LIGNIN BIODEGRADATION BY *Thermomyces lanuginosus* EFB2 AND *Aspergillus flavus* EFB4 CO-CULTURE AND PURE CULTURE IN SOLID STATE FERMENTATION

AMSAL BINTI HJ ABD GHANI

A dissertation submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Science (Biotechnology)

Faculty of Biosciences and Medical Engineering
Universiti Teknologi Malaysia

JANUARY 2013

Specially dedicated to my inspiration…

My beloved parents

Abdul Ghani @ Mohd Azmi bin Kasa & Solhah binti Haron… for their utmost love, continuous support and advice, and endless prayers. Thank you Allah for such wonderful parents

My dearest siblings

Ahlam, Asyraf, and Ajwad Mubarak… for their concern, assistance, and continuous encouragement and motivation

ACKNOWLEDGEMENT

Alhamdulillah, thank you to Allah S.W.T, Most Gracious, Most Merciful, whom with His willing and blessing, I am able to complete this research and the dissertation, as well as to complete Master of Science (Biotechnology).

I would like to express my deepest gratitude and thanks to my dedicated supervisor *Dr. Adibah Yahya* for her tremendous encouragement and guidance. The invaluable expertise, ideas and constructive comments shared by her throughout the experimental and dissertation works have contributed a lot to the success of this research.

My sincere thanks also extended to all colleagues from Project Lab, Biochemistry Lab and Research Lab for their extraordinary help, guidance and encouragement throughout the research is carried out. My acknowledgement also goes to all the lab assistants, lab technicians, and other staffs of Faculty of Biosciences and Medical Engineering for their assistance and cooperation.

Special thanks to my beloved parents: *Tn. Hj Abd Ghani bin Kasa* and *Pn. Hjh. Solhah binti Hj Haron*, and my siblings: *Ahlam binti Hj Abd Ghani*, *Asyraf bin Hj Abd Ghani* and *Ajwad Mubarak bin Hj Abd Ghani* for always being my strength and providing me with continuous support. To those who indirectly contributed in this research, your kindness and helps also means a lot to me.

ABSTRACT

The performance of pure culture and co-culture of *T. lanuginosus* EFB2 and *A. flavus* EFB4 in lignin biodegradation were observed in solid state fermentation (SSF) using oil palm empty fruit bunch (OPEFB) as the substrate. Biodegradation of lignin was evaluated based on the activity of crude ligninolytic enzymes (LiP, MnP and Lac), FPase assay and fibre content analysis of OPEFB through gravimetric method after SSF. Results showed that EFB2, EFB4 and EFB2+EFB4 were able to produce all major ligninolytic enzymes showing the ability of both strains to grow and degrade the OPEFB in SSF. Higher activity of MnP (27.17 U/L) and Lac (2.81 U/L) in EFB2+EFB4 compared to EFB2 (5.41 U/L and 2.20 U/L) and EFB4 (22.2 U/L and 2.37 U/L) pure culture demonstrated that co-culture may degrade lignin better than pure culture. MnP was predominant in both fungi as shown by the highest activity produced (27.17 U/L) among all of the lignolytic enzymes. As a pure culture, EFB4 produced significantly higher activity of LiP, MnP and Lac than EFB2. A very low level of FPase activity was detected in all cultures throughout the SSF period. The evaluation of the fibre content in OPEFB showed that EFB2, EFB4, and EFB2+EFB4 caused significant decrease of lignin, cellulose and hemicellulose amount after SSF. A maximum loss of lignin at 7.3 % was recorded on the day 8 of SSF by EFB2+EFB4. Low level of correlation between ligninolytic enzymes activity and the decrease of lignin content was observed. Characterization of LiP, MnP and Lac demonstrated that they were stable at acidic condition and LiP and MnP exhibited optimum activity at pH 4 - 5, while Lac at pH 3. Optimum temperature for LiP and MnP were recorded at 60ºC and they were stable at 30ºC-50ºC over 3 hours of incubation while optimum temperature of Lac is 70ºC and stable at 30 - 60ºC. Results suggest that co-culture of EFB2 and EFB4 in SSF effectively improved lignin biodegradation in OPEFB.

ABSTRAK

Prestasi kultur tulen dan ko-kultur *T. lanuginosus* EFB2 dan *A. flavus* EFB4 dalam penguraian lignin telah dilihat dengan "Solid state fermentation (SSF)" menggunakan tandan kosong kelapa sawit (OPEFB) sebagai substrat. Tahap penguraian lignin diukur berdasarkan aktiviti enzim penguraian lignin (LiP, MnP and Lac), FPase, dan analisis kandungan serat dalam OPEFB selepas SSF menggunakan kaedah gravimetrik. Keputusan menunjukkan EFB2, EFB4 dan EFB2+EFB4 boleh menghasilkan semua enzim penguraian lignin yang utama dan ini menunjukkan kebolehan kedua-dua strain untuk tumbuh dan mengurai OPEFB dalam SSF. EFB2+EFB4 menunjukkan aktiviti MnP (27.17 U/L) dan Lac (2.81 U/L) yang lebih tinggi berbanding kultur tulen EFB2 (5.41 U/L and 2.20 U/L) dan EFB4 (22.2 U/L and 2.37 U/L) menandakan ko-kultur boleh mengurai lignin lebih baik daripada kultur tulen. MnP adalah dominan dalam kedua-dua fungi dan ini ditunjukkan melalui aktivitinya yang paling tinggi (27.17 U/L). Sebagai kultur tulen, EFB4 menghasilkan aktiviti LiP, MnP dan Lac yang lebih tinggi berbanding EFB2. Aktiviti FPAse dikesan sangat rendah dalam semua kultur sepanjang masa SSF. Penilaian kandungan serat dalam OPEFB menunjukkan EFB2, EFB4 dan EFB2+EFB4 menyebabkan pengurangan jumlah lignin, selulosa dan hemiselulosa selepas SSF. Sebanyak 7.3% kehilangan lignin dicatat pada hari ke 8 SSF oleh EFB2+EFB4. Korelasi yang rendah antara aktiviti enzim dan pengurangan kandungan lignin telah dilihat. Pencirian LiP, MnP dan Lac menunjukkan bahawa enzim stabil dalam keadaan berasid serta aktiviti optimum LiP dan MnP pada pH4 – 5 manakala Lac pada pH 3. Suhu optimum LiP dan MnP dicatat pada 60ºC dan mereka stabil pada suhu 30ºC-50ºC selepas 3 jam inkubasi manakala suhu optimum Lac adalah pada 70ºC dan ia stabil pada suhu 30 - 60ºC. Keputusan menunjukkan ko-kultur EFB2 dan EFB4 dalam SSF memberi kesan yang baik dalam penguraian lignin dalam OPEFB.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ºC	-	Degree Celsius
β	-	Beta
µ	-	Micro liter
g	-	Gram
mg	-	Milligram
ml	-	Milliliter
mm	-	Millimeter
nm	-	nanometer
L	-	Liter
M	-	Molar
mM	-	Millimolar
Min	-	Minute
rpm	-	Rotation per minute
U	-	Unit activity of enzyme
v/v	-	Volume per volume
w/v	-	Weight per volume
kDa	-	Kilo Dalton
psi	-	Pounds per square inch
OPEFB	-	Oil palm empty fruit bunch
EFB2	-	*Thermomyces lanuginosus*
EFB4	-	*Aspergillus flavus*
PDA	-	Potato Dextrose Agar
BSA	-	Bovine Serum Albumin
DNS	-	Dinitrosalicyclic acid
HCl	-	Hydrochloric acid

NaOH	-	Sodium hydroxide
$(NH_4)_2SO_4$	-	Ammonium sulfate
KH_2PO_4	-	Monopotassium phosphate
$CaCl_2.2H_2O$	-	Calcium chloride dihydrate
$MgSO_4.7H_2O$	-	Magnesium sulfate heptahydrate
$FeSO_4.7H_2O$	-	Ferrous sulfate heptahydrate
$MnSO_4.H_2O$	-	Manganese sulfate monohydrate
$ZnSO_4.7H_2O$	-	Zinc sulfate heptahydrate
$CoCl_2.6H_2O$	-	Cobalt (II) chloride hexahydrate
SSF	-	Solid state fermentation
LiP	-	Lignin peroxidase
MnP	-	Manganese peroxidase
Lac	-	Laccase
$MnSO_4$	-	Manganese sulfate
H_2O_2	-	Hydrogen peroxide
FPA	-	Filter Paper Assay
ABTS	-	2, 2’-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid)
$CuSO_4.5H_2O$	-	Copper sulfate pentahydrate
$Na_3C_6H_5O_7.2H_2O$	-	Sodium citrate
Na_2CO_3	-	Sodium carbonate
KCl	-	Potassium chloride
H_2SO_4	-	Sulfuric acid
NDF	-	Neutral Detergent Fiber
ADF	-	Acid Detergent Fiber
ADL	-	Acid Detergent Lignin

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Research

The abundance of solid waste produced from agro-industries every year caused pollution to the environment. In oil palm industry, approximately 26 tons of oil palm empty fruit bunches (OPEFB) was discharged from the mills for every 100 tons of fresh fruit bunches processed and this is increasing year by year. (Lawrence *et al*., 2010). They were either incinerated or dumped in nature and that have caused serious pollution problems. While the unused OPEFBs were accumulated and occupied large area consumption, their natural degradation were very slow as they contained high content of lignin (25-35%) (Sreekala *et al.*, 1997). Lignin is the second most abundant aromatic polymer in nature with three-dimensional structure composed of phenyl propanoid units linked through several carbon-carbon and ether bonds (Wong, 2008). Such complex structure of lignin is designed in plant cell wall to protect plant cells from microbial attack (Higuchi, 1990).

In order to overcome the problems, the use of some lignin degrading fungi such as *Thermomyces lanuginosus* EFB2 and *Aspergillus flavus* EFB4 is one of the strategic ways. This is because lignin degrading fungi have developed the necessary enzymes to break lignin apart. Three main lignolytic enzymes are involved in the lignin biodegradation, namely lignin peroxidase (LiP) (EC 1.11.1.4), manganese peroxidase (MnP) (EC1.11.1.3), and laccase (Lac) (EC 1.10.3.2). *Thermomyces lanuginosus* EFB2 and *Aspergillus flavus* EFB4 were previously isolated from composted lignobiomass material and capable of growing using OPEFB as the main source of substrate (data not yet published). The ability of both fungal strains to degrade OPEFB has been observed in submerged (SmF), shake flask fermentation. However, their ability to grow and degrade EFB or other types of lignobiomass in solid state fermentation (SSF) is yet to be studied.

SSF process is more preferable to be used in the degradation of lignobiomass compared to SmF due to various advantages it renders. SSF is more economical process because various cheap agro-industrial wastes such as OPEFB can be exploited to be used as the substrates to induce the production of lignolytic enzymes to degrade lignin. In addition, SSF processes are simple, use low volume equipment, easier to handle in regarding sterility and regulation demand, and are yet effective by providing higher activity of enzymes (Pandey *et al*., 2000; Pandey, 2003; Pandey, 2008).

Furthermore, biodegradation of lignobiomass by co-cultures has been reported to result in much higher rate of degradation due to higher production of lignolytic enzyme in comparison with that of pure cultures through synergistic interactions (Hu *et al*. 2012; Chen *et al.*, 2011b). Thus, by studying the co-culture activities of *T. lanuginosus* EFB2 and *A. flavus* EFB4 in SSF using EFB as the sole source of substrate will facilitate in providing an effective and eco-friendly method for the biodegradation of lignin. Besides, enzyme characterization studies allow control of the SSF condition within the range where enzymes are at active and stable condition. This also ensures the efficiency of process in terms of lignin biodegradation.

1.2 Problem Statement

OPEFB, a residue left after the fruit bunches pressed at oil palm mill is the highest lignocellulose waste generated from oil palm industry estimated about 82 million tons annually (MPOB, 2000). The large amount and the bulky nature of OPEFB caused a high land-fill disposal cost. The mills, therefore, burn the OPEFB down to ash which is used as potash fertilizer or distributed directly in the field as mulch. Particulates such as tar and soot droplets of 20-100 microns and a dust loads emitted from the furnaces sometimes cause air pollution to the nearby communities (Igwe and Onyegbado, 2007). In addition to that, gases such as SO_2, CO_2, CO and NO_2 were also emitted and caused additional methane emission into the atmosphere (Amal *et al*., 2008). Its results in public outcries, and hence is prohibited by the Environment Protection Act (1974). In abiding to the regulations, these residues are becoming more expensive to dispose. Thus, unused OPEFBs are accumulated and occupied large area which also caused pests attraction.

With the above concerns in mind, one should conclude that strategic ways to overcome this problem have to be studied. Understanding and improving the production and activity of lignin-degrading enzymes in biodelignification became of significance and could be useful in providing a better biodelignification method for the efficient treatment of the lignocellulosic wastes. In addition, at present, much attention has only been currently drawn to the white rot fungi such as *Phanerochaete chrysosporium* (Wu *et al*., 2005), *Trametes versicolor* (Erden *et al*., 2009), *Pleurotus ostreatus (*Liu *et al*., 2009), and *Phlebia radiata* (Makela *et al*., in press) and many other white rot fungi. However, less literature was reported to study *Thermomyces lanuginosus* and *Aspergillus flavus* in lignin biodegradation.

1.3 Objectives

The objectives of this study were:

1. To analyse the performance of pure culture *Thermomyces lanuginosus* EFB2 and *Aspergillus flavus* EFB4 in lignin biodegradation of OPEFB.

2. To analyse the performance of co-culture *Thermomyces lanuginosus* EFB2 and *Aspergillus flavus* EFB4 in lignin biodegradation of OPEFB

3. To characterize the effect of pH and temperature on the optimum activity and stability of the crude ligninolytic enzymes produced by pure and co-culture of *Thermomyces lanuginosus* EFB2 and *Aspergillus flavus* EFB4

1.4 Scope of Work

The scope of this research was focused on the study of lignin biodegradation in oil palm empty fruit bunch by locally isolated fungal strains *Thermomyces lanuginosus* EFB2 and *Aspergillus flavus* EFB4 in solid state fermentation. Their potential to degrade lignin in pure culture and in co-culture condition was evaluated by crude enzymatic activity (ligninolytic and hydrolytic enzymes) assay and the amount of lignin loss in the EFB after SSF. The crude ligninolytic enzymes produced were characterized based on their optimum pH and stability, and optimum temperature and stability.

1.5 Significant of Research

The study of lignin biodegradation from lignobiomass using fungi is very important as it could be used to provide an efficient and improved method to control the abundance of solid waste in the environment. Besides, this study also has the potential to be used in a variety of industrial and biotechnological applications. These applications include biopulping, biobleaching of paper pulps, and biotransformation of lignocellulosic biomass to feed. In biopulping, the use of fungi can reduce the usage of energy and chemicals in the process of paper-making. Furthermore, by studying the lignin biodegradation, pretreatment of lignobiomass to remove lignin using chemicals can be omitted. This is mostly required in the bioconversion of cellulose to sugar for biofuel production such as bioethanol.

REFERENCES

Abraham, W.R., Nogales, B., Golyshin, P.N., Pieper, D.H., Timmis, K.N. (2002). Polychlorinated-biphenol-degrading microbial communities in soils and sediments. *Current Opinion in Microbiology*. 5(3), 246-253.

Adamovic, M., Grubi, G., Milenkovic, I., Jovanovic, R., Protic, R., Sretenovic, L., Stoicevic, L. (1998). The biodegradation of wheat straw by *Pleurotus ostreatus* mushrooms and its use in cattle feeding. *Animal Feed Science and Technology*. 71(3), 357-362.

Adenipekun, C.O. and Okunlade, O.A. (2012). Biodegradation of rattan wood and maize stovers By *Pleurotus ostreatus. Nature and Science*. 10(5), 49.

Ahammed, S. and Prema, P. (2002). Influence of media nutrients on synthesis of lignin peroxidase from *Aspergillus* sp. *Applied Biochemistry Biotechnol*ogy 103, 327–336.

Alam, M.Z., Mahmat, M.E., Muhammad, N. (2005a). Solid state bioconversion of oil palm biomass for ligninase enzyme production. *Artificial Cells, Blood Substitutes and Biotechnology*. 33(4), 457 – 466.

Alam, M. Z., Muhammad, N., Mahmat, M. E. (2005b). Production of cellulase from oil palm biomass as substrate by solid state bioconversion. *American Journal of Applied Sciences*. 2.

Amal, N.M.T., Fathie, A.Z., Wan, N.F.M.F., Noorhalieza, A., Onn, H. (2008). The usage of empty fruit bunch (EFB) and palm pressed fibre (PPF) as substrates for the cultivation of *Pleurotus ostreatus*. *Jurnal Teknologi*. 49, 189–196.

Anastasi, A., Coppola, T., Prigione, V., Varese, G. (2009). Pyrene degradation and detoxification in soil by a consortium of basidiomycetes isolated from compost: Role of laccases and peroxidases. *Journal of Hazardous Materials*. 165(1-3), 1229-1233.

Anderson, W.F., Akin, D.E. (2008). Structural and chemical properties of grass lignocelluloses related to conversion for biofuels. *Journal of Industrial Microbiology and Biotechnol*ogy. 35, 355–366.

Archibald, F.S. (1992). A new assay for lignin-type peroxidase employing the dye Azure B. *Applied Environmental Microbiology*. 58(9), 3110–3116.

Arias, M.E., Arenas, M., Rodriguez, J., Soliver, 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 Environmental Microbiology*. 69(4), 1953-1958.

Arora, D.S. and Gill, P.K. (2000). Laccase production by some white rot fungi under different nutritional conditions. *Bioresource Technology*. 73, 283 – 285

Arora, D.S., Chander, M., Gill, P.K., (2002). Involvement of lignin peroxidase, manganese peroxidase and laccase in degradation and selective ligninolysis of wheat straw. *International Biodeterioration and Biodegradation*. 50, 115-120.

Arora, D.S. and Sharma, R.K. (2009). Enhancement in in vitro digestibility of wheat straw obtained from different geographical regions during solid state fermentation by white rot fungi. *BioResource*. 4(3), 909–920.

Asiegbu, F.O., Paterson, A., Smith, J.E. (1996). The effects of co-fungal cultures and supplementation with carbohydrate adjuncts on lignin biodegradation and substrate digestibility. *World Journal of Microbiology and Biotechnology*. 12, 273–279.

Aydinoglu, T and Sargin, S. (2012). Production of laccase from *Trametes versicolor* by solid-state fermentation using olive leaves as a phenolic substrate. *Bioprocess Biosystem Engineering*. 1-8.

Baharuddin, A.S., Kazunori, N., Abd-Aziz, S., Tabatabaei, M., Abdul Rahman, N.A., Hassan, M.A. (2009). Characteristics and microbial succession in co-composting of oil palm empty fruit bunch and partially treated palm oil mill effluent. *The Open Biotechnology Journal*. 3, 92–100.

Bahrin, E.K., Seng, P.Y., Abdul Aziz, S. (2011). Effect of oil palm empty fruit bunch paticle size on cellulose production by Botryosaphaeria sp. under solid state fermentation. *Australian Journal of Basic and Applied Sciences*. 5(3), 276-280.

Bajpai, P. (2004). Biological bleaching of chemical pulps. *Critical Reviews in Biotechnology*. 24(1), 1-58.

Baldrian, P. and Gabriel, J. (2002). Variability of laccase activity in the white rot basidiomycete *Pleurotus ostreatus*. *Folia Microbiologica*. 47, 385–390

Baldrian, P. (2004). Increase of laccase activity during interspecific interactions of white-rot fungi. *FEMS Microbiology Ecology*. 50, 245–253.

Bamforth, S.M. and Singleton, I. (2005). Bioremediation of polycyclic aromatic hydrocarbons: current knowledge and future directions. *Journal of Chemical Technology and Biotechnology*. 80(7), 726-736.

Barbosa, E.S., Perrone, D., Vendramini, A.L.A., Leite, S.G.F. (2008). Vanillin production by *Phanerochaete chrysosporium* grown on green coconut agro-industrial husk in solid state fermentation. *BioResources.* 3(4), 1042-1050.

Barbosa, T.C.P., Luz, A.P., Bedin, M.L., Gabilan, N.H. (1996). Effect of ceramic plant effluent on phenol degradation by *Acinetobacter calcoaceticus*. *International Biodeterioration and Biodegradation*. 37, 122.

Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science and Technology*. 109(4), 289–295

Bjerre, A.B., Olesen, A.B., Fernqvist, T., Ploger, T., Schmidt, A.S. (1996). Pretreatment of wheat straw using combined wet oxidation and alkaline hydrolysis resulting in convertable cellulose and hemicellulose. *Biotechnology and Bioengineering*. 49, 568-577.

Blanchette, R.A. (1995). Degradation of lignocellulose complex in wood. *Canadian Journal of Botany*. 73, 999-1010.

Boddy, L. (2000). Interspecific combative interactions between wood decaying basidiomycetes. *FEMS Microbiology Ecology*. 31, 185–194.

Bonugli-Santos, R.C., Durrant, L.R., da Silva, M., Sette, L.D. (2010). Production of laccase, manganese peroxidase and lignin peroxidase by Brazilian marine-derived fungi. *Enzyme and Microbial Technology*. 46(1), 32-37.

Bosco, F., Capolongo, A., Ruggeri, B. (2002). Effect of temperature, pH, ionic strength, and sodium nitrate on activity of LiPs: Implications for bioremediation. *Bioremediation Journal*. 6, 65–76.

Bourbonnais, R. and Paice, M.G. (1988). Veratryl alcohol oxidases from the lignin-degrading basidiomycete *Pleurotus sajor-caju*. *Biochemistry Journal*. 255(2), 445-450.

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 2,22′-azinobis(3-ethylbenzthiazoline-6-sulfonate) in kraft lignin depolymerization. *Applied and Environmental Microbiology*. (61)5, 1876–1880.

Bourbonnais, R., Paice, M.G., Freiermuth, B., Bodie, E., Borneman, S. (1997). Reactivities of various mediators and laccases with kraft pulp and lignin model compounds. *Applied and Environmental Microbiology*. 63, 4627-4632.

Bourbonnais, R. Leech, D., Paice, M.G. (1998). Electrochemical analysis of the interactions of laccase mediators with lignin model compounds. *Biochimica et Biophysica Acta*. 1379(3), 381–390.

Brijwani, K., Oberoi, H.S., Vadlani, P.V. (2010). Production of cellulolytic enzyme system in mixed culture solid-state fermentation of soybean hulls supplemented with wheat bran. *Process Biochemistry*. 45,120-128.

Brown, J. A., Glenn, J. K., Gold, M. H. (1990). Manganese regulates expression of manganese peroxidase by *Phanerochaete chrysosporium*. *Journal of Bacteriology*. 172(6), 3125-3130.

Buchholz, K., Kasche, V., Bornscheuer, U.T. (2005). *Biocatalysis and Enzyme Technology*. Germany: Wiley – VCH.

Budda, W., Sarnthima, R., Khammuang, S., Milintawisamai, N., Naknil, S. (2012). Ligninolytic enzymes of *Lentinus polychrous* grown on solid substrates and its application in black liquor treatment. *Journal of Biological Sciences*. 12(1). 25-33.

Buswell, J.A. and *Eriksson*, K. E. (*1988*). Vanillate Hydroxylase from *Sporotrichum pulverulentum*. *Methods in Enzymology* 161:274-281.

Call, H.P. and Muncke, I. (1997). History, overview and applications of mediated lignolytic systems, especially laccase-mediator systems (lignozyme(R)-process). *Journal Biotechnology*. 53, 163-202.

Camarero, S., Garcia, O., Vidal, T., Colom, J., Del Rio, J.C., Gutierrez, A., Gras, J.M., Monje, R., Martinez, M.J., Martinez, A.T. (2004). Efficient bleaching of non-wood high-quality paper pulp using laccase-mediator system. *Enzyme and Microbial Technology*. 35(2-3), 113-120.

Chahal, P. S., Chahal, D. S. and Le, G. B. B. (1996). Production of cellulose in solid state fermentation with *Trichoderma reesei* MCG 80 on wheat straw. *Applied Biochemistry and Biotechnology*. 57-58, 433-442.

Champagne, P.P. and Ramsay, J.A. (2005). Contribution of manganese peroxidase and laccase to dye decoloration by *Trametes versicolor*. *Applied Microbiology and Biotechnology*. 69(3). 276-285.

Chen, H.Y., Xue, D.S., Feng, X.Y., Yao, S.J. (2011a). Screening and production of ligninolytic enzyme by a marine-derived fungal *Pestalotiopsis* sp. J63. *Applied Biochemistry and Biotechnology*. 165(7-8), 1754-1769.

Chen, Q.H., Sven, K., Thomas, H., Steffen, R., Susanne, Z. (2011b). Cocultured production of lignin-modifying enzymes with white-rot fungi. *Applied Biochemistry and Biotechnology*. 165, 700–718.

Chi, Y., Hatakka, A., Maijala, P. (2007). Can co-culturing of two white-rot fungi increase lignin degradation and the production of lignin-degrading enzymes?. *International Biodeterioration and Biodegradation*. 59(1), 32-39.

Chmelova, D. and Ondrejovic, M. (2012). Determination of enzymes produced by *Ceriporiopsis subvermispora* during pretreatment of different biomass sources. *Journal of Microbiology, Biotechnology, and food Sciences*. 1 (4), 1168-1178.

Claus, H. (2004). Laccases: structure, reactions, distribution. *Micron*. 35(1-2), 93-96.

Cohen, R., Persky, L., Hazan-Etian, Z., Yarden, O., Yitzhak, H. (2002). Mn^{2+} alters peroxidase profiles and lignin degradation by the white-rot fungus *Pleurotus ostreatus* under different nutritional and growth conditions. *Applied Biochemistry and Biotechnology*. 102–103, 415–429.

Cole, J.L., Clark, P.A., Solomon, E.I. (1990). Spectroscopic and chemical studies of the laccase trinuclear copper active site: Geometric and electronic structure. *Journal of the American Chemical Society*. 112, 9534–9548.

Cooney, D.G. and Emerson, R. (1964). *Thermophilic Fungi: An Account of their Biology, Activities and Classification*. San Francisco: Freeman.

Couto, S. R., Moldes, D., Sanroman, M. A. (2006). Optimum stability conditions of pH and temperature for ligninase and manganese-dependent peroxidase from *Phanerochaete chrysosporium*. Application to in vitro decolorization of Poly R-478 by MnP. *World Journal of Microbiology and Biotechnology*. 22(6), 607-612.

Cui, Z., Wan, C., Shi, J., Sykes, R.W., Li, Y. (2012). Enzymatic Digestibility of Corn Stover Fractions in Response to Fungal Pretreatment. *Industrial and Engineering Chemical Resource.* 51(21), *7153 - 7159.*

D'Annibale, A., Celleti, D., Felici,M., Di Mattia, E., Giovannozzi-Sermani, G. (1996). Substrate specificity of laccase from *Lentinus edodes*. *Acta Biotechnologica*. 16, 257–270.

Deacon, J.W. Environmental conditions for growth, and tolerance of extremes. In: Deacon, J.W. *Modern Mycology*. 3rd. ed. Oxford: Blackwell Science. 121-135; 1997.

Del Pilar-Castillo, M., Ander, P., Stenstrom, J. (1997). Lignin and manganese peroxidase activity in extracts from straw solid substrate fermentation. *Biotechnology Technol*ogy. 11, 701–706.

de la Rubia, T., Linares, A., Perez, J., Munoz-Dorado, J., Romera, J., Martinez, J. (2002). Characterization of manganese-dependent peroxidase isoenzymes from the ligninolytic fungus *Phanerochaete flavido-alba*. *Resource Microbiology*. 153, 547- 554.

Deobald, L.A. and Crawford, D.L. (1989). Lignin biotransformations by an aromatic aldehyde oxidase *pr*oduced by *Streptomyces viridosporus* T7A. *Applied Biochemistry and Biotechnology*. 20-21(1), 153-163.

Deraman, M. (1993). Carbon pellets from fibre of palm empty fruit bunches: a quantitative X-ray diffraction analysis. *Palm Oil Research Institute Malaysia Bulletin*. 26, 13–18.

Ding, Z., Peng, L., Chen, Y.,Zhang, L., Gu, Z., Shi, G., Zhang, K. (2012). Production and characterization of thermostable laccase from the mushroom, *Ganoderma lucidum*, using submerged fermentation. *African Journal of Microbiology Research*. 6(6), 1147-1157.

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, 29-41.

Dong, Y.C., Wang, W., Hu, Z.C., Fu, M.L., Chen, Q.H. (2012). The synergistic effect on production of lignin-modifying enzymes through submerged co-cultivation of *Phlebia radiata*, *Dichomitus squalens* and *Ceriporiopsis subvermispora* using agricultural residues. *Bioprocess Biosystem Engineering*. 35(5), 751-60.

Dorrestijin, E., Laarhoven, L.J.J., Arends, I.W.C.E., Mulder, P. (2000). The occurence and reactivity of phenoxyl linkages in lignin and low rank coal. *Journal of Analytical and Applied Pyrolysis*. 54(1-2). 153-192.

Elisashvili, V., Parlar, H., Kachlishvili, E., Chihua, D., Bakrazde, M., Kokhreidze, N., Kvesitadze. (2001). Ligninolytic activity of basidiomycetes grown under submerged and solid-state fermentation on plant raw material (sawdust of grapevine cuttings). *Advances in Food Science*. 23, 117–123.

Erden, E., Ucar, M.C., Kaymaz, Y., Pazarlioglu, N.K. (2009). New and different lignocellulosic materials from Turkey for laccase and manganese peroxidase production by *Trametes versicolor*. *Engineering in Life Sciences*. 9(1), 60-65.

Ergul, F. E., Sargin, S., Ongen, G., Sukan, F. V. (2009). Dephenolisation of olive mill wastewater using adapted *Trametes versicolor*. *International Biodeterioration & Biodegradation*. 63(1), 1-6.

Eriksson, K.E.L. and Bermek, H. Lignin, lignocelluloses, ligninases. In: Schaechter, M. *Encyclopedia of Microbiology*. 3rd. ed. Oxford: Elsevier. 373 – 384; 2009.

Fackler, K., Gradinger, C., Hinterstoisser, B., Messner, K., Schwanninger, M. (2006). Lignin degradation by white rot fungi on spruce wood shavings during short-time solid-state fermentations monitored by near infrared spectroscopy. *Enzyme and Microbial Technology*. 39(7), 1476-1483.

Faix, O., Mozuch, M. D., Kirk, T. K. (1985). Degradation of gymnosperm (guaiacyl) vs angiosperm (syringyl guaiacyl) lignins by *Phanerochaete chrysosporium*. *Holzforschung.* 39, 203–208.

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

Ferraroni, M., Myasoedova, N.M., Schmatchenko, V., Leontievsky, A.A., Golovleva, L.A., Scozzafava, A., Briganti, F. (2007). Crystal structure of a blue laccase from *Lentinus tigrinus*: evidences for intermediates in the molecular oxygen reductive splitting by multicopper oxidases. *BMC Structural Biology*. 7, 60.

Ferraz, A., Cordova, A. M., Machuca, A. (2003). Wood biodegradation and enzyme production by *Ceriporiopsis subvermispora* during solid-state fermentation of *Eucalyptus grandis*. *Enzyme and Microbial Technology*. 32, 59–65.

Flores, C., Casasanero, R., Trejo-Hernandez, M.R., Galindo, E., Serrano-Carreon, L. (2010). Production of laccases by *Pleurotus ostreatus* in submerged fermentation in co-culture with *Trichoderma viride*. *Journal of Applied Microbiology*. 108(3), 810-817.

Freudenberg, K. and Neish, A.C. (1968). *Constitution and biosynthesis of lignin*. New York: Springer-Verlag.

Fujian, X., Hongzhang, C., Zuohu, L. (2001). Solid state production of lignin peroxidase (LiP) and manganese peroxidase (MnP) by *Phanerochaete chrysosporium* using steam – exploded straw as substrate. *Bioresource Technology*. 80(2), 149-151.

Galliano, H., Gas, G., Seris, J.L., Boudet, A.M. (1991). Lignin degradation by *Rigidoporus lignosus* involves synergistic action of two oxidizing enzymes: manganese peroxidase and laccase. *Enzyme and Microbial. Technology*. 13, 478–482.

Ghindilis, A.L. (2000). Direct electron transfer catalysed by enzymes: Application for biosensor development. *Biochemical Society Transactions*, 28(2), 84-89.

Givaudan, A., Effosse, A., Faure, D., Potier, P., Bouillant, M., 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.

Glenn, J.K., Morgan, M.A., Mayfield, M.B., Kuwahara, M., Gold, M.H. (1983). An extracellular H_2O_2-requiring enzyme preparation involved in lignin biodegradation by the white rot basidiomycete *Phanerochaete chrysosporium*. *Biochemical and Biophysical Research and Communication*. 114: 1077-1083.

Glenn, J.K., Gold, M.H. (1985). Purification and characterization of an extracellular Mn(ll)-dependent peroxidase from the lignin-degrading basidiomycete, *Phanerochaete chrysosporium*. *Archives of Biochemistry and Biophysics*. 242, 329–341.

Goering, H.K. and Van Soest, P.J. (1970). Forage Fiber Analysis (Apparatus, Reagent, Procedures and Some Application) *Agricultural Handbook No. 379*. Agricultural Research Service, United State Department of Agriculture, Washington, DC. 1–20.

Golovleva, L.A., Malt'seva, O.V., Leont'evskii, A.A., Myasoedova, N.M., Skryabin, G.K. (1987). Ligninase biosynthesis by the fungus *Panus tigrinus* during solid-state fermentation of straw. *Dokladi Akademi Nauk SSSR*. 294, 992–995.

Gomes, E., Aguiar, A.P., Carvalho, C.C., Bonfa, M.R.B., Da Silva., R., Boscolo, M. (2009). Ligninases production by Basidiomycetes strains on lignocellulosic agricultural residues and their application in the decolorization of synthetic dyes. *Brazilian Journal of Microbiology* 40(1), 31-39.

Guerra, A., Mendonca, R., Ferraz, A., Lu, F., Ralph, J. (2004). Structural characterization of lignin during *Pinus taeda* wood treatment with *Ceriporiopsis subvermispora*. *Applied Environmental Microbiology*. 70, 4073–4078.

Gutierrez-Correa, M. and Tengerdy, R.P. (1997). Production of cellulase on sugarcane bagasse by fungal mixed culture solid substrate fermentation. *Biotechnology Letter*. 19, 665–667.

Gutierrez, L. F., Sanchez, O.J., Cardona, C.A. (2007). *Integrated Production of Biodiesel from Palm Oil using In Situ Produced Bioethanol*. Proceedings of European Congress of Chemical Engineering (ECCE-6), Copenhagen.

Hakala, T.K., Maijala, P., Konn, J., Hatakka, A. (2004). Evaluation of novel wood-rotting polypores and corticoid fungi for the decay and biopulping of Norway spruce (*Picea abies*) wood. *Enzyme and Microbial Technology*. 34, 255-263.

Hakulinen, N., Kruus, K., Koivula, A. Rouvinen, J. A. (2006). Crystallographic and spectroscopic study on the effect of X-ray radiation on the crystal structure of *Melanocarpus albomyces* laccase. *Biochemical and Biophysical Research Communications*. 350, 929- 934.

Halaburgi, V.M., Sharma, S., Sinha, M., Singh, T.P., Karegoudar, T.B. (2011). Purification and characterization of a thermostable laccase from the ascomycetes *Cladosporium cladosporioides* and its applications. *Process Biochemistry*. 46(5), 1146-1152.

Haltrich, D., Nidetzky, B. and Kulbe, K. D. (1996). Production of fungal xylanases. *Bioresource Technology*. 58, 137-161.

Hames, B.D., Hooper, N.M., Houghton, J.D. (1997). *Instant Notes in Biochemistry*. Oxford: BIOS Science Publishers.

Hamisan, A. F., Abd-Aziz, S., Kamaruddin, K., Shah, U. M., Shahab, N., Hassan, M. A. (2009). Delignification of oil palm empty fruit bunch using chemical and microbial pretreatment methods. *International Journal of Agricultural Research*. 4(8), 250-256.

Hatakka, A. I. (1983). Biological pretreatment of lignocellulose. *Applied Microbiology and Biotechnology*. 18, 350-357.

Hatakka, A. and Hammel, K. E. (2010). Fungal biodegradation of lignocelluloses. *Industrial Applications*. 319-340.

Hedayati, M.T. Pasqualotto, A.C., Warn, P.A., Bowyer, P., Denning, D.W. (2007). *Aspergillus flavus*: human pathogen, allergen and mycotoxin producer. *Microbiology*. 153(6), 1677-1692.

Hernandez Fernaud, J. R., Marina, A., Gonzalez, K., Vazquez, J., & Falcon, M. A. (2006). Production, partial characterization and mass spectrometric studies of the extracellular laccase activity from *Fusarium proliferatum*. *Applied Microbiology and Biotechnology*. 70(2), 212-221.

Higuchi, T. (1990). Lignin biochemistry: Biosynthesis and biodegradation. *Wood Science and Technology*. 24(1), 23–63.

Hilden, L., Johansson, G., Pettersson, G., Li, J., Ljungquist, P., Henrikson, G. (2000). Do the extracellular enzymes cellobiose dehydrogenase and manganese peroxidase form a pathway in lignin biodegradation? *FEBS Letters*. 477, 79-83.

Hilden, K.S, Hakala, T., Maijala, P., Lundell, T., Hatakka, A. (2007). Novel thermotolerant laccases produced by the white-rot fungus *Physisporinus rivulosus*. *Applied Microbiology and Biotechnology*. 77(2), 301-309.

Hilden, K.S., Bortfeldt, R., Hofrichter, M., Hatakka, A. Lundell, T.K. (2008). Molecular characterization of the basidiomycete isolate *Nematoloma frowardii* b19 and its manganese peroxidase places the fungus in the corticioid genus *Phlebia*. *Microbiology*. 154, 2371-2379.

Hofrichter, M. (2002). Review: lignin conversion by manganese peroxidase (MnP). *Enzyme and Microbial Technology*. 30(4), 454-466.

Holker, U., Dohse, J., Hofer, M. (2002). Extracellular laccases in ascomycetes *Trichoderma atroviride* and *Trichoderma harzianum*. *Folia Microb*iologica. 47(4), 423–427.

Holker U., Holker, M., Lenz, J. (2004). Biotechnological advantages of laboratory-scale solid state fermentation with fungi. *Applied Microbiology and Biotechnology*. 64, 175-186.

Holker, U. and Lenz, J. (2005). Solid-State Fermentation — Are There Any Biotechnological Advantages? *Current Opinion in Microbiology*. 8, 301–306.

Hong,Y., Dashtban, M., Chen, S., Song, R., Qin, W. (2012). Enzyme Production and Lignin Degradation by Four Basidiomycetous Fungi in Submerged Fermentation of Peat Containing Medium. *International Journal of Biology*. 4(1).

Hoshino, F., Kajino, T., Sugiyama, H., Asami, O., Takahashi, H. (2002). Thermally stable and hydrogen peroxide tolerant manganese peroxidase (MnP) from *Lenzites betulinus*. *FEBS Letters*. 530, 249-252.

Hu, H.L., van den Brink, J., Gruben, B. S., Wo sten, H.A.B., Gu, J.D., de Vries, R.P. (2011). Improved enzyme production by co-cultivation of *Aspergillus niger* and *Aspergillus oryzae* and with other fungi. *International Biodeterioration and Biodegradation*. 65, 48–252.

Huerta-Ochoa, S., Nicolas-Santiago, S., Acosta-Hernandez, M., Dayanara, W., Prado-Barragan, L.A., Gutierrez-Lopez, G.F., Garcia-Almendarez, B.E., Regalado-Gonzalez, C. (2003). Production and partial purification of glycosidases obtained by solid state fermentation of grape pomace using *Aspergillus niger. Food Science and Food Biotechnology*. 10, 119–138.

Iakovlev, A., Stenlid, J. (2000). Spatiotemporal patterns of laccase activity in interacting mycelia of wood-decaying basidiomycete fungi. *Microbial Ecology*. 39, 236–245.

Iakovlev, A., Olson, A., Elfstrand, M., Stenlid, J. (2004). Differential gene expression during interactions between *Heterobasidion annosum* and *Physisporinus sanguinolentus*. *FEMS Microbiology Letters*. 241, 79–85.

Igwe, J.C. and Onyegbado, C.C. (2007). A review of palm oil mill effluent (POME) water treatment. *Global Journal of Environmental Research*. 1(2), 54–62.

Ishigami, T. and Yamada, Y.(1986). Purification and properties of polyphenol oxidase from *Chaetomium thermophile*, a thermophilic fungus. *Journal of General and Applied Microbiology*. 32, 293-301.

Jaszek, M., Malarczyk, E., Leonowicz, A. (1998). Investigation of ligninolytic enzymes during solid state fermentation of cotton wastes by selected strains of basidiomycetes. *Proceedings of the 7th International Conference on Biotechnology in the Pulp and Paper Industry*. June 16-18, 1998. Vancouver.

Jech, L. (2000). Solid-state fermentation of agricultural wastes for endoglucanase production. *Industrial Crops and Products*. 11, 1-5.

Kachlishvili, E., Penninckx, M.J., Tsiklauri, N. (2006). Effect of nitrogen source on lignocellulolytic enzyme production by white-rot basidiomycetes under solid-state cultivation. *World Journal of Microbiology and Biotechnology*. 22, 391-397.

Kanayama, N., Tohru, S., Keiichi, K. (2002). Purification and characterization of an alkaline manganese peroxidase from *Aspergillus terreus* LD-1. *Journal of Bioscience and Bioengineering*. 93(4), 405-410.

Kanmani, P., Karuppasamy, P., Pothiraj, C., Arul, V. (2009). Studies on lignocellulose biodegradation of coir waste in solid state fermentation using *Phanerocheate chrysosporium* and *Rhizopus stolonifer*. *African Journal of Biotechnology*. 8 (24), 6880-6887.

Kasinath, A., Novotny, C., Svobodova, K., Patel, K.C., Saseck, V. (2003). Decolorization of synthetic dyes by *Irpex lacteus* in liquid cultures and packed-bed bioreactor. *Enzyme and Microbial Technology*. 32(1), 167-173.

Ke, L., Wu, Q., Zhang, D. (2011). Bioconversion of rape straw into a nutritionally enriched substrate by *Ganoderma lucidum* and yeast. *African Journal of Biotechnology*. 10(29), 5648-5653.

Kelly-Yong, T.L., Lee, K.T., Mohamed, A.R., Bhatia, S. (2007). Potential of hydrogen from oil palm biomass as source of renewable energy worldwide. *Energy Policy*. 35, 5692-5701.

Kersten PJ. (1990). Glyoxal oxidase of *Phanerochaete chrysosporium*: Its characterization and activation by lignin peroxidase. *Proceedings of the National Academy of Sciences*. 87(8), 2936–2940.

Khalil, H.P.S.A., Hanida, S., Kang, C.W., Fuaad, N.A. (2007). Agro-hybrid composite: the effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyster composites. *Journal of Reinforced Plastic Composites*. 26(2), 203–18.

Kim, H., Lee, S., Ryu, S., Choi, H. T. (2012). Decolorization of remazol brilliant blue R by a purified laccase of *Polyporus brumalis*. *Applied Biochemistry and Biotechnology*, 1-6.

Kirk, T.K. and Adler, E. (1970). Methoxyl-deficient structural elements in lignin of sweetgum decayed by a brown-rot fungus. *Acta Chemica Scandinavica*. 24, 3379-3390.

Kirk, T.K. and Farrel, R.L. (1987). Enzymatic "combustion". The microbial degradation of lignin. *Annual Review of Microbiology*. 41, 465-505.

Kluczek-Turpeinen, B., Tuomela, M., Hatakka, A., Hofrichter, M. (2003). Lignin degradation in a compost environment by the deuteromycete *Paecilomyces inflatus*. *Applied microbiology and Biotechnology*. 61(4), 374-379.

Koller, G., Moeder, M., Czihal, K. (2000). Peroxidative degradation of selected PCB: A mechanistic study. *Chemosphere*. 41(12), 1827-1834.

Kong, L. Y., Guo, D. S., Zhao, B. G., Li, R. G. (2010). Preliminary purification and characterization of extracellular lignin peroxidase from *Pseudomonas*

fluorescens GcM 5-1 A. *Journal of Beijing Forestry University*. 32(3), 112-116.

Koroleva, O.V., Gavrilova, V.P., Stepanova, E.V., Lebedeva, V.I., Sverdlova, N.I., Landesman, E.O., Yavmetdinov, I.S., Yaropolov, A.I. (2002). Production of lignin modifying enzymes by co-cultivated white-rot fungi *Cerrena maxima* and *Coriolus hirsutus* and characterization of laccase from *Cerrena maxima*. *Enzyme and Microbial Technology*. 30(4), 573–580.

Kumaran, S., Sastry, C. A., & Vikineswary, S. (1997). Laccase, cellulase and xylanase activities during growth of *Pleurotus sajor-caju* on sago hampas. *World Journal of Microbiology and Biotechnology*. 13(1), 43-49.

Kunamneni, A., Ballesteros, A., Plou, F. J., & Alcalde, M. (2007). Fungal laccase—a versatile enzyme for biotechnological applications. *Communicating Current Research and Educational Topics and Trends in Applied Microbiology. Microbiology Book Series.* Badajoz: Formatex. 233-245.

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 Biochemistry*. 43(2), 169-178.

Lackner, R., Srebotnik, E., and Messner, K. (1991). Oxidative degradation of high molecular weight chlorolignin by manganese peroxidase of *Phanerochaete chrysosporium*. *Biochemistry and Biophysics Resource Communications*. 178, 1092-1098.

Lang, E., Nerud F., Novotna, E., Martens, R. (1996). Production of ligninolytic exoenzymes and 14C-pyrene mineralization by *Pleurotus* sp. in lignocellulose substrate. *Folia Microbiologica*. 41, 489–493.

Lankinen, V.P., Bonnen, A.M., Anton, L.H., Wood, D.A., Kalkkinen, N., Hatakka, A., Thurston, C.F. Characteristics and N-terminal amino acid sequence of manganese peroxidase from solid substrate cultures of *Agaricus bisporus*. *Applied Microbiology and Biotechnology*. 55, 170-176.

Law, K.N., Daud, W.R., Amiza, G. (2007). Morphological and chemical nature of fibre strands of oil palm empty fruit-bunch (OPEFB). *Bioresources*. 2(3), 351-362.

Lawrence, K.W., Hwa Tay, J., Stephen, T.L.T., Hung, Y.T. (2010). *Environmental Bioengineering*. London: Human Press.

Lebrun, J. D., Lamy, I., & Mougin, C. (2011). Favouring the bioavailability of Zn and Cu to enhance the production of lignin-modifying enzymes in *Trametes versicolor* cultures. *Bioresource Technology*. 102(3), 3103-3109.

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, 281-284.

Leisola, M.S.A., Fietcher, A. New trends in lignin biodegradation. In: Mizrahi, A. and Van Wezel, A.L. eds. *Advances in Biotechnological Processes*. New York: Alan R.Liss. 59-90; 1985.

Leonowicz, A., Matuszewska, A., Luterek, J., Ziegenhagen, D., Wasilewska, M., Cho, N., Hofrichter, M., Rogalski, J. (1999). Review: Biodegradation of Lignin by White Rot Fungi. *Fungal Genetics and Biology*. 27, 175–185

Lesage-Meesen, L., Delattre, M., Haon, M., Thibault., J.F., Ceccaldi, B.C., Brunerie, p., Asther, M. (1996). A two-step bioconversion process for vanillin production from ferulic acid combining *Aspergillus niger* and *Pycnoporus cinnabarinus*. *Journal of Biotechnology*. 50(2-3), 107-113.

Li, X., Liun, Y., Ji, L. (2000). Production of lignocellulolytic enzymes in solid state fermentation using corn stalks as substrate. *Henong Xuebao*. 14, 99–103.

Lisov, A.V., Leontievsky, A.A. Golovleva, L.A. (2003). Hybrid Mn-peroxidase from the ligninolytic fungus *Panus tigrinus* 8/18. Isolation, substrate specificity, and catalytic cycle. *Biochemistry (Mosc)*. 68, 1027-1035.

Liu, L., Lin, Z., Zheng, T., Lin, L., Zheng, C.Q., Lin, Z.X., Wang, S.H., Wang, Z.H. (2009). Fermentation optimization and characterization of the laccase from *Pleurotus ostreatus* strain 10969. *Enzyme and Microbial Technology*. 44(6-7), 426-433.

Ljungdahl, L.G. (2008). The cellulase/hemicellulase system of the anaerobic fungus *Orpinomyces* PC-2 and aspects of its applied use. *Annals of the New York Academy of Sciences.* 1125, 308-321.

Lobos, S., Tello, M., Polanco, R., Larrondo, L.F., Manubens, A., Salas, L. (2001). Enzymology and molecular genetics of the ligninolytic system of the basidiomycete *Ceriporiopsis subvermispora. Current Science*. 81, 992–997.

Lomascolo, A., Stentelaire, C., Asther, M., Lesage-Meesen, L. (1999). Basidiomycetes as new biotechnological tools to generate natural aromatic flavours for the food industry. *Trends in Biotechnology*. 17(7), 282-289.

Lorestani, A.A.Z. *Biological treatment of palm oil mill effluent (POME) using an up-flow anaerobic sludge fixed film (UASFF) bioreactor*. Ph.D. Thesis. Universiti Sains Malaysia; 2006.

Lowry, O. H., Rosebrough, N. J., Farr, A.L., Randall, R. J. *(*1951). Protein measurement with the Folin-Phenol reagents. *Journal of Biological Chemistry*. 193, 265-275.

Lozovaya, V.V., Lygin, A.V., Zernova, O.V., Ulanov, A.V., Li, S., Hartman, G.L., Widholm, J.M. (2007). Modification of phenolic metabolism in soybean hairy roots through down regulation of chalcone synthase or isoflavone synthase. *Planta*. 225, 665-679.

Lu, L., Zhao, M., Wang, T. N., Zhao, L. Y., Du, M. H., Li, T. L., Li, D. B. (2012). Characterization and dye decolorization ability of an alkaline resistant and organic solvents tolerant laccase from *Bacillus licheniformis* LS04. *Bioresource Technology*. 115, 35-40.

Mabrouk, A.M., Kheiralla, Z.H., Hamed, E.R., Youssry, A.A., Abd El Aty, A.A. (2010). Screening of some marine-derived fungal isolates for lignin degrading enzymes (LDEs) production. *Agriculture and Biology Journal of North America*. 1(4), 591-599.

Machuca, A., Aoyama, H., Duran, N. (1998). Production and characterization of thermostable phenol oxidases of the ascomycete *Thermoascus aurantiacus*. *Biotechnology and Applied Biochemistry*. 27, 217-223.

Maciel, M.J.M., e Silva, A.C., Ribeiro, H.C.T. (2010). Industrial and biotechnological applications of ligninolytic enzymes of the basidiomycota: A review. *Journal of Biotechnology*. 13(6).

Mai, C., Kues, U. Militz, H. (2004). Biotechnology in the wood industry. *Applied Microbiology and Biotechnology*. 63, 477-494.

Maijala, P., Mettala, A., Kleen, M., Westin, C., Poppius-Levin, K., Herranen, K., Lehto, J.H., Reponen, P., Maentausta, O. (2007). Treatment of softwood chips with enzymes may reduce refining energy consumption and increase surface charge of fibers. In: *10th International Congress on Biotechnology in the Pulp and Paper Industry*. Madison Wisconsin, Book of Abstracts. p. 65.

Makela, M.R., Lundell, T., Hatakka, A., Hilden, K. (in press). Effect of copper, nutrient nitrogen, and wood-supplement on the production of lignin-modifying enzymes by the white rot fungus *Phlebia radiata*. *Fungal Biology*.

Mandels, M., Hontz, L., Nystrom, J. (1974). Enzymatic hydrolysis of waste cellulose. *Biotechnology and Bioengineering*. 16(11), 1471-1493.

Mario, C.N., Saparrat, Mocchiutti, P., Liggieri, C.S., Aulicino, M.B., Caffini, N.O., Balatti, P.A., Martinez, M.J. (2008). Ligninolytic enzyme ability and potential biotechnology applications of the white-rot fungus *Grammothele subargentea* LPSC no. 436 strain. *Process Biochemistry*. 43, 368–375.

Marques de Souza, C.G., Zilly, A., Peralta, R.M. (2002). Production of laccase as the sole phenoloxidase by a Brazilian strain of *Plerotus pulmonarius* in solid state fermentation. *Journal of Basic Microbiology*. 42, 83–90.

Martinez, A.T., Speranza, M., Ruiz-Duenas, F.J., Ferreira, P., Camarero, S., Guillen, F., Martinez, M.J., Gutierrez, A., del Rio, J.C. (2005). Biodegradation of lignocellulosics: microbial, chemical, and enzymatic aspects of the fungal attack of lignin. *International Microbiology*. 8, 195-204.

Martinez, M.J., Ruiz-Duenas, F.J., Guillen, F., Martinez, A.T. (1996). Purification and catalytic properties of two manganese-peroxidase isoenzymes from *Pleurotus eryngii*. *European Journal of Biochemistry*. 237, 424–432.

Martins, L.O., Soares. C.M., Pereira, M.M., Teixera, M., Costa, T., Jones, G.H., Henriques, A.O. (2002). Molecular and biochemical characterization of a highly stable bacterial laccase that occurs as a structural component of the *Bacillus subtilis* endospore coat. *The Journal of Biological Chemistry.* 277, 18849-18859.

Matera, I., Gullotto, A., Tilli, S., Ferraroni, M., Scozzafava, A., Briganti, F., (2008). Crystal structure of the blue multicopper oxidase from the white rot fungus *Trametes trogii* complexed with p-toluate. *Inorganica Chimica*. 361(14-15), 4129-4137.

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

Mester, T., Sierra-Alvarez, R., Field, J. (1998). Peroxidase and aryl metabolite production by the white rot fungus *Bjerkandera* sp. strain BOS55 during solid state fermentation of lignocellulosic substrates. *Holzforschung*. 52, 351–358.

Michniewicz, A., Ullrich, R., Ledakowicz, S. Hofrichter, M. (2006). The white-rot fungus *Cerrena unicolor* strain 137 produces two laccase isoforms with different physico-chemical and catalytic properties. *Applied Microbiology and Biotechnology*. 69, 682-688.

Miller. G.L. (1959). Use of dinitrosalicyclid acid reagent for determination of reducing sugars. *Analytical Chemistry*. 31, 426-428.

Ministry of Plantation Industries and Commodities. (2009). Speech: *7th routable meeting on sustainable palm oil*, November 2009, 1 – 3.

Minussi, R.C., Pastore, G.M., Duran, N. (2002). Potential applications of laccase in the food industry. *Trends in Food Science and Technology*.13(6-7), 205-216.

Minussi, R.C., Miranda, M.A., Silva, J.A., Ferreira, C.V., Aoyama, H., Marangoni, S., Rotilio, D., Pastore, G.M., Duran, N. (2007). Purification, characterization and application of laccase from *Trametes versicolor* for colour and phenolic removal of olive mill wastewater in the presence of 1-hidroxybenzotriazole. *African Journal of Biotechnology*. 6(10), 1248-1254.

Mohammad,N., Alam, M.Z., Kabbashia, N.A.,Ahsan, A. (2012). Effective composting of oil palm industrial waste by filamentous fungi: A review. *Resources, Conservation and Recycling*. 58, 69-78.

Monties, B. and Fukushima, Y. Occurence, function and biosynthesis of lignins. In: Hofrichter, M. and Steinbuchel, A. eds. *Biopolymers*. Weinheim: Wiley – VCH. 1-64; 2001.

Moreira, M.T., Feijoo, G., Canaval, J., Lema, J.M. (2003). Semipilot-scale bleaching of Kraft pulp with manganese peroxide. *Wood Science and Technology*. 37(2), 117-123.

MPOB (Malaysian Palm Oil Board). (2000). Fresh fruit bunches (FFB) yield by states: 1987 – 2007 (tons/hectares).

Nigam, P., Pandey, A., Prabhu,K.A. (1987). Cellulase and ligninase production by basidiomycete culture in solid-state fermentation. *Biological Wastes*. 20, 1–9.

Niladevi, K.N. and Prema, P. (2005). Mangrove actinomycete as the source of ligninolytic enzymes. *Actinomycetologica*. 19(2), 40-47.

Niladevi, K.N. Ligninolytic enzymes. In: Nigam, P.S and Pandey, A. eds. *Biotechnology for Agro-Industrial Residues Utilisation*. Netherlands: Springer. 397-414; 2009.

Nishizawa, Y., Nakabayashi, K., Shinagawa, E. (1995). Purification and characterization of laccase from white-rot fungus *Trametes sanguinea* M85–2. *Journal of Fermentation and Bioengineering*. 80, 91–93.

Ohtsubo, Y., Kudo, T., Tsuda, M., Nagata, Y. (2004). Strategies for bioremediation of polychlorinated biphenyls. *Applied Microbiology and Biotechnology*. 65(3), 250-258.

Pal, M., Calvo,A., Terron,M.C., Gonzalez, A.E. (1995). Solid-state fermentation of sugarcane bagasse with *Flammulina velutipes* and *Trametes versicolor*. *World Journal of Microbiology and Biotechnology*. 11, 541–545.

Palma, C., Martinez, A.T., Lema, J.M., Martinez, M.J. (2000). Different fungal manganese-oxidizing peroxidases: a comparison between *Bjerkandera* sp. and *Phanerochaete chrysosporium*. *Jounal of Biotechnology*. 77, 235-245.

Palmieri, G., Giardina, P., Bianco, C., Fontallella, B., Sannina, G. (2000) Copper induction of laccase isoenzyme in the lignolytic fungus *Pleurotus ostreatus*. *Applied Microbiology and Biotechnology*. 66, 920–924.

Pandey, A., Selvakumar, P., Soccol, C.R. Nigam, P. (1999). Solid state fermentation for the production of industrial enzymes. *Current Sciences*. 77, 149–162.

Pandey, A., Soccol, C.R., Mitchell, D. (2000). New developments in solid state fermentation: I-Bioprocesses and products, *Process Biochemistry*. 35,1153–1169.

Pandey, A. (2003). Solid-state fermentation. *Biochemical Engineering Journal*. 14, 81–84.

Pandey, A. (2008). *Current developments in solid state fermentation*. India: Asiatech Publishers.

Pant, D. and Adholeya, A. (2007). Enhanced production of ligninolytic enzymes and decolorization of molasses distillery wastewater by fungi under solid state fermentation. *Biodegradation*.18, 647–659.

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 and Biotechnology*. 30, 157–160.

Pasti, M.B., Hagen, S.R., Korus, R.A., Crawford, D.L. (1991). The effects of various nutrients on extracellular peroxidases and acid-precipitable polymeric lignin production *by Streptomyces chromofuscus* A2 and *S. viridosporus* T7A. *Applied Microbiology and Biotechnology*. 34, 661-667.

Patrick, F., Mtui, G., Mshandete, A., Kivaisi, A. (2010). Optimum production of lignin peroxidase, manganese peroxidase and laccase in submerged culture of *Trametes trogii* using various growth media compositions. *Tanzania Journal of Science*. 36, 1-18.

Patrick, F., Mtui, G., Mshandete, A.M., Kivaisi, A. (2011). Optimization of laccase and managnese peroxidase production in submerged culture of *Pleurotus sajor-caju*. *African Journal of Biotechnology*. 10(50), 10166-10177.

Pearl, I.W. (1967). *The Chemistry of Lignin*. New York: Marcel Dekker Inc.

Piontek, K., Smith, A.T., Blodig, W. (2001). Lignin peroxidase structure and function. *Biochemical Society Transaction*. 2, 111-116.

Piontek K, Antorini M, Choinowski T (2002). Crystal structure of a laccase from the fungus *Trametes versicolor* at 1.90-A resolution containing a full complement of coppers. *Journal of Bioloical Chemistry*. 277, 37663-37669.

Pointing, S.B. (2001). Feasibility of bioremediation by white-rot fungi. *Applied Microbiology and Biotechnology*. 57(1-2), 20-33.

Pomeroy, L.R. Detritus and its role as a food source. In Barnes, R.S.K. and Mann, K.H. ed. Fundamentals of Aquatic Ecosystems. London: Blackwell Scientific Publications. 84-102; 1980.

Pozdniakova, N. N., Turkovskaia, O. V., Iudina, E. N., Rodakiewicz-Nowak, Y. (2006). Yellow laccase from the fungus *Pleurotus ostreatus* D1: purification and characterization. *Prikl Biokhim Mikrobiol, 42*, 63-69.

Pradeep, V and Datta, M. (2002). Production of ligninolytic enzymes for decolorization by cocultivation of white-rot fungi *Pleurotus ostreatus* and *Phanerochaete chrysosporium* under solid-state fermentation. *Applied Biochemistry and Biotechnology*. 102–103, 109–118.

Reddy, G.V., Ravindra, B.P., Komaraiah, P., Roy, K.R.R.M., Kothari, I.L. (2003). Utilization of banana waste for the production of lignolytic and cellulolytic

enzymes by solid substrate fermentation using two *Pleurotus* species (*P. ostreatus* and *P. sajor-caju*). *Process Biochemistry*. 38, 1457–1462.

Reid, I.D. (1991). Intermediates and products of synthetic lignin (dehydrogenative polymerizate) degradation by *Phlebia tremellosa*. *Applied Environmental Microbiology*. 57(10), 2834–2840.

Robles-Hernandez, l., Gonzales-Franco, A.C., Crawford, D.L., Chun, W.W.C (2008). Review of environmental organopollutants degradation by white-rot basidiomycete mushrooms. *Tecnociencia Chihuahua*. 2(1), 32-39.

Rodriguez Couto, S. and Sanroman, M. A. (2005). Application of solid-state fermentation to ligninolytic enzyme production. *Biochemical Engineering Journal*. 22(3), 211-219.

Rodriguez Couto, S., Sanroman, M.A, Gubitz, G.M. (2005). Influence of redox mediators and metal ions on synthetic acid dye decolourization by crude laccase from *Trametes hirsuta*. *Chemosphere*. 58(4), 417-422.

Rodriguez Couto, S., Lopez, E., Sanroman, M. (2006). Utilisation of grape seeds for laccase production in solid-state fermentors. *Journal of Food Engineering*. 74(2), 263-267.

Rodriguez Couto, S. and Toca, J.L. (2006). Industrial and biotechnological applications of laccases: A review. *Biotechnology Advances*. 24(5), 500-513.

Rosales, E, Couto, S.R., Sanromán, M.A. (2007). Increased laccase production by *Trametes hirsuta* grown on ground orange peelings. *Enzyme and Microbial Technology*. 40(5): 1286-1290.

Ruttimann-Johnson, C., Salas, L., Vicuna, R., Kirk, T.K. (1993). Extracellular enzyme-production and synthetic lignin mineralization by *Ceriporiopsis subvermispora*. *Applied Environmental Microbiology*. 59, 1792–1797.

Sanchez C. (2009). Lignocellulosic residues: Biodegradation and bioconversion by fungi. *Biotechnology Advances*. 27, 185-194.

Saparrat, M. C., Mocchiutti, P., Liggieri, C. S., Aulicino, M. B., Caffini, N. O., Balatti, P. A., Martínez, M. J. (2008). Ligninolytic enzyme ability and potential biotechnology applications of the white-rot fungus *Grammothele subargentea* LPSC no. 436 strain. *Process Biochemistry*. 43(4), 368-375.

Sarkanen, K.V. and Ludwig, C.H. (1971). *Lignin: occurence, formation, structure and reactions*. New York: Wiley – Interscience.

Savoie, J.M., Mata, G., Mamaoun, M. (2001). Variability in brown line formation and extracellular laccase production during interaction between white-rot basidiomycetes and *Trichoderma harzianum* biotype Th2. *Mycologia*. 93, 243–248.

Schmidt, B., Heimagartner, U., Kozulic, B. and Leisola, M.S.A. (1990). Lignin peroxidases are oligomannose type glycoproteins. *Journal of Biotechnology*. 13, 223 - 228.

Schoemaker, H.E., Harvey, P.J., Bowen, R.M., Palmer, J.M. (1985). On the mechanisms of enzymatic lignin breakdown. *FEBS Letters*. 183,7-12.

Selinheimo,, E., Kruus, K., Buchert, J., Hopia, A., Autio, K. (2006). Effects of laccase, xylanase and their combination on the rheological properties of wheat doughs. *Journal of Cereal Science*. 43(2),152-159.

Shabtay, A., Hadar, Y., Eitam, H., Brosh, A., Orlov, A., Tadmor, Y., Izhaki, I., Kerem, Z. (2009) The potential of *Pleurotus* treated olive mill solid waste as cattle feed. *Bioresource Technology*. 100, 6457–6464.

Shah, M. P., Reddy, G. V., Banerjee, R., Ravindra Babu, P., Kothari, I. L. (2005). Microbial degradation of banana waste under solid state bioprocessing using two lignocellulolytic fungi (*Phylosticta* spp. MPS-001 and *Aspergillus* spp. MPS-002). *Process Biochemistry*. 40(1), 445-451.

Sharma, R.K. and Arora, D.S. (2010) Changes in biochemical constituents of paddy straw during degradation by white rot fungi and its impact on in vitro digestibility. *Journal of Applied Microbiology*. 109, 679–686.

Shi, J., R.R. Sharma-Shivappa and M.S. Chinn, 2009. Microbial pretreatment of cotton stalks by submerge cultivation of *Phanerochaete chrysosporium*. *Bioresource Biotechnology*. 100, 4388-4395.

Shinners-Carnelley, T.C., Szpacenko, A., Tewari, J.P., Palcic, M.M. (2002). Enzymatic activity of *Cyathus olla* during solid state fermentation of canola roots. *Phytoprotection*. 83, 31–40.

Shrivastava, B., Thakur, S., Khasa, Y.P., Gupte, A., Puniya, A.K., Kuhad, R.C. (2011). White rot fungal conversion of wheat straw to energy rich cattle feed. *Biodegradation*. 22, 823–831.

Sigoillot, C., Camarero, S., Vidal, T., Record, E., Asther, M., Perez-Boada, M., Martinez, M.J., Sigoillot, J.C., Asther, M., Colom, J.F., Martinez, A.T. (2005). Comparison of different fungal enzymes for bleaching high-quality paper pulps. *Journal of Biotechnology*. 115(4), 333-343.

Sik, S. and Unyayar, A. (1998). *Phanerochaete chrysosporium* and *Funalia trogii* for the degradation of cotton stalk and their laccase, peroxidase, ligninase and cellulase enzyme activities under semi-solid state conditions. *Turkish Journal of Biology*. 22, 287–298.

Singh, D., Zeng, J., Laskar, D.D., Deobald, L., Hiscox, W.C., Chen, S. (2011). Investigation of wheat straw biodegradation by *Phanerochaete chrysosporium*. *Biomass Bioenergy*. 35, 1030-1040.

Singh, R.P., Ibrahim, M.H., Esa, N., Iliyana, M.S. (2010). Composting of waste from palm oil mill: a sustainable waste management practice. *Reviews in Environmental Science and Biotechnology*. 9(4), 331–344.

Singh, S., Pillay, B., Dilsook, V., Prior, B.A. (2000). Production and properties of hemicellulases by a *Thermomyces lanuginosus* strain. *Journal of Applied Microbiology*. 88, 975-982.

Sivakumar, R., Rajendran, R., Balakumar, C., Tamilvendan, M. (2010). Isolation, screening and optimization of production medium for thermostable laccase production from *Ganoderma sp*. *International Journal of Engineering Science and Technology*. 2(12), 7133-7141.

Sjostrom, E. (1993). *Wood chemistry: Fundamentals and application*. Orlando: Academic Press.

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

Sreekala, M.S., Kumaran, M.G., Thomas, S. (1997). Oil palm fibres: Morphology, chemical composition, surface modification and mechanical properties. *Journal of Applied Polymer Science*. 66, 821–835.

Strebotnik, E. and Hammel, K.E. (2000). Degradation of nonphenolic lignin by the laccase/1-hidroxybenzotriazole system. *Journal of Biotechnology*. 81(2-3), 179-188.

Streitwieser, J.A., Heathcock, C.H. (1981). *Introduction to Organic Chemistry*. 2nd ed. New York: Macmillan.

Sundman, V. and Na se, L. (1972). The synergistic ability of some wood degrading fungi to transform lignins and lignosulfonates on various media. *Archives of Microbiology*. 86, 339–348.

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

Tanaka H, Itakura, S. Enoki, A. (1999). Hydroxyl radical generation by an extracellular low-molecular-weight substance and phenol oxidase activity during wood degradation by the white-rot basidiomycete *Trametes versicolor*. *Journal of Biotechnology*. 75, 57-70.

Taniguchi, M., Suzuki, H., Watanabe, D., Sakai, K., Hoshino, K., Tanaka, T. (2005). Evaluation of pretreatment with *Pleurotus ostreatus* for enzymatic hydrolysis of rice straw. *Jounal of Bioscience and Bioengineering*. 100, 637–643.

ten Have, R. and Teunissen, P.J.M. (2001). Oxidative mechanisms involved in lignin

degradation by white-rot fungi. *Chemical Reviews*. 101, 3397-3413.

Tien. M. andTK. Kirk. 1983. Lignin-degrading enzyme from the basidiomycete *Phanerochaete chrysosporium* burds. *Science*. 221: 661-663.

Tortora, G.J., Funke, B.R., Case, C.L. (2004). *Microbiology – An Inroduction*. 8th. ed. San Francisco: Pearson Education Inc.

Tripathi, J.P. and Yadav, J.S. (1992). Optimization of solid substrate fermentation of wheat straw into animal feed by *Pleurotus ostreatus*: A pilot effort. *Animal Feed Science Technology*. 37, 59-72.

Tychanowicz, G.K., Zilly, A., Marques de Souza, C.G., Peralta, R.M. (2004). Decolourisation of industrial dyes by solid-state cultures of *Pleurotus pulmonarius. Process Biochemistry*. 39, 855–859.

Tychanowics, G.K., de Souza, D.F., Souza, C.G., Kadowaki, M.K., Peralta, R.M. (2006). Copper improves the production of laccase by the white-rot fungus *Pleurotus pulmonarius* in Solid State Fermentation. *Brazilian Archives of Biology and Technology*. 49(5), 699-704.

Umasaravanan, D., Jayapriya1, J., Rajendran, R.B. (2011). Comparison of lignocellulose biodegradation in solid state fermentation of sugarcane bagasse and rice straw by *Aspergillus tamarii*. *Ceylon Journal of Science (Biological Sciences)*, 40(1), 65-68.

Van Soest, P.J. (1967). Development of a comprehensive system of feed analyses and its application to forages. *Journal of Animal Science*. 26, 119-128.

Van Soest, P.J. (1994). *The Nutritional Ecology of the Ruminant*, 2nd. ed. Ithaca: Cornell University Press.

Vares, T., Kalsi, M., Hatakka, A. (1995). Lignin peroxidases, manganese peroxidases and other ligninolytic enzymes produced by *Phlebia radiata* during solid state fermentation of wheat straw. *Applied Environmental Microbiology*. 61, 3515–3520.

Velazquez-Cede, N., Farnet, M.A., Ferre'E, A.M., Savoie, J.M. (2004). Variations of lignocellulosic activities in dual cultures of *Pleurotus ostreatus* and *Trichoderma longibrachiatum* on unsterilized wheat straw. *Mycologia* 96, 712–719.

Verma, P. and Madamwar, D. (2003). Decolourization of synthetic dyes by a newly isolated strain of *Serratia marcescens*. *World Journal of Microbiology and Biotechnology*. 19(6), 615-618.

Vikineswary, S., Abdullah, N., Renuvathani, M., Sekaran, M., Pandey, A., Jones, E. B. G. (2006). Productivity of laccase in solid substrate fermentation of selected agro-residues by *Pycnoporus sanguineus*. *Bioresource Technology*, 97(1), 171-177.

Viswanath, B., Subhosh Chandra, M., 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.

Wan-Rosli, W.D., Law, K.N., Zainuddin, Z., Asro, R. (2004). Effect of pulping variables on characteristics of oil palm frond fiber. *Bioresource Technology*. 93, 233-240.

Wang, H.X. and Ng, T.B. (2006a). A laccase from the medicinal mushroom *Ganoderma lucidum*. *Applied Microbiology and Biotechnology*. 72(3). 508-513.

Wang, H.X. and Ng, T.B. (2006b). Purification of a laccase from fruiting bodies of the mushroom *Pleurotus eryngii*. *Applied Microbiology and Biotechnology*. 69(5), 521-525.

Wang, L., Yan, W., Chen, J., Huang, F. Gao, P. (2008). Function of the iron-binding chelator produced by *Coriolus versicolor* in lignin biodegradation. *Science China Life Sciences.* 51, 214-221.

Wang, Z.X., Cai, Y.J., Liao, X.R., Tao, G.J., Li, Y.Y., Zhang, F., Zhang, D.B. (2010). Purification and characterization of two thermostable laccases with high cold adapted characteristics from *Pycnoporus* sp. SYBC-L1. *Process Biochemistry*. 45(10), 1720-1729.

Wariishi, H., Valli, K., and Gold, M. H. (1991). *In vitro* depolymerization of lignin by manganese peroxidase of *Phanerochaete chrysosporium*. *Biochemistry and Biophysics Resource Communications.* 176, 269-275.

Wasenberg, D., Kryriakides, I., Agathos, S.N. (2003). White-rot fungi and their enzymes for the treatment of industrial dye effluents. *Biotechnology Advances*. 22(1-2), 161-187.

Wen, X., Jia, Y., Li, J. (2009). Degradation of tetracycline and oxytetracycline by crude lignin peroxidase prepared from *Phanerochaete chrysosporium*-a white rot fungus. *Chemosphere*. 75(8), 1003-1007.

Widsten, P. and Kandelbauer, A. (2008). Laccase applications in the forest products industry: A review. *Enzyme and Microbial Technology*. 42(4), 293-307.

Wong, S.D. (2009). Structure and action mechanism of lignolytic enzymes. *Applied Biochemistry and Biotechnology*. 157(2), 174 – 209.

Wood, T.M. and K.M. Bhat, 1988. Methods for measuring cellulase activities. *Methods Enzymology*. 160, 87-112.

Wu, J., Xiao, Z.Y., Yu, H.Q. (2005). Degradation of lignin in pulp mill wastewaters by white-rot fungi on biofilm. *Bioresource Technology*. 96(12), 1357 – 1363.

Xie, J., Sun, X., Ren, L., Zhang, Y.Z. (2001). Studies in lignocellulolytic enzymes production and biomass degradation of *Pleurotus* sp.2 and *Trametes gallica* in wheat straw cultures. *Sheng Wu Kung Cheng Hsueh Pao*. 17, 575–578.

Xu, C., Ma, F., Zhang, X. (2009). Lignocellulose degradation and enzyme production by *Irpex lacteus* CD2 during solid-state fermentation of corn stover. *Journal of Bioscience and Bioengineering*. 108, 372–375.

Yadav, J.S. and Tripathi, J.P. (1991). Optimization of cultivation and nutrition conditions and substrate pretreatment for solid-substrate fermentation of wheat straw by *Coriolus versicolor*. *Folia Microbiologica*. 36(3), 294-301.

Yang, J., Liu, W., Ni, J.R. (2006). Isolation, identification of lignin-degrading bacteria and purification of lignin peroxidase. *Environmental Science*. 27(5), 981-985.

Yang, Y. S., Zhou, J. T., Lu, H., Yuan, Y. L., Zhao, L. H. (2012). Isolation and characterization of *Streptomyces* spp. strains F-6 and F-7 capable of decomposing alkali lignin. *Environmental Technology*. 33(23), 2603-2609.

Yoshida, H. (1883). Chemistry of lacquer (Urushi*). Journal of the Chemical Society*. 43(1), 472–486.

Youn, H., Hah, Y., Kang, S. (1995). Role of laccase in lignin degradation by white-rot fungi. *FEMS Microbiology Letters*. 132, 183-188.

Zhang, G.Q., Wang, Y.F., Zhang, X.Q., Ng, T.B., Wang, H.X. (2010). Purification and characterization of a novel laccase from the edible mushroom *Clitocybe maxima*. *Process Biochemistry*. 45(5), 627-633.

Zhang, H., Hong, Y.Z., Xiao, Y.Z., Yuan, J., Tu, X.M., Zhang, X.Q. (2006). Efficient production of laccases by *Trametes* sp. AH28–2 in cocultivation with a *Trichoderma* strain. *Applied Microbiology and Biotechnology*. 73, 89–94.

Zhang, L., Dong, L., Li-jun, W., Ti-peng, W., Zhang, L., Xiao, D.C., Zhi-huai, M. (2008). Effect of steam explosion on biodegradation of lignin in wheat straw. *Bioresource Technology*. 99, 8512–8515.

Zorn, H., Langhoff, S., Scheibner, M., Ninmtz, M., Berger, R.G. (2003). A peroxidase from *Lepista irina* cleaves β,β-Carotene to flavor compounds. *Biological Chemistry*. 384(7), 1049-1056.