosine, and 37% Phenol red	Darvishi, *et al.*, 2018
P. pastoris or *A. thaliana* expressing Lcc9 from *Laccaria bicolour*	Crystal violet	Wang, *et al.*, 2018

Table II. Some unique fungal laccases are being used in various industrial effluent treatments by removal of phenol and phenolic compounds, Chemical Oxygen Demand & decolorization.

Fungal Laccases	Effluent treatments	References
Clavariopsis gallica	Degrade xenoestrogen nonylphenol	Calvo, *et al.*, 1998
Trametes sp.	Bioremediates the distillery wastewater generated from the sugarcane molasses with high content of organic matter	Gonzalez, *et al.*, 2000
Trametes villosa	Degrades bisphenol	Raghukumar, 2000
Flavodon flavus	Decolourize the effluent from a Kraft paper mill bleach plant	Soares, & coworkers, 2001
Coriolopsis rigida LPSC 232	Detoxification of water-soluble fraction	Torres, & coworkers, 2003
Pleurotus ostreatus	Degradation of PCBs as well as phenol	Keum and Li, 2004
Trametes pubescens MB 89	79±1.1% COD removal, 80±4.6% total phenols removal, 71 ± 1.6% decrease in colour from wine distillery wastewater	Strong and Burgess, 2007
Trametes pubescens	Biodegradation of a mixture of pentachlrophenol 9PCP), 2 chlorophenol (2-CP), 2,4-dichlorophenol (2,4-DCP), and 2, 4, 6-trichlorophenol (2,4,6-TCP)	Gaitan *et al.*, 2011
Pleurotus sajor-caju	Oxidize catechols, quinols, methoxyphenols, some aromatic amines and their methyl derivatives, and also resorcinol and phloroglucinol	Zucca *et al.*, 2011
Trametes versicolor	degradation of PCBs as well as phenol Colour and aromatic compounds were reduced up to 70–80% and COD was reduced up to 60%. Bisphenol A	Keum and Li, 2004 Blánquez & coworkers, 2004 Margot, *et al.*, 2013
Pleurotus ostreatus and *Pichia pastoris* (which produces rPOXA 1B laccase)	80.3% COD removal and 70.6% decolourization from Synthetic Black Liquor	Claudia, *et al.*, 2018

Fungal laccases, take attentiveness in the field of biotechnology because they have the capability to oxidized substrates due to high redox potential ($E° > 400$ mV) (Rodgers, *et al.*, 2010). Synthetic dyes, which are hazardous to mammals, are found in textile and paper industry effluents. As a result, efforts to eradicate industrial wastewaters employing laccases from *Trametes versicolor* and *Trametes trogii* "Table I" have been made (Grassi, *et al.*, 2011; Garcia, *et al.*, 2019). Laccases from white-rot fungus, such as *T. versicolor*, immobilised onto silica-alginate and loofa-sponge as support for phenol removal, have the potential to degrade phenolic compounds (Carabajal, *et al.*, 2016). *Trametes pubescens* crude extract was employed in the study of degradation of chlorophenols "Table II" (Gaitan *et al.*, 2011), whereas purified laccase from *Trametes villosa* able to degrade BPA without any mediators (Piscitelli, *et al.*, 2010). *Pycnoporus sanguineus* (CS43) immobilised on ceramic membranes that decompose BPA (20 mg/L) within 24 hours. "Table II". *T. pubescens* MB was able to eliminate 8979.1% COD, 80±4.6% total phenolic content, and reduce 71.6% in colour from wine distillery wastewater (Strong & Burgess, 2007) "Table II".

To find out the interest of laccase for the industrial need is challenging, especially when the enzyme isn't widely expressed as a result, heterologous laccase expression can be used as a substitute (Piscitelli, *et al.*, 2010; Viswanath, *et al.*, 2014). Many fungal laccases, such as *Pichia pastoris* and *Yarrowia lipolytica*, in filamentous fungi *Aspergillus oryzae*, *A. niger*, *T. villosa* (Yaver, *et al.*, 1996; Bohlin, *et al.*, 2006), and *Pycnoporus*

cinnabarinus (Madzak, *et al.,* 2005) have been found to have heterologous expression. Yeasts and filamentous fungi as a host are typically more appealing for heterologous protein production to produce large proteins amount into the growing medium, faster microbial growth, easy gene manipulation, as well as the potential to produce posttranslational modifications Yeasts and filamentous fungi that serve as hosts are frequently more appealing (Piscitelli, *et al.,* 2010).

Bioremediation has also benefited from the use of recombinant fungal laccases. Several polluting dyes, has been reported such as indigo carmine, etc. undergo oxidative degradation, by recombinant proteins Lcc1 and Lcc3 isolated from *T. trogii*, produced in *P. pastoris* (Colao, *et al.,* 2006; Campos & coworkers, 2016). After 4 hours of treatment, a recombinant laccase (Lcc IIIb) from *T. versicolor* in *Y. lipolytica* decolorizes five phenolic azo dyes with > 40% efficiency (Darvishi, *et al.,* 2018). Likewise, *Laccaria bicolor*, an ectomycorrhizal fungus found in *P. pastoris* and *A. thaliana*, was established as a means of decolorizing > 80% of the crystal violet dye (Wang, *et al.,* 2018). In another study, *Pleurotus ostreatus* and *Pichia pastoris* (producers of rPOXA 1B laccase) were shown 80.3% COD removal and 70.6% decolourization from Synthetic Black Liquor (Claudia, *et al.,* 2018) "Table II".

CONCLUSION

Presently, the diversity of pollutants discharged without any treatment into water bodies by various industries causes' water pollution and health issues. There is an obvious need to overthrow contamination of the world's water sources. Laccases, an efficient biocatalytic tool, are now being studied as an alternate approach for oxidising these molecules, with the goal of producing fewer toxic and hazardous inactive chemicals while also removing poisonous xenobiotics from the environment. Their wide substrate specificity and usability drew interest in research as well as in commercial processes such as pulp delignification, textile bleaching, phenolic elimination, and biosensors. This review compiles recent laccase findings from a variety of sources, characteristics, mechanisms of action, and optimization of various fungal laccase production conditions and enzymatic activity to achieve their efficient use in pollutant molecule bioremediation and biotransformation in water. Consequently, there has been a need to discover and innovate new laccases capable of catalytic activity under adverse conditions, as well as develop novel approaches and techniques to facilitate their widespread use in the treatment of pollutants from water. Laccase has found applications in the design of biosensors and nanotechnology.

REFERENCES

Abadulla, E., Tzanov, T., Costa, S., Robra, K.H., Cavaco-Paulo, A., Gübitz, G.M. (2000). Decolorization and detoxification of textile dyes with a laccase from *Trametes hirsuta*. *Appl. Environ. Microbiol.*, 66(8), 3357–3362.

Abd, R.A., Monssef, E., Hassan, E.A., Ramadan, E.M. (2016). Production of laccase enzyme for their potential application to decolorize fungal pigments on aging paper and parchment. *Annals of Agricultural Sciences*. 61(1), 145-154.

Akpinar, M. & Urek, R.O. (2017). Induction of fungal laccase production under solid-state bioprocessing of new agro-industrial waste and its application on dye decolorization. *3 Biotech.*, 2017(7), 98.

Ali, M.I. A., Ouf, S.A., Khalil, N.M., & El-Ghany, M.N.A. (2015). Biosynthesis of laccase by *Aspergillus flavus* NG85 Isolated from Saint Catherine protectorate. *Egypt. J. Bot.*, 55(1), 127 -147.

Aquino, J.M., Rocha-Filho, R.C., Ruotolo, L.A., Bocchi, N., Biaggio, S.R. (2014). Electrochemical degradation of a real textile wastewater using β-PbO2 and DSA anodes. *Chemical Engineering Journal*, 251, 138-145.

Archibald, F.S., Bourbonnais, R., Jurasek, L., Paice, M.G. & Reid, I.D. (1997). Kraft pulp bleaching delignification by *Trametes versicolor*. *Journal of Biotechnology*, 53(2-3), 215–236.

Arias, M.E., Arenas, M., Rodr´ıguez, J., Soliveri, J., Ball, A.S., & Hernandez, M. (2003). Kraft pulp biobleaching and mediated oxidation of a nonphenolic substrate by laccase from *Streptomyces cyaneus* CECT 3335. *Applied and Environmental Microbiology*, 9(4), 1953–1958.

Arora, D.S. & Rampal, P. (2002). Laccase production by some *Phlebia* species. *Journal of Basic Microbiology*, 42, 295–301.

Baldrian, P. (2006). Fungal laccases-occurrence and properties. *FEMS Microbiology Reviews*, 30(2), 215–242.

Baldrian, P. & Gabriel, J. (2002). Copper and cadmium increase laccase activity in *Pleurotus ostreatus*. *FEMS Microbiology Letters*, 206(1), 69–74.

Battistuzzi, G., Di Rocco, G., Leonardi, A. & Sola, M. (2003). 1H NMR of native and azide-inhibited laccase from *Rhus vernicifera*. *Journal of Inorganic Biochemistry,* 96(4), 503–506.

Bertrand, G., (1985). Sur la laccase et sur le pouvoir oxydant de cette diastase. *Comptes Rendus de L'Academie des Sciences,* 120, 266–269.

Bettin, F., Rosa, L.O., Montanari, Q., Calloni, R., Gaio, T.A., Malvessi, E., Silveira, M.M., Dillon, A.J.P. (2011). Growth kinetics, production, and characterization of extracellular laccases from *Pleurotus sajor-caju* PS-2001. *Process Biochem.* 46, 758-764.

Bhatia, S.C. (2017). Pollution Control in the textile industry. New Delhi: India, *Woodhead Publishing India*.

Bhattacharya, S.S., Karmakar, S., & Banerjee, R. (2009). Optimization of laccase mediated biodegradation of 2,4-dichlorophenol using genetic algorithm. *Water Res.*, 43(14), 3505-3510.

Blaich, R., & Esser, K. (1975). The function of enzymes in wood-destroying fungi. II. Multiple forms of laccase in white-rot fungi. *Archives of Microbiology*, 103(3), 271–277.

Blanquez, P., Casas, N., & Font, X. (2004). Mechanism of textile metal dye biotransformation by *Trametes versicolor*. *Water Research*, 38(8), 2166–2172.

Bohlin, C., Jönsson, L.J., Roth, R., Van-Zyl, W.H. (2006). Heterologous expression of *Trametes versicolor* laccase in *Pichia pastoris* and *Aspergillus niger*. *Appl. Biochem. Biotechnol.*, 129(132), 195-214.

Bollag, J.M., Shuttleworth, K.L. & Anderson, D.H. (1988). Laccase mediated detoxification of phenolic compounds. *Applied and Environmental Microbiology*, 54(12), 3086–3091.

Bourbonnais, R. & Paice, M.G. (1990). Oxidation of non-phenolic substrates. An expanded role for laccase in lignin biodegradation. *FEBS Letters*, 267(1), 99–102.

Bourbonnais, R. & Paice, M.G., (1996). Enzymatic delignification of kraft pulp using laccase and a mediator. *Tappi Journal*, 79(6), 199–204.

Bourbonnais, R. & Paice, M.G., Reid, I.D., Lanthier, P. & Yaguchi, M. (1995). Lignin oxidation by laccase isozymes from *Trametes versicolor* and role of the mediator 2,2'-azinobis(3-ethylbenzthiazoline-6-sulfonate) in kraft lignin depolymerization. *Applied and environmental microbiology*, 61(5), 1876–1880.

Brijwani, K., Rigdon, A., & Praveen vadlani, V. (2010). Fungal laccases: production, function, and applications in food processing.*Enzyme Research*, 2010, 1-10.

Buswell, J.A., Cai, Y., & Chang, S.T. (1995). Effect of nutrient nitrogen and manganese on manganese peroxidase and laccase production by *Lentinula edodes*. *FEMS Microbiology Letters*, 128(1), 81–88.

Calvo, A.M., Copa-Pati˜no, J.L., Alonso, O. & Gonz´alez, A.E. (1998). Studies of the production and characterization of laccase activity in the basidiomycete *Coriolopsis gallica*, an efficient decolorizer of alkaline effluents. *Archives of Microbiology*, 171(1), 31-36.

Campos, P.A., Levin, L.N., & Wirth, S.A. (2016). Heterologous production, characterization, and dye decolorization ability of a novel thermostable laccase isoenzyme from *Trametes trogii* BAFC 463. *Process Biochem.*, 51, 895-903.

Carabajal, M., Perullini, M., Jobbágy, M., Ullrich, R., Hofrichter, M, & Levin, L. (2016). Removal of phenol by immobilization of *Trametes versicolor* in silica– alginate–fungus biocomposites and loofa sponge. *CLEAN Soil Air Water*. 44, 180-188.

Casas, N., Parella, T., Vicent, T., Caminal, G., & Sarrà, M. (2009). Metabolites from the biodegradation of triphenylmethane dyes by *Trametes versicolor* or laccase. Chemosphere, 75(10), 1344–1349.

Cavallazzi, J.R.P., Kasuya, C.M. & Soares, M.A. (2005). Screening of inducers for laccase production by *Lentinula edodes* in liquid medium. *Brazilian Journal of Microbiology*, 36(4), 383–387.

Chandra, R., & Chowdhary, P. (2015). Properties of bacterial laccase and their application in bioremediation of industrial wastes. *Environ Sci Process Impacts*, 17,326-342.

Chauhan, R. (2019). Nitrogen sources and trace elements influence the Laccase and peroxidase enzymes activity of *Grammothele fuligo*. *Vegetos*, 32,316–323.

Chen, S., Ge, W., & Buswell, J.A. (2004). Biochemical and molecular characterization of a laccase from the edible straw mushroom, *Volvariella volvacea*. *European Journal of Biochemistry*, 271(2), 318-328.

Chen, S., Ma, D., Ge, W., &. Buswell, J.A. (2003). Induction of laccase activity in the edible straw mushroom, *Volvariella volvacea*. *FEMS Microbiology Letters*, 218(1), 143–148.

Chernykh, A., Myasoedova, N., & Kolomytseva, M. (2008). Laccase isoforms with unusual properties from the basidiomycete *Steccherinum ochraceum* strain 1833. *Journal of Applied Microbiology*, 105(6), 2065–2075.

Claudia, M., Rivera-Hoyos, E.D., Morales-Álvarez, Abelló-Esparza, J., Daniel F., Buitrago-Pérez, N., Martínez, A., Juan, C. Salcedo R., Raul, A., Poutou, P. & Aura, M., Rodríguez, P. (2018). Detoxifcation of pulping black liquor with *Pleurotus ostreatus* or recombinant *Pichia pastoris* followed by CuO/TiO_2/visible photocatalysis. *Scientific Reports*, 8(3503), 1-15.

Colao, M.C., Lupino, S., Garzillo, A.M., Buonocore, V., & Ruzzi, M. (2006). Heterologous expression of lcc1 gene from *Trametes trogii* in *Pichia pastoris* and characterization of the recombinant enzyme. *Microb. Cell Fact.*, 5,31.

Collins, P.J. & Dobson, A.D.W. (1995). Extracellular lignin and manganese peroxidase production by the white-rot fungus *Coriolus versicolor* 290. *Biotechnology Letters*, 17(9), 989–992.

Collins, P.J. & Dobson, A.D.W. (1997). Regulation of laccase gene transcription in *Trametes versicolor*. *Appl. Environ. Microbiol.*, 63(9), 3444-3450.

Courty, P.E., Poletto, M., Duchaussoy, F., Buee, M., Garbaye, J., & Martin, F. (2008). Gene transcription in *Lactarius quietus-quercus petraea* ectomycorrhizas from forest soil. *Applied and Environmental Microbiology*, 74(21), 6598–6605.

Couto, S.R. & Toca-Herrera, J.L. (2007). Laccase production at reactor scale by filamentous fungi. *Biotechnology Advances*, 25(6), 558–569.

D'Souza-Ticlo, D., Verma, A.K., Mathew, M. & Raghukumar, C. (2006). Effect of nutrient nitrogen on laccase production, its isozyme pattern, and effluent decolorization by the fungus NIOCC#2a, isolated from mangrove wood. *Indian Journal of Marine Sciences*, 35(4), 364–372.

Da Cunha, M.A.A., Barbosa, A.M., Giese, E.C. & Dekker, R.F.H. (2003). The effect of carbohydrate carbon sources on the production of constitutive and inducible laccases by

Botryosphaeria sp. *Journal of Basic Microbiology*, 43(5), 385–392.

Daphne, V., Gnanasalomi, V., & Gnanadoss, J.J. (2019). Laccase production by *Myrothecium gramineum* and its optimization under solid-state fermentation using cowpea pod as substrate. *Journal of Applied Biology & Biotechnology*, 7(02), 59-63.

Darvishi, F., Moradi, M., Jolivalt, C., & Madzak, C. (2018). Laccase production from sucrose by recombinant *Yarrowia lipolytica* and its application to decolorization of environmental pollutant dyes. *Ecotox Environ Safe.* 165, 278-283.

De Jesus, M., Nicola, A.M., Rodrigues, M.L., Janbon, G. & Casadevall, A. (2009). Capsular localization of the *Cryptococcus neoformans* polysaccharide component galactoxylomannan. *Eukaryotic Cell*, 8(1), 96–103.

De Souza, C.G.M., Tychanowicz, G.K., De Souza, D.F., & Peralta, R.M. (2004). Production of laccase isoforms by *Pleurotus pulmonarius* in response to presence of phenolic and aromatic compounds. *Journal of Basic Microbiology*, 44(2), 129–136.

Dekker, R.F.H. & Barbosa, A.M. (2001). The effects of aeration and veratryl alcohol on the production of two laccases by the ascomycete *Botryosphaeria* sp. *Enzyme and Microbial Technology*, 28(1), 81–88.

Desai, S.S. & Nityanand, C. (2011). Microbial laccases and their applications: a review. *Asian Journal of Biotechnology*, 3(2), 98–124.

Dhakar, K., Jain, R., Tamta, S., & Pandey, A. (2014). Prolonged Laccase Production by a Cold and pH Tolerant Strain of *Penicillium pinophilum* (MCC 1049) isolated from a Low-Temperature Environment. *Enzyme Research*, 2014, 1-6.

Dhawan, S., & Kuhad, R.C. (2001). Effect of amino acids and vitamins on laccase production by the bird's nest fungus *Cyathus bulleri*. *Bioresource Technology*, 84(1), 35–38.

Dittmer, J.K., Patel, N.J., Dhawale, S.W., & Dhawale, S.S. (1997). Production of multiple laccase isoforms by *Phanerochaete chryosporium* grown under nutrient sufficiency. *FEMS Microbiology Letters*, 149(1), 65–70.

Dittmer, N.T., Suderman, R.J., Jiang, H., (2004). Characterization of cDNAs encoding putative laccase-like multicopper oxidases and developmental expression in the tobacco hornworm, Manduca sexta, and the malaria mosquito, *Anopheles gambiae*. *Insect Biochemistry and Molecular Biology*, 34(1), 29– 41.

Dombrovskaya, E.N., & Kostyshin, S.S. (1996). Effects of surfactants of different ionic nature on the ligninolytic enzyme complexes of the white-rot fungi *Pleurotus floridae* and *Phellinus igniarius*. *Biochemistry*, 61(2), 215-220.

Dong, J.L., Zhang, Y.W., Zhang, R.H., Huang, W.Z., & Zhang, Y.Z. (2005).Influence of culture conditions on laccase production and isozyme patterns in the white-rot fungus *Trametes gallica*. *Journal of Basic Microbiology*, 45(3), pp. 190–198.

Dosoretz, C.G., Chen, A.H.-C., & Grethlein, H.E. (1990). Effect of oxygenation conditions on submerged cultures of *Phanerochaete chrysosporium*. *Applied Microbiology and Biotechnology*, 34(1), 131-137.

Du, W., Sun, C., Yu, J. (2012). Effect of synergistic inducement on the production of laccase by a novel *Shiraia bambusicola* strain GZ11K2. *Applied Biochemistry and Biotechnology*, 168(8), 2376–2386.

Edae, T. and Alemu, M. (2017). Selection and optimization of lignocellulosic substrate for laccase production from *Pleurotus* species. 8(4), 38-48.

Eggert, C., Temp, U., & Eriksson, K.E.L. (1996). The ligninolytic system of the white-rot fungus *Pycnoporus cinnabarinus*: purification and characterization of the laccase. *Applied and Environmental Microbiology*, 62(4), 1151–1158.

Elshafei, A., Hassan, M.M., Haroun, B.M., Elsayed, M.A., & Othman, A. (2012). Optimization of laccase production from *Penicillium martensii* NRC 345. *Advances in Life Sciences*, 2(1), 31-37.

Eugenio, M.E., Carbajo, J.M., Mart´ın, J.A., Gonzalez, A.E. & Villar, J.C. (2009). Laccase production by *Pycnoporus sanguineus* under different culture conditions. *Journal of Basic Microbiology*, 49(5), 433–440.

Farnet, A.M., Criquet, S., Tagger, S., Gil, G. & Le Petit, J. (2000). Purification, partial characterization, and reactivity with aromatic compounds of two laccases from *Marasmius quercophilusstrain* 17. *Canadian Journal of Microbiology*, 46(3), 189–194.

Faure, D., Bouillant, M.L., & Bally, R. (1994). Isolation of *Azospirillum lipoferum* 4T Tn5 mutants affected melanization and laccase activity. *Applied and Environmental Microbiology*, 60(9), 3413–3415.

Fenice, M., Sermanni, G.G., Federici, F., & D'Annibale, A. (2003). Submerged and solid-state production of laccase and Mn-peroxidase by *Panus tigrinus* on olive mill waste-water-based media. *Journal of Biotechnology*, 100(1), 77-85.

Fernanda, B.F.,Cousseau, K., Martins, S., Zaccaria, V., Girardi, M., Silveira M.da., Jose, A. & Dillon, P. (2019). Effect of pH, temperature, and agitation on the decolourization of dyes by a laccase-containing enzyme preparation from *Pleurotus sajor-caju, Braz. Arch. biol. Technol.*, 62, 1-21.

Fitzgibbon, F., Singh, D., McMullan, G., & Marchant, R. (1998). The effect of phenolic acids and molasses spent wash concentration on distillery wastewater remediation by fungi. *Process Biochem.*, 33(8), 799–803.

Gaitan, I.J., Medina, S.C., González, J.C., Rodríguez, A., Espejo, Á.J., Osma, J.F., Sarria, V., Alméciga-Díaz, C.J., & Sánchez, O.F. (2011). Evaluation of toxicity and degradation of a chlorophenol mixture by the laccase produced

by *Trametes pubescens*. *Bioresour. Technol.,* 102(3), 3632-3635.

Garcia, L.F., Lacerda, M.F., Thomaz, D.V., de Souza, J.C., Pereira, M., de Souza, G., Schimidt, F., & Santiago, M.F. (2019). Optimization of laccase-alginate-chitosanbased matrix toward 17 α-ethinylestradiol removals. *Prep. Biochem. Biotechnol.,* 49, 375-383.

Garzillo, A.M.V., Colao, M.C., Caruso, C., Caporale, C., Celletti, D., & Buonocore, V. (1998). Laccase from the white-rot fungus *Trametes trogii*. *Applied Microbiology and Biotechnology,* 49(5), 545-551.

Gavnholt, B., & Larsen, K. (2002). Molecular biology of plant laccases about lignin formation. *Physiologia Plantarum*. 116(3), 273–280.

Gerrnann, U. A. & Lerch, K. (1986). Isolation and partial nucleotide sequence of the laccase gene from *Neurospora crassa*: amino acid sequence homology of the protein to human ceruloplasmin. *Proc. Natl. Acad. Sci. USA*, 83, 8854-8858.

Gianfreda, L., Xu, F. & Bollag, J.M. (1999). Laccases: a useful group of oxidoreductive enzymes. *Bioremediation Journal*, 3(1), 1–25.

Givaudan, A., Effosse, A., Faure, D., Potier, P., Bouillant, M.L. & Bally, R. (1993). Polyphenol oxidase in *Azospirillum lipoferum* isolated from rice rhizosphere: evidence for laccase activity in non-motile strains of *Azospirillum lipoferum*. *FEMS Microbiology Letters*, 108(2), 205–210.

Gochev, V.K. & Krastanov, A.I. (2007). Fungal laccases, *Bulgarian Journal of Agricultural Science*, 13, 75–83.

Gonzalez, T., Terron, M.C., Yague, S., Zapico, E., Galletti, G.C., & González, A.E. (2000). Pyrolysis/gas chromatography/mass spectrometry monitoring of fungal-biotreated distillery wastewater using *Trametes* sp. I-62 (CECT 20197). *Rapid Communications in Mass Spectrometry*, 14(15), 1417–1424.

Grassi, E., Scodeller, P., Filiel, N., Carballo, R., & Levin, L. (2011). Potential of *Trametes trogii* culture fluids and its purified laccase for the decolorization of different types of recalcitrant dyes without the addition of redox mediators. *Int. Biodeter. Biodegr.,* 65, 635–643.

Grotewold, E., Taccioli, G.E., Aisemberg, G.O., & Judewicz, N.D. (1989). Early response and induced tolerance to cycloheximide in *Neurospora crassa*. *Current Genetics*, 15(6), 429–434.

Harkin, J.M. & Obst, J.R. (1973). Syringaldazine, an effective reagent for detecting laccase and peroxidase in fungi. *Experientia,* 29(4), 381–387.

Hassan, M.M., & Carr, C.M. (2018). A critical review on recent advancements of the removal of reactive dyes from dyehouse effluent by ion-exchange adsorbents. *Chemosphere*, 209(1), 201-219.

Hatakka, A., (2001). Biodegradation of lignin, in Lignin, Humic Substances, and Coal. Hofrichter, M., & Steinbuchel, A., Eds., (pp. 129–179), Wiley-VCH, Weinheim, Germany.

Heinzkill, M., Bech, L., Halkier, T., Schneider, P. & Anke, T. (1998). Characterization of laccases and peroxidases from woodrotting fungi (family Coprinaceae). *Applied and Environmental Microbiology*, 64(5), 1601–1606.

Hilden, K., Hakala, T.K. & Lundell, T. (2009). Thermotolerant and thermostable laccases. *Biotechnology Letters*, 31(8), 1117–1128.

Hong, F., Meinander, N.Q., & Jonsson, L.J. (2002). Fermentation strategies for improved heterologous expression of laccase in *Pichia pastoris. Biotechnology and Bioengineering*, 79(4), 438-449.

Hoopes, J.T., & Dean, J.F.D. (2004).Ferroxidase activity in a laccase like multicopper oxidase from *Liriodendron tulipifera*. *Plant Physiology and Biochemistry*, 42(1), 27–33.

Iark, D., dos Reis Buzzo, A.J., Garcia, J.A.A., Côrrea, V.G., Helm, C.V., Corrêa, R.C.G., Peralta, R.A., Moreira, R.F.P.M., Bracht, A., & Peralta, R.M. (2019). Enzymatic degradation and detoxification of azo dye Congo red by a new laccase from *Oudemansiella canarii*. *Bioresour Technol.,* 289, 1-10.

Ikeda, R., Sugita, T., Jacobson, E.S., & Shinoda, T. (2003). Effects of melanin upon susceptibility of *Cryptococcus* to antifungals. *Microbiology and Immunology*, 47(4), 271–277.

Ikehata, K., Buchanan, I.D., & Smith, D.W. (2004). Recent developments in the production of extracellular fungal peroxidases and laccases for waste treatment. *J. Environ. Eng. Sci.,* 3, 1-19.

Imran, M., Crowley, D.E., Khalid, A., Hussain, S., Mumtaz, M.W., & Arshad, M. (2015). Microbial biotechnology for decolorization of textile wastewaters, Reviews. *Environmental Science and Biotechnology*, 14(1), 73-92.

Iyer, G., & Chattoo, B.B. (2003). Purification and characterization of laccase from the rice blast fungus, *Magnaporthe grisea*. *FEMS Microbiology Letters*, 227 (1), 121–126.

Janusz, G., Rogalski, J., Barwinska, M., & Szczodrak, J. (2006). Effects of culture conditions on production of extracellular laccase by *Rhizoctonia praticola*. *Polish Journal of Microbiology*, 55(4), 309–319.

Jaouani, A., Sayadi, S., Vanthournhout, M., & Penninck, M.J. (2003). Potent fungi for decolourization of olive oil mill wastewaters. *Enzyme Microbial. Technol.,* 33, 802-809.

Jaouani, A., Tabka, M.G., &Penninckx, M.J. (2006). Lignin modifying enzymes of *Coriolopsis polyzona* and their role in olive oil mill wastewaters decolourization. *Chemosphere*, 62(9), 1421–1430.

Johnson, D.L., Thompson, J.L., Brinkmann, S.M., Schuller, K.A. & Martin, L.L. (2003). Electrochemical characterization of purified *Rhus vernicifera* laccase: voltammetric evidence

for a sequential four-electron transfer. *Biochemistry*, 42(34), 10229– 10237.

Junghanns, C., Moeder, M., Krauss, G., Martin, C., & Schlosser, D. (2005). Degradation of the xenoestrogen nonylphenol by aquatic fungi and their laccases. *Microbiology*, 151(1), 45–57.

Kalsoom, U., Bhatti, H.N., & Asgher, M. (2015). Characterization of plant peroxidases and their potential for degradation of dyes: a review. *Appl. Biochem. Biotechnol.*, 176, 1529-1550.

Keum, Y.S. & Li, Q.X. (2004). Fungal laccase-catalyzed degradation of hydroxy polychlorinated biphenyl. *Chemosphere*, 56(1), 23-30.

Khan, R., Bhawana, P., Fulekar, M.H. (2013). Microbial decolorization and degradation of synthetic dyes: a review. *Rev. Environ. Sci. Biotechnol.*, 12, 75-97.

Khatri, J., Nidheesh, P.V., Singh, Kumar, M.S. (2018). Advanced oxidation processes based on zero-valent aluminium for treating textile wastewater. *Chemical Engineering Journal*, 348, 67-73.

Khelifi, E., Ayed, L., Bouallagui, H., Touhami, Y., Hamdi, M. (2009). Effect of nitrogen and carbon sources on Indigo and Congo red decolourization by *Aspergillus alliaceus* strain 121C. *J. Hazard Mat.*, 163, 1056-1062.

Kiiskinen, L.L., Viikari, L., & Kruus, K. (2002). Purification and characterization of a novel laccase from the ascomycete *Melanocarpus albomyces*. *Applied Microbiology and Biotechnology*, 59(2-3), 198–204.

Kim, Y., Cho, N.S., Eom, T.J. & Shin, W. (2002). Purification and characterization of a laccase from *Cerrena unicolor* and its reactivity in lignin degradation. *Bulletin of the Korean Chemical Society*, 23(7), 985–989.

Ko, E.M., Leem, Y.E., & Choi, H.T. (2001). Purification and characterization of laccase isozymes from the white-rot basidiomycete *Ganoderma lucidum*. *Applied Microbiology and Biotechnology*, 57(1-2), 98–102.

Kocyigit, A., Pazarbasi, M.B., Yasa, I., Ozdemir, G., & Karaboz, I. (2012). Production of laccase from *Trametes trogii* TEM H2 a newly isolated white-rot fungus by air sampling. *Journal of Basic Microbiology*, 52, 661–669.

Kunamneni, A., Ghazi, I., Camarero, S., Ballesteros, A., Plou, F.J., & Alcalde, M. (2008). Decolorization of synthetic dyes by laccase immobilized on epoxy activated carriers. *Process Biochem.*, 43,169-178.

Leatham, G.F., & Kirk, T.K. (1983). Regulation of ligninolytic activity by nutrient nitrogen in white-rot basidiomycetes. *FEMS Microbiology Letters*, 16(1), 65–67.

Lee, K.H., Wi, S.G., Singh, A.P., & Kim, Y.S. (2004). Micromorphological characteristics of decayed wood and laccase produced by the brown-rot fungus *Coniophora puteana*. *Journal of Wood Science*, 50(3), 281–284.

Leonowicz, A., & Trojanowski, J. (1975). Induction of laccase by ferulic acid in Basidiomycetes. *Acta Biochimica Polonica*, 22 (4), 291-295.

Levasseur, A., Saloheimo, M., & Navarro, D. (2010). Exploring laccase-like multicopper oxidase genes from the ascomycete *Trichoderma reesei*: a functional, phylogenetic and evolutionary study. *BMC Biochemistry*, 11(1), 32.

Levin, L., Forchiassin, F., & Ramos, A.M. (2002). Copper induction of lignin-modifying enzymes in the white-rot fungus *Trametes trogii*. *Mycologia*, 94(3), 377–383.

Liang Yin, Jiayin Ye, Sibi Kuang, Yanqing Guan, Rong You, (2017). Induction, purification, and characterization of a thermo and pH stable laccase from *Abortiporus biennis* J2 and its application on the clarification of litchi juice. *Bioscience, Biotechnology, and Biochemistry*, 81(5), 1033-1040.

Liu, S.X., Dong, J.L. & Zhang, Y.Z. (2000). Analysis of laccase isozymes from *Pleurotus osteatus*. *Sichuan Da Xue Xue Bao (Natural Science Edition)*, 37, 769–771.

Liu, Z., Zhang, D., Hua, Z., Li, J., Du, G., & Chen, J. (2009). A newly isolated Paecilomyces sp.WSH-L07 for laccase production: isolation, identification, and production enhancement by complex inducement. *Journal of Industrial Microbiology & Biotechnology*, 36(10), 1315–1321.

Lo, S.C., Ho, Y.S. & Buswell, J.A. (2002). Effect of phenolic monomers on the production of laccases by the edible mushroom *Pleurotus* sajor-caju, and partial characterization of a major laccase component. *Mycologia*, 93(3), 413–421.

Lomascolo, A., Record, E., Herpo¨el-Gimbert I. (2003). Overproduction of laccase by a monokaryotic strain of *cinnabarinus* using ethanol as inducer. *Journal of Applied Microbiology*, 94(4), 618-624.

Lu, S.X.F., Jones, C.L., & Lonergan, G.T. (1996). Correlation between fungal morphology and laccase expression under the influence of cellobiose induction. In *Proceedings of the 10th International Biotechnology Symposium and the 9th International Symposium on Yeasts* (Poster session 1), Sydney, Australia.

Luterek, J., Gianfreda, L., Wojta´s Wasilewska, M. (1997). Screening of the wood-rotting fungi for laccase production: induction by ferulic acid, partial purification, and immobilization of laccase from the high laccase-producing strain, *Cerrena unicolor*. *Acta Microbiologica Polonica*, 46(3), 297–311.

Madzak, C., Otterbein, L., Chamkha, M., Moukha, S., Asther, M., Gaillardin, C., Beckerich, J.M. (2005). Heterologous production of a laccase from the basidiomycete *Pycnoporus cinnabarinus* in the dimorphic yeast *Yarrowia lipolytica*. *FEMS Yeast Res.*, 5, 635-646.

Mansur, M., Suarez, T., Fernandez-Larrea, J.B., Brizuela, M.A., & Gonzalez, A.E. (1997). Identification of a laccase gene family in the new lignin-degrading basidiomycete CECT

20197. *Applied and Environmental Microbiology*, 63(7), 2637-2646.

Marbach, I., Harel, E., & Mayer A.M.(1984). Molecular properties of extracellular *Botrytis cinerea* laccase," *Phytochemistry*, 23(12), 2713–2717.

Marbach, I., Harel, E., & Mayer, A.M. (1985). Pectin, a second inducer for laccase production by *Botrytis cinerea*," *Phytochemistry*, 24(11), 2559–2561.

Margot**,** J., Bennati-Granier**,** C., Maillard**,** J., Blánquez**,** P. David, A., Holliger, B. **&** Holliger**,** C. (2013). Bacterial *versus* fungal laccase: potential for micropollutant degradation. *AMB Express*, 3, 63.

Martins, L.O., Soares, C.M., Pereira M.M. (2002). Molecular and biochemical characterization of a highly stable bacterial laccase that occurs as a structural component of the *Bacillus subtilis* endospore coat. *Journal of Biological Chemistry*, 277(21), 18849–18859.

Mayer, A.M. & Staples, R.C. (2002). Laccase: new functions for an old enzyme. *Phytochemistry*, 60(6), 551–565.

Mikiashvili, N., Wasser, S.P., Nevo, E., & Elisashvili, V. (2006). Effects of carbon and nitrogen sources on *Pleurotus ostreatus* ligninolytic enzyme activity. *World Journal of Microbiology & Biotechnology*, 22, 999–1002.

Minussi, R.C., Miranda, M.A., Silva J.A. (2007). Purification, characterization, and application of laccase from *Trametes versicolor* for colour and phenolic removal of olive mill wastewater in the presence of 1-hydroxybenzotriazole. *African Journal of Biotechnology*, 6(10), 1248–1254.

Minussi, R.C., Pastore, G.M., & Duran, N. (2002). Potential applications of laccase in the food industry. *Trends in Food Sci. Technol.*, 13, 205-216.

Moin, S.F., & Omar, M.N. (2013). Laccase enzymes: purification, structure to catalysis, and tailoring. *Protein Peptide Letters*, 20, 12.

Monteiro, M.C. & De Carvalho, M.E.A., (1998). Pulp bleaching using laccase from *Trametes versacolor* under high temperature and alkaline conditions. *Applied Biochemistry and Biotechnology Part A*, 70(72), 983–993.

More, S.S., Renuka P. S., Pruthvi K., Swetha M., S. Malini, & Veena S. M., (2011). Isolation, Purification, and Characterization of Fungal Laccase from *Pleurotus* sp. *Enzyme Research*, 2011, 1-7.

Murugesan, K., Dhamija, A., Nam, I.H., Kim, Y.M., & Chang, Y.S.(2007). Decolourization of Reactive Black 5 by laccase: optimization by response surface methodology. *Dyes Pigments*, 75, 176-184.

Naclerio, G., Falasca, A., Petrella, E., Nerone, V., Cocco, F., & Celico, F. (2010). Potential role of *Bacillus endospores* in soil amended by olive mill wastewater. *Water Science and Technology*, 61(11), 2873–2879.

Nandal, P., Ravella, S.R., & Kuhad, R.C. (2-13). Laccase production by *Coriolopsis caperata* RCK2011: optimization under solid-state fermentation by Taguchi DOEmethodology. *Scientific Reports*, 3, 1386.

Nghi, D.H., Bittner, B., & Kellner, H. (2012). The Wood Rot Ascomycete *Xylaria polymorpha* produces a novel GH78 glycoside hydrolase that exhibits L-Rhamnosidase and feruloyl esterase activities and releases hydroxycinnamic acids from lignocelluloses. *Applied Environmental Microbiology*, 78(14), 4893-4900.

Ni, J., & Tokuda, G. (2013). Lignocellulose-degrading enzymes from termites and their symbiotic microbiota," *Biotechnology Advances*, 31, 838–850.

Niku-Paavola, M.L., Karhunen, E., Salola, P., & Raunio, V. (1988). Ligninolytic enzymes of the white-rot fungus *Phlebia radiate*. *Biochemical Journal*, 254(3), 877–884.

Nishida, T., Yoshinori, K., Mimura, A., & Takahara, Y. (1988). Lignin biodegradation by wood-rotting fungi I. Screening of lignindegrading fungi. *Mokuzai Gakkaishi*, 34, 530–536.

Nora, A.I.E.B., Aymen, M.E.K., Amin, S.Y.M.A. (2015). Laccase production by Pleurotus ostreatus *and its application in the synthesis of gold nanoparticles.* Biotechnology Reports,*31-39.*

Palazzolo, M.A., Postemsky, P.D., & Kurina-Sanz, M. (2019). From agro-waste to the tool: biotechnological characterization and application of *Ganoderma lucidum* E47 laccase in dye decolorization. *3 Biotech*, 9 (6), 213.

Palmieri, G., Giardina, P., Bianco, C., & Sannia, G. (1998). A novel white laccase from *Pleurotus ostreatus*. *In Proceedings of the 7th International Conference on Biotechnology in the Pulp and Paper Industry*, (pp. A93–A96), Vancouver, Canada.

Palmieri, G., Giardina, P., Bianco, C., Fontanella, B. & Sannia, G. (2000). Copper induction of laccase isoenzymes in the ligninolytic fungus *Pleurotus ostreatus*. *Applied and Environmental Microbiology*, 66(3), 920-924.

Palvannan, T., & Sathishkumar, P. (2010). Production of laccase from *Pleurotus florida* NCIM 1243 using Plackett-Burman design and response surface methodology. *Journal of Basic Microbiology*, 50(4), 325–335.

Papinutti, V.L., Diorio, L.A. & Forchiassin, F. (2003). Production of laccase and manganese peroxidase by *Fomes sclerodermeus* grown on wheat bran. *Journal of Industrial Microbiology & Biotechnology*, 30(3), 157–160.

Patel, H., Gupte, A., Gupte, S. (2009). Effect of different culture conditions and inducers on the production of laccase by basidiomycete fungal isolates *Pleurotus ostreatus* HP-1 under solid-state fermentation. *Bioresources*, 4, 268-284.

Perry, C.R., Matcham, S.E., Wood, D.A., Thurston, C.F., (1993). The structure of laccase protein and its synthesis by the commercial mushroom *Agaricus bisporus. J.Gen. Microbiol.*, 139(1), 171-178.

Perumal, K. (1997). *Biochemical studies of lignolytic enzymes of Gonoderma lucidum, a white-rot fungus, and its application in the treatment of paper mill effluent*. Unpublished doctoral dissertation, University of Madras, Madras, India.

Pickard, M.A., Roman, R., Tinoco, R., & Vazquez-Duhalt, R. (1999). Polycyclic aromatic hydrocarbon metabolism by white-rot fungi and oxidation by *Coriolopsis gallica* UAMH8260 laccase. *Applied and Environmental Microbiology*, 65(9), 3805–3809.

Piscitelli, A., Pezzella, C., Giardina, P., Faraco, V., Sannia, G. (2010). Heterologous laccase production and its role in industrial applications. *Bioen. Bugs.* 1, 254-264.

Raghukumar, C., (2000). Fungi from marine habitats: an application in bioremediation. *Mycological Research*, 104(10), 1222-1226.

Raghukumar, C., D'Souza, T.M., Thorn, R.G. & Reddy, C.A. (1999). Lignin-modifying enzymes of *Flavodon flavus*, a basidiomycete isolated from a coastal marine environment. *Applied and Environmental Microbiology*, 65(5), 2103–2111.

Ranocha, P., McDougall, G., & Hawkins, S. (1999). Biochemical characterization, molecular cloning, and expression of laccases- a divergent gene family in poplar. *European Journal of Biochemistry*, 259(1-2), 485–495.

Rehman, K., Shahzad, T., Sahar, A., Hussain, S., Mahmood, F., Siddique, M.H. (2018). Effect of Reactive Black 5 azo dye on soil processes related to C and N cycling, *Peer, J.*, 6, 4802.

Revankar, M.S. & Lele, S.S. (2006). Increased production of extracellular laccase by the white-rot fungus *Coriolus versicolor* MTCC 138. *World Journal of Microbiology and Biotechnology*, 22(9), 921–926.

Riva, S. (2006). Laccases: blue enzymes for green chemistry," *Trends in Biotechnology*, 24(5), 219–226.

Robene-Soustrade, I. & Lung-Escarmant, B. (1997). Laccase isoenzyme patterns of European *Armillaria* species from culture filtrates and infected woody plant tissues. *European Journal of Forest Pathology*, 27(2), 105-114.

Rodrıguez Couto, S., Longo, M.A., Cameselle, C., Sanroman, A., (1998). Influence of some inducers on the activity of lignolytic enzymes from corncob culture of *Phanerochaete chrysosporium* in semi solid-state conditions. *Progressing Biotechnology*, 15, 703-708.

Rodrıguez Couto, S., Rosales, E., Gundın, M. & Sanroman, M.A. (2004). The exploitation of waste from the brewing industry for laccase production by two *Trametes* species. *J. Food Eng.*, 64, 423–428.

Rodrıguez, E., Pickard, M.A., & Vazquez-Duhalt, R. (1999). Industrial dye decolorization by laccases from ligninolytic fungi. *Current Microbiology*, 38(1), 27–32.

Rodrıguez, S., Sanrom´an, C.M. & Gubitz, G.M. (2005). Influence of redox mediators and metal ions on synthetic acid dye decolourization by crude laccase from *Trametes hirsute*. *Chemosphere*, 58(4), 417–422.

Rogalski, J., Lundell, T., Leonowicz, A., & Hatakka, A. (1991). Production of laccase, lignin peroxidase, and manganese-dependent peroxidase by various strains of *Trametes versicolor* depending on culture conditions. *Acta Microbiologica Polonica*, 40, 221–234.

Rothschild, N., Hadar, Y., Dosoretz, C. (1995). Ligninolytic system formation by *Phanerochaete chrysosporium* in air. *Appl. Environ. Microbiol.*, 61, 1833-1838.

Sandhya, S. (2010). Biodegradation of azo dyes under the anaerobic condition: Role of azoreductase, H.A. Erkurt (Ed.), Biodegradation of azo dyes. The handbook of environmental chemistry, vol. 9, (pp. 39-57). Springer, Berlin, Heidelberg.

Sabu, A., Pandey, A., Daud, M.J., Szakacs, G. (2005). Tamarind seed powder and palm kernel cake: Two novel agro residues for the production of tannase under solid-state fermentation by *Aspergillus niger* ATCC 16620. *Bioresour Technol*., 96, 1223-1228.

Sanchez-Amat, A., Lucas-El´ıo, P., Fernandez, E., Garcıa-Borr´on, J.C., & Solano, (2001). F. Molecular cloning and functional characterization of a unique multipotent polyphenol oxidase from *Marinomonas mediterranea*. *Biochimica et Biophysica Acta*, vol. 1547(1), 104–116.

Sannia, G., Giardina, P., & Luna, M. (1986). Laccase from *Pleurotus ostreatus*. *Biotechnology Letters*, 8(11), 797–800.

Saratale, R.G., Saratale, G.D., Chang, J.S., & Govindwar, S.P. (2011). Bacterial decolorization and degradation of azo dye: a review. *J. Taiwan Inst. Chem. Eng.*, 42, 138-157.

Sayyed, R.Z., Bhamare, H.M., Marraiki, N., Elgorban, A.M., Syed, A., Ali, H., Enshasy, E. (2020). Tree bark scrape fungus: A potential source of laccase for application in bioremediation of non-textile dyes, *PLOS ONE*, 15(6), 1-17.

Scharf, M.E., Karl, Z.J. Sethi, A. & Boucias, D.G., (2011). Multiple levels of synergistic collaboration in termite lignocellulose digestion. *PLoS ONE*, 6(7),

Scherer, M., & Fischer, R. (1998). Purification and characterization of laccase II of *Aspergillus nidulans*. *Archives of Microbiology*, 170(2), 78–84.

Schneider, P., Caspersen, M.B., & Mondorf, K. (1999). "Characterization of a Coprinus cinereus laccase," *Enzyme Microbial Technology*, 25, 502–508.

Schuckel, J., Matura, A. V., & Pee, K. H. (2011). One-copper laccase-related enzyme from *Marasmius* sp.: purification, characterization, and bleaching of textile dyes. *Enzyme Microb. Technol.*, 48, 278-284.

Selvam, K., Swaminathan, K., & Chae, K.S. (2003). Decolourization of azo dyes and a dye industry effluent by a white-rot fungus *Thelephora* sp. *Bioresour Technol.*, 88, 115-119.

Sethuraman, A., Akin, D.E., Eisele, J.G., & Eriksson, K.E.L. (1998). Effect of aromatic compounds on growth and ligninolytic enzyme production of two white-rot fungi *Ceriporiopsis subvermispora* and *Cyathus stercoreus*. *Canadian Journal of Microbiology*, 44(9), 872–885.

Setiadi, T., Andriani, Y., & Erlania, M. (2006). Treatment of textile wastewater by a combination of anaerobic and aerobic processes: A denim processing plant case**,** S. Ohgaki, K. Fukushi, H. Katayama, S. Takizawa, C. Polprasert (Eds.), Southeast Asian Water environment 1: Selected papers from the First International Symposium on Southeast Asian: Water environment (biodiversity and Water environment) (pp. 159-166). Bangkok, Thailand, Oxford, IWA Publishing.

Setti, L., Giuliani, G., Pifferi, S. & Pifferi, P.G. (1999). Laccase catalyzed-oxidative coupling of 3-methyl 2-benzothiazolinone hydrazone and methoxy phenols. *Enzyme and Microbial Technology,* 25(3-5), 285–289.

Shankar, S., & Shikha, S. (2012). Laccase production and enzymatic modification of lignin by a novel *Peniophora* sp. *Applied Biochemistry and Biotechnology*, 166(4), 1082–1094.

Sharma, R.K., & Arora, D.S. (2010). Production of lignocellulolytic enzymes and enhancement of in vitro digestibility during solid-state fermentation of wheat straw by *Phlebia floridensis*. *Bioresource Technology*, 101(23), 9248–9253.

Shi, Y., chai, L., Tang C. (2013). Characterization and genomic analysis of kraft lignin biodegradation by the beta-proteobacterium *Cupriavidus basilensis* B-8. *Biotechnology for Biofuels,* 6, 1-6.

Shraddha, Shekher, R., Sehgal, S., Kamthania, M., & Kumar, A. (2011). Laccase: microbial sources, production, purification, and potential biotechnological applications. *Enzyme Research*, 2011, 1-11.

Sidhu, A.K., Darade, S.B., Bhavsar, P.P., Gaikwad, V.B., & Patil, S.N. (2017). Isolation, Screening, and Optimization for Laccase production by *Scytalidium lignicola* pesante under submerged. *Int. J. Curr. Microbiol. App. Sci.* 6(4), 2477-2491.

Simoes, M.F., Maiorano, A.E., dos Santos, J.G., Peixoto, L., de Souza, R.F.B., Neto, A.O., Brito, A.G., Ottoni, C.A. (2019). Microbial fuel cell-induced production of fungal laccase to degrade the anthraquinone dye remazol brilliant blue R. *Environ. Chem. Lett.*,17, 1413-1420.

Singh, G., Bhalla, A., Kaur, P., Capalash, N. & Sharma, P. (2011). Laccase from prokaryotes: a new source for an old enzyme. *Reviews in Environmental Science and Biotechnology*, 10(4), 309–326.

Singh, G., Sharma, P., & Capalash, N., (2009). Performance of an alkalophilic and halotolerant laccase from γ-proteobacterium JB in the presence of industrial pollutants. *Journal of General and Applied Microbiology*, 55(4), 283-289.

Snajdr, J., & Baldrian. P. (2007). Temperature affects the production, activity, and stability of ligninolytic enzymes in *Pleurotus ostreatus* and *Trametes versicolor*. *Folia Microbiol (Praha)*, 52(5), 498-502.

Soares, G.M.B., Costa-Ferreira, M., & Pessoa de Amorim, M.T. (2001). Decolorization of an anthraquinone-type dye using a laccase formulation. *Bioresource Technology*, 79(2), 171-177.

Soares, G.M.B., De Amorim, M.T.P., & Costa-Ferreira, M. (2001). Use of laccase together with redox mediators to decolourize Remazol Brilliant Blue R. *Journal of Biotechnology*, 89(2-3), 123–129.

Soden, D.M., & Dobson, A.D.W. (2001). Differential regulation of laccase gene expression in *Pleurotus sajor-caju*. *Microbiology*, 147(7), 1755-1763.

Strong, P.J. & Burgess, J.E. (2007). Bioremediation of wine distillery wastewater using white-rot fungi and the subsequent production of laccase. *Water Science & Technology*, 56 (2), 179-186.

Strong, P.J. (2011). Improved laccase production by *Trametes pubescens* MB89 in distillery wastewaters. *Enzyme Research*, 2011, 1-8.

Sun, J., Peng, R.H., & Xiong, A.S. (2012). Secretory expression and characterization of a soluble laccase from the *Ganoderma lucidum* strain 7071-9 in *Pichia pastoris*. *Molecular Biology Reports*, 39, 3807–3814.

Suzuki, T., Endo, K., Ito, M., Tsujibo, H., Miyamoto, K., & Inamori, Y. (2003). A thermostable laccase from *Streptomyces lavendulae* REN-7: purification, characterization, nucleotide sequence, and expression. *Bioscience, Biotechnology, and Biochemistry*, 67(10), 2167–2175.

Swamy, J., & Ramsay, J.A. (1999). The evaluation of white-rot fungi in the decoloration of textile dyes. *Enzyme Microbial. Technol.*, 24, 130–137.

Tanesaka, E. (2012). Colonizing success of saprotrophic and ectomycorrhizal basidiomycetes on islands. *Mycologia*, 104(2), 345–352.

Taprab, Y., Johjima, T., Maeda, Y. (2005). Symbiotic fungi produce laccases potentially involved in phenol degradation in fungus combs of fungus-growing termites in Thailand. *Applied and Environmental Microbiology*, 71(12), 7696–7704.

Thiruchelvam, A.T. & Ramsay, J.A. (2007). Growth and laccase production kinetics of *Trametes versicolor* in a stirred tank reactor. *Applied Microbiology and Biotechnology*, 74(3), 547–554.

Thurston, C. F. (1994). The structure and function of fungal laccases. *Microbiology*, 140(1), 19–26.

Torres, E., Bustos-Jaimes, I., & Le Borgne, S. (2003). Potential use of oxidative enzymes for the detoxification of organic pollutants. *Applied Catalysis B.*, 46(1), 1-15, 2003.

Viswanath, B., Chandra, M.S., Pallavi, H., & Reddy, B.R. (2008). Screening and assessment of laccase-producing fungi isolated from different environmental samples. *African Journal of Biotechnology*, 7(8), 1129-1133.

Viswanath, B., Chandra, M.S., Pallavi, H., & Reddy, B.R. (2008). Production and purification of laccase from *Stereum ostrea* and its ability to decolorize textile dyes. *Dynamic*

Biochemistry Process Biotechnology Molecular Biology, 2, 19-25.

Viswanath, B., Rajesh, B., Janardhan, A., Kumar, A.P., & Narasimha, G. (2014). Fungal laccases and their applications in bioremediation. *Enzyme Res.*, 2014, 1-21.

Wakil, S.M., Adebayo-Tayo., B.C., Odeniyi., O.A., Salawu., K., Eyiolawi., S., Onilude., A.A. (2017). Production, Characterization, and Purification of Laccase by Yeasts Isolated from Ligninolytic Soil. *Journal of Pure and Applied Microbiology*, 11(2), 847-869.

Wang, B., Yan, Y., Xu, J., Fu, X., Han, H., Gao, J., Li, Z., Wang, L., Tian, Y., & Peng, R. (2018). Heterologous expression and characterization of a laccase from *Laccaria bicolor* in *Pichia pastoris* and *Arabidopsis thaliana*. *J. Microbiol Biotechnol.,* 28, 2057-2063.

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

Wong, D.W.S. (2009). Structure and action mechanism of ligninolytic enzymes. *Appl. Biochem. Biotechnol.* 157, 174-209.

Wong, Y., & Yu, J. (1999). Laccase-catalyzed decolorization of synthetic dyes. *Water Res.*, 33, 3512-3520.

Wood, D. A. (1980). Production, purification, and properties of extracellular laccase of *Agaricus bisporus*. *Journal of General Microbiology*, 117, 327–338.

Xiao, Y.Z., Tu, X.M., Wang, J., Zhang, M., Cheng, Q., Zeng, W.Y., Shi, Y.Y., (2003). Purification, molecular characterization, and reactivity with aromatic compounds of a laccase from basidiomycete *Trametes* sp. strain AH28-2, *Appl. Microbiol. Biotechnol.*, 60(6), 700-707.

Xing, Z.T., Cheng, J.H., Tan, Q., & Pan, Y.J. (2006). Effect of nutritional parameters on laccase production by the culinary and medicinal mushroom, *Grifola frondosa*. *World Journal of Microbiology and Biotechnology*, 22(8), 799–806.

Yadav, M., Bista, G., Maharjan, R., Poudyal, P., Mainali, M., Sreerama, L., & Joshi, J. (2019), Secretory Laccase from *Pestalotiopsis* Species CDBT-F-G1 Fungal Strain Isolated from High Altitude: Optimization of Its Production and Characterization. *Appl. Sci*., 9(2), 429-457.

Yague, S., Terron, M.C., Gonzalez, T., Zapico, E., Bocchini, P., Galletti, G.C., & Gonzalez, A.E. (2000). Biotreatment of tannin-rich beer-factory wastewater with white-rot basidiomycete *Coriolopsis gallica* monitored by pyrolysis/gas chromatography/mass spectrometry. Rapid Commun. *Mass Spectrometry*, 14, 905-910.

Yang, F.C., & Yu, J.T. (1996). Development of a bioreactor system using an immobilized white-rot fungus for decolorization. *Bioprocess Eng.,* 15, 307-310.

Yaver, D.S., Xu, F., Golightly, E.J., Brown, K.M., Brown, S.H., Rey M.W., Schneider, P., Halkier, T., Mondorf, K., Dalboge, H. (1996). Purification, characterization, molecular cloning, and expression of two laccase genes from the white-rot basidiomycete *Trametes villosa*. *Appl Environ Microbiol.* 62, 834-841.

Yoshida, H., (1884). Chemistry of lacquer (Urushi) part 1. *J. Chem. Soc.*, 43, 472-486.

Zervakis, G.I., Venturella, G., & Papadopoulou, K. (2001). Genetic polymorphism and taxonomic infrastructure of the *Pleurotus eryngii* species-complex as determined by RAPD analysis, isozyme profiles, and ecomorphological characters. *Microbiology*, 147(11), 3183-3194.

Zhao, J., Mou, Y., Shan, T., Li, Y., Zhou, L., Wang, M., & Wang, J. (2010).Antimicrobial metabolites from the endophytic fungus *Pichiaguillier mondii* isolated fr*om Pasis polyphylla* var. *yunnanensis. Molecules*, 15, 7961-7970.

Zucca, P., Rescigno, A., Olianas, A., Maccioni, S., Sollai, F.A., & Sanjust, E. (2011). Induction, purification, and characterization of a laccase isoenzyme from *Pleurotus sajor-caju* and the potential in decolorization of textile dyes. *J. Mol. Catal. B: Enzym.*, 68, 216-222.

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