Mycoremediation: An approach in bioremediation

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Abstract: In today's scenario the industrialization, Healthcare sectors, agricultural sectors and municipality discharging hazardous chemicals and wastes in water, soil and air which are polluting the environment. Accumulation of heavy metal in living system mainly humans, animals, Plants and micro organism are at a risk. These wastes are also deteriorating the fertility of soil and quality of air and water. Current biological approach for bioremediation is comprised of mycoremediation. Therefore mushroom consist of competent enzymes that significantly promote the biosorption of heavy metal and biodegradation of various substrates, pollutants, agricultural wastes and house hold solid wastes. As well degradation, mushroom produced beneficial food for human consumption. However, sometimes mushroom mycelium also absorb toxic materials through biosorption are not consumable due to toxicity. The current review emphasized the mycoremediation as a potent tool for bioremediation of pollutants through biosorption by mushroom cultivation. This review also focused on mushroom as a safe food product for consumption.

Index terms- Mushrooms; Bioremediation; Biodegradation; Mycormediation; Pollutants and Food product

Introduction

In present scenario industrial wastes, heavy metals, dyes, dairy industrial sludge, lignocellulosic wastes, petroleum products and simultaneous inclusion of pesticides and its drastic usage in agriculture to enhance the productivity is a serious concern for environment. Petroleum products are the back bone of world's economy besides it, the present hydrocarbons posing a detrimental impact on environment through discharging huge quantity of oily sludge as well as crude oil in water and soil. Hydrocarbon molecules and a huge volume of oily sludge, which are carcinogenic and potent immunotoxicants (Propst, et al.1999; Ojumu, et al.2004).

Pesticides increase crop yields and protect them from pests and organic modifications, preserving soil health and quality. On the other hand, this involves a high consumption of pesticides to ensure food supply for the world's growing population (currently over 7.4 billion people, with this figure expected to rise to 9.7 billion by 2050); consequently, there is a need to increase in the organic matter content of soils is required to improve their fertility and avoid their degradation by agricultural practices (Oerke, 2010).

Agricultural activities involve the exercise of pesticides to eliminate pests and diseases from crops. Nowadays, farmers have gone habitual of pesticides as essential compounds for controlling the pests and diseases that intimidating our yield. Although products for Chemical protection of crops from pests, is easy to maintain, however it is quite expensive in commercial way. Large investments are made annually throughout the world. In 2012, the sales of pesticides reached $47.26 billion (AEPLA, 2016). Among a wide variety of pesticides, the highest percentages of application correspond to herbicides (48.5%), followed by fungicides and bactericides (26.6%), and insecticides (18.9%) (FAOSTAT, 2016).

Pesticides production and supply is the origin of point source as well as diffuse source of pollution. Point source pollution is characterized by high pesticides usage in limited area, which is also considered as a result of an inappropriate handling of pesticides during their storage and use, or during the equipment cleaning process after application (Castillo, 2004; Ramwell, 2004). On the other hand, diffuse source contamination elucidate the use of low concentration pesticides over large area, it is also coupled with the use of pesticides in agricultural practices. Therefore, the reported ways of minimizing or avoiding the risk of contamination by diffuse and point sources are different. Agronomical practices are applied in the case of diffuse contamination, while other physicochemical systems or strategies are implemented to avoid point contamination (Castillo, 2004; Álvarez.2016). However, both strategies are based on the same physicochemical processes, namely, the modification of pesticide behavior in soils after the application and/or use (as components of the biobed biomixtures) of different organic wastes with a high OM content (Karanasios, 2010; Rodríguez, 2014).

Mushroom as a mycoremediation approach

Biotechnoilogical and environmental approaches is now concentrating on the development of "biologically feasible technologies" which emphasize on the maximum production, reduced waste generation, treatment and conversion of waste in some useful form. Further, these biologically feasible technologies based on the use of biotechnological methods for the remediation of waste. One such biological method is mycoremediation which is based on the use of fungi and mushroom for the removal of waste from the environment. The mushrooms and other fungi possess significant enzymes, are capable of the degradation of waste/pollutants and therefore, can be applied for a wide variety of pollutants (Purnomo et al. 2013; Kulshreshtha et al. 2013). However, presently popularity of mushrooms from basidiomycetes , are significantly increasing for bioremediation purpose because it is not only a bioremediation tool but also provide mycelium or fruiting bodies as a source of protein. The efficiency of mushroom species in producing food protein in the form of biomass or fruiting bodies from different wastes lies in their ability to degrade waste via secretion of a variety of hydrolyzing and oxidizing enzymes (Kuforiji and Fasidi 2008; Zhu et al. 2013). This quality has attracted research attention in the field of mushroom cultivation and waste management. Many reports have published to emphasize the role of mushroom in bioremediation of wastes by the process of biodegradation, biosorption and bioconversion (Akinyele et al. 2012, Kulshreshtha et al. 2013a; Kumhomkul and Panich-pat 2013; Lamrood and Ralegankar 2013). Many scientists have studied the role of different enzymes in the degradation process; degradation products formed by it and conditions affecting the degradation process (Novotný et al. 2004; Akinyele et al. 2011; Zhu et al. 2013). However, safety aspects of the process and products have not been reported so far. There is a little availability of reports concerning with the pros and cons of mushroom cultivation on wastes and the role of spent in bioremediation purpose. Moreover, mushroom as an edible product is meagerly reported on usage of waste as substrates. Keeping this in mind, the present review is discussing about the use of mushroom as a mycological tool for bioremediation. Mushroom and its spent are not only a mycoremediation tool but also a product for bioremediaon.

Biotechnological approaches employ the chemistry of living organisms as tools to develop alternative and innovative methods intended for more effective ways to maintain natural environment. During twentieth to twenty-first centuries, the researchers have studied a series of technological advancement that have facilitated significant benefits to improve the environment. Use of mushroom in this concern is a new biotechnological approach for bioremediation.

Remediation through fungi is also called as mycoremediation. Mycoremediation refers to growing of mushrooms on wastes materials and degradation of a wide variety of environmentally persistent pollutants through their enzymes by transforming industrial and agro-industrial wastes into valuable product known as fruiting body.

Bioremediation and Biodegradation

Mushrooms degrade the Waste materials by using different modes which (i) Biodegradation (ii) Biosorption (iii) Bioconversion.

The 'Biodegradation' is a biological process of degradation and recycling of complex molecule to its mineral constituents. This process leads to complete mineralization of the starting compound to simpler ones like CO_2, H_2O, NO_3 and other inorganic compounds by living organisms. Many researches have been done on the degradation abilities of mushroom and their enzymes. Many reports have been published on the compounds produced by degradation of various wastes and factor affecting the processes. Mushroom can produce extracellular peroxidases, ligninase (lignin peroxidase, manganese dependent peroxidase and laccase), cellulases, pectinases, xylanases and oxidases (Nyanhongo et al. 2007). These are able to oxidize recalcitrant pollutants in vitro after typically stimulated by their substrates. These enzymes have also been found to degrade nonpolymeric, recalcitrant pollutants such as nitrotoluenes (VanAcken et al. 1999), PAHs (Hammel et al. 1991; Johannes et al. 1996), organic and synthetic dyes (Ollikka et al. 1993; Heinfling et al. 1998), and pentachlorophenol (Lin et al. 1990) under in vitro conditions. Recently, it is reported that mushroom species are able to degrade polymers such as plastics (da Luz et al. 2013). The biodegradation mechanism is very complex. The reason is the influence of other biochemical systems and interactions of ligninolytic enzymes with cytochrome P_{450} monooxygenase system, hydroxyl radicals and the level of H_2O_2 which are produced by the mushroom.

Bioabsorption is the process of removal of metals/pollutants from the environment by mushroom, is also considered as an alternative to the remediation of industrial effluents as well as the recovery of metals present in effluent. In Biosorption, metallic ions/pollutants/xenobiotics from effluent are absobed by live or dried biomass which often displayed a marked tolerance towards metals and other adverse conditions (Gavrilescu 2004).Bioabsorption and bioaccumation are the combined process of uptake of pollutants/xenobiotics by mushrooms. Mar'in et al. (1997) told that polar groups of proteins, amino acids, lipids and structural polysaccharides (chitin, chitosan, glucans) may be involved in the process of biosorption. Mar'in et al. (1997) reported that the biosorption capacity of dead biomass may be greater, similar to or less than that of living cells.Therefore, Biosorption process is now becoming very popular for the management of pollutants. Biosorption is an efficient method due to the high absorption capacity and very cost effective source of the raw material.

Presently, the research is focused toward the conversion of industrial or agro-industrial wastes and sludges into some other usable forms. Mushroom ia most significant most bioconversible product. Any lignocellulosic waste, generated by industries, can be used for cultivation of mushroom which can be further use as a product. The selection of the substrate for the cultivation of mushroom is usually determined by the regional availability of the material. Mushroom has also been successfully cultivated on various industrial wastes (Singhal et al. 2005; Kulshreshtha et al. 2010; Dulay et al. 2012 and Kulshreshtha et al. 2013b).

Accidentally discharge of crude oil in the environment is known as oil spillage.oil spillage badly affects the aquatic ecosystem by contaminating it. Economically important crude oil is the product of hydrocarbons and non hydrocarbons compounds, which are toxic to living beings. This toxicity is depends on the composition of petroleum product or crude oil, concentration, biological state of organisms as well as environmental factors at the time of contamination (Obire,2009). In the aquatic ecosystems, fungi play an important role with their ability in removing hazardous compounds from the water. Several authors have made lists containing bacteria and fungi that are able to degrade a wide spectrum of pollutants. Recently, many researchers studied the role of fungi in the biodegradation of petroleum products and the most common fungi which have been recorded as a biodegrader belong to the following genera: *Alternaria*, *Aspergillus*, *Candida*, *Cephalosporium*, *Cladosporium*, *Fusarium*, *Geotrichum*, *Gliocladium*, *Mucor*, *Paecilomyces*, *Penicillium*, *Pleurotus*, *Polyporus*, *Rhizopus*, *Rhodotolura*, *Saccharomyces*, *alaromyces* and *Torulopsis* (Bouchez,et al.1996; Yateem,et al.1998; Juhasz, et al.2000; Adekunle,et al.2007; Hadibarata,et al.2009; Adekunle,et al.2004; Atagana,et al.2006; Husaini,et al.2008; Romero,et al.2010; Saraswathy,et al.2002).

This environmental deterioration has attracted the researchers with leading technological advances that facilitate significant benefits to anthropological interests in terms of health, food production, transport, housing and tourism. The anthropogenic activities demand the development of new chemical, materials and enormous quantities of energy, exploitation of natural resources tha create large amounts of waste, which result the environmental pollution. Direct or indirect release of heavy metals from metallurgical ovens (Lee et al. 2006; Govarthanan et al. 2013), radionuclides (Mclean and Abbe 2008), sewage sludge/wastewater (from industrial, municipal and domestic origin) (Deng et al. 2007; Kumar and Mani 2010; Mapanda et al. 2005; Robinson et al. 2011) and un-hygienic approach of rapidly growing population having an unfavorable impact on environment . The existing condition requires severe action to repair the proper functioning of biological cycle, which is the only approach behind life on our planet. Biochemical cycles are depending on metabolic activity of microbial communities, are able to assimilate pollutants and give rise valuable products and prevent pollutants from reaching the biosphere (Li et al. 2013). Yet, the functional potential coded within microbial genome is poorly understood (Jeffries et al. 2012). Polluted environment are causing grim impacts on plants, microorganisms, aquatic organisms and life support functions such as immobilization, mineralization and nitrification that is eventually disturbing human health as well as the health of the ecosystem (Batayneh 2012). Scientists are approached on a consensus to decrease the release of pollutants by ameliorating their effects mediated by living organisms such as plants, an approach known as phytoremediation. It has been observed as an ideal solution for pollution control and the most effective innovative technology that uses biological systems for treatments of contaminants (Cardenas et al. 2008; Dua et al. 2002). Bioremediation is an ecologically sound and state-of-the-art technique that employs natural biological processes to completely eliminate toxic contaminants. It may be any process that uses microorganisms, fungi, green plants or their enzymes to return the natural environment altered by contaminants to its original condition (Chakraborty et al. 2012; Kensa 2011).

Mushroom as a food product

Mushrooms are the produced on biological wastes, agricultural wastes, agro-industrial wastes and industrial wastes. Besides this, these mushrooms are the main source of proteins, amino acids, carbohydrate, fat, vitamins, minerals and several biological active molecules which not only provide nutrition but also use for therapeutic purposes. Therefore, mushroom can be considered as an important food product. Mushroom fruiting bodies developed on industrial and agro-industrial wastes are considered as a valuable product. We have also paying attention on the safety aspects of mushroom cultivation on waste.

Conclusion

No doubt pollution is the serious threat to environment. As the pollution increasing the various vulnerable flora and fauna has been lost. But it is the time to protect the environment from polluting agents by converting to useful products. Present review has focused on a biological approach in this context. Researchers are now concentrating on use of macro fungi as well as it's spent against waste management. From this point view mushroom spent is used in remediated soil to convert into fertile. Exploitation of mushroom for bioconversion of wastes is futuristic potential tool. So in this regard, further research is needed for excellence of environment.

References

[1] Adekunle, A.A. and O.A. Adebambo, 2007. Petroleum hydrocarbon utilization by fungi isolated from *Detarium senegalensis* (J.F. Gmelin) seeds. J. Am. Sci., 3: 69-76.

[2] Adekunle, A.A., P.O. Uaboi-Egbenni and T. Ajayi, 2004. Biodegradation of petroleum products by *Saccharomyces cerevisea*. Niger. J. Bot., 17: 83-94.

[3] AEPLA. Asociación Empresarial para la Protección de las Plantas. Available online: www.aepla.es (accessed on 19 April 2016). agricultural wastes. Bioresource Technol., 99:4275–4278, doi:10.1016/j.biortech.2007.08.053

[4] Akinyele, B.J., Olaniyi, O.O. and Arotupin, D.J. 2011. Bioconversion of selected agricultural wastes and associated enzymes by *Volvariella volvacea*: An edible mushroom. Res. J. Microbiol., 6:63–70, doi:10.3923/jm.2011.63.70

[5] Akinyele, J.B., Fakoya, S., Adetuyi, C.F. 2012. Anti-growth factors associated with *Pleurotus ostreatus* in a submerged liquid fermentation. Malaysian J. Microbiol., 8:135–140.

[6] Álvarez-Martín, A.; Rodríguez-Cruz, M.S.; Andrades, M.S.; Sánchez-Martín, M.J.2016. Application of a biosorbent to soil: A potential method for controlling water pollution by pesticides. Environ. Sci. Pollut. Res., 23,9192–9203. [CrossRef] [PubMed]

[7] Atagana, H.I., R.J. Haynes and F.W. Wallis, 2006. 20. APHA, AWWA and WEF, 1995. Standard Methods Fungal bioremediation of creosote-contaminated soil: A laboratory scale bioremediation study using indigenous soil fungi. Water Air Soil Pollut., 172: 201-219.

[8] Batayneh, A.T. (2012). Toxic (aluminum, beryllium, boron, chromium and zinc) in groundwater: health risk assessment. Int. J. Environ.Sci. Technol., 9:153–162.

[9] Bouchez, M., D. Blanchet, J.P. Vandecasteele and F. Haeseler, 1996. [Les hydrocarbures aromatiques polycycliques dans l'environnement. Deuxieme partie: La degradation par voie microbienne. Polycyclic aromatic hydrocarbons in the environment. Part two: Microbial degradation]. Oil Gas Sci. Technol., 51: 797-828.

[10] Cardenas, E., Wu, W.M., Leigh, M.B., Carley, J., Carroll, S., Gentry, T., Luo,J., Watson, D., Gu, B. and Ginder-Vogel, M. (2008). Microbial communities in contaminated sediments, associated with bioremediation of uranium to sub micro molar levels. Appl. Environ. Microbiol., 74:3718–3729.

[11] Castillo, M.D.P., Torstensson, L., Stenstrom, J.2008. Biobeds for environmental protection from pesticide use-a review. J. Agric. Food Chem. 56, 6206–6219.

[12] Chakraborty, R., Wu, C.H., Hazen, T.C. (2012). Systems biology approach to bioremediation. Curr. Opin. Biotechnol., 23:1–8.

[13] Da Luz, J.M.R., Paes, S.A., Nunes, M.D., da Silva, M.C.S.and Kasuya, M.C.M. 2013. Degradation of Oxo-Biodegradable Plastic by *Pleurotus ostreatus*. PLoS ONE, 8(8):69386, doi:10.1371/journal.pone.0069386

[14] Deng, L., Su, Y., Su, H., Wang, X. and Zhu, X. (2007). Sorption and desorption of lead (II) from wastewater by green algae *Cladophora fascicularis*. J. Hazard Mater, 143(1–2):220–225.

[15] Dua, M., Sethunathan, N., Johri and A.K. (2002). Biotechnology bioremediation success and limitations. App. Microbiol. Biotechnol., 59(2–3):143–152.

[16] Dulay, R.M.R., Parungao, A.G., Kalaw, S.P.and Reyes, R.G. 2012. Aseptic cultivation of *Coprinus comatus* (O. F. Mull.) Gray on various pulp and paper wastes. Mycosphere, 3:392–397, doi:10.5943/mycosphere/3/3/10. 392

[17] FAOSTAT. Food and Agriculture Organization of the United Nations (2016). Available online: http://faostat3.fao.org (accessed on 19 April 2016).
[18] Gavrilescu, M. 2004. Removal of heavy metals from the environment by biosorption. Eng Life Sci. 4:219–232, doi:10.1002/elsc.200420026
[19] Govarthanan, M., Lee, K.J., Cho, M., Kim, J.S., Kamala-Kannan, S., Oh, B.T.(2013). Significance of autochthonous *Bacillus sp*. KK1 on biomineralization of lead in mine tailings. Chemosphere 8:2267–2272.
[20] Hadibarata, T. and S. Tachibana, 2009. Microbial Degradation of n-Eicosane by Filamentous Fungi. In: Interdisciplinary Studies on Environmental Chemistry: Environmental Research in Asia, Obayashi, Y., T. Isobe, A. Subramanian, S. Suzuki and S. Tanabe (Eds.). TERRAPUB, Tokyo, Japan, pp: 323-329.
[21] Hammel, K.E., Green, B. and Gai, W.Z.1991. Ring fission of anthracene by a eukaryote. Proc Natl. Acad. Sci. USA., 88:10605–10608, doi:10.1073/pnas.88.23.10605
[22] Heinfling, M.J., Martínez, A.T., Martínez, M. and Bergbauer Szewzyk, U. 1998. Transformation of industrial dyes by manganese peroxidases from *Bjerkandera adusta* and *Pleurotus eryngii* in a manganese-independent reaction. Appl. Environ. Microbiol., 64:2788–2793.
[23] Husaini, A., H.A. Roslan, K.S.Y. Hii and C.H. Ang, 2008. Biodegradation of aliphatic hydrocarbon by indigenous fungi isolated from used motor oil contaminated sites. World J. Microbiol. Biotechnol., 24: 2789-2797.
[24] Jeffries, T.C., Seymour, J.R., Newton, K., Smith, R.J., Seuront, L. and Mitchell, J.G. (2012). Increases in the abundance of microbial genes encoding halotolerance and photosynthesis along a sediment salinity gradient. Biogeosciences, 9(2):815–825.
[25] Johannes, C., Majcherczyk, A.and Hüttermann A.1996. Degradation of anthracene by laccase of *Trametes versicolor* in the presence of different mediator compounds. Appl. Microbiol. Biot., 46:313–317, doi:10.1007/s002530050823
[26] Juhasz, A.L. and R. Naidu, 2000. Bioremediation of high molecular weight polycyclic aromatic hydrocarbons: A review of the microbial degradation of benzo[*a*]pyrene. Int. Biodet. Biodeg., 45: 57-88.
[27] Karanasios, E., Tsiropoulos, N.G., Karpouzas, D.G. and Menkissoglu-Spiroudi, U.2010. Novel biomixtures based on local Mediterranean lignocellulosic materials: Evaluation for use in biobed systems. Chemosphere, 80, 914–921. [CrossRef] [PubMed]
[28] Kensa, M.V. 2011. Bioremediation: an overview. J. Ind. Pollut. Control, 27(2):161–168.
[29] Kuforiji, O.O. and Fasidi, I.O. 2008. Enzyme activities of *Pleurotus tuber*-regium (Fries) Singer, cultivated on selected agricultural wastes. Bioresource Technol., 99:4275–4278, doi:10.1016/j.biortech.2007.08.053
[30] Kulshreshtha, S., Mathur, N., Bhatnagar, P. 2013. Mycoremediation of paper, pulp and cardboard industrial wastes and pollutants. In: Goltapeh EM, Danesh YR Varma A (eds) Fungi as Bioremediators: Soil Biology. Springer Berlin,Heidelberg, pp 77–116.
[31] Kulshreshtha, S., Mathur, N., Bhatnagar, P. and Jain, B.L. 2010. Bioremediation of industrial wastes through mushroom cultivation. J. Environ. Biol. 31:441–444.
[32] Kulshreshtha, S., Mathur, N., Bhatnagar, P. and Kulshreshtha, S. 2013b. Cultivation of *Pleurotus citrinopileatus* on handmade paper and cardboard industrial wastes. Ind. Crop Prod., 41:340–346.
[33] Kumar, C.and Mani, D. 2010. Enrichment and management of heavy metals in sewage irrigated soil. LAP LAMBERT Academic Publishing AG & Co. KG, Saarbru¨cken.
[34] Kumhomkul, T., Panich pat, T. 2013. Lead accumulation in the straw mushroom, *Volvariella volvacea*, from lead contaminated rice straw and stubble. Bull Environ. Contam. Toxicol, 91:231–234, doi: 10.1007/s00128-013-1025-4.
[35] Lamrood, P.Y. and Ralegankar, S.D. 2013. Biosorption of Cu, Zn, Fe, Cd, Pb and Ni by non-treated biomass of some edible mushrooms. Asian J. Exp. Biol. Sci., 4:190–195.
[36] Lee, C.S., Li, X.D., Shi, W.Z., Cheung, S.C. and Thornton, I. (2006). Metal contamination in urban, suburban and country park soils of Hong Kong: a study based on GIS and multivariate statistics. Sci. Total Environ., 356:45–61.
[37] Li, M., Cheng, X. and Guo, H. (2013). Heavy metal removal by biomineralization of urease producing bacteria isolated from soil. Int. Biodeterior. Biodegr., 76:81–85.
[38] Lin, J.E., Wang, H.Y. and Hickey, R.F.1990. Degradation kinetics of pentachloro-phenol by *Phanerochaete chrysosporium*. Biotechnol. Bioeng, 35:1125–1134,doi:10.1002/bit.260351108
[39] Mapanda, F., Mangwayana, E.N., Nyanangara, J. and Giller, K.E. (2005). The effect of long-term irrigation using wastewater on the heavy metal contents of soils under vegetables in Harare, Zimbabwe. Agr. Ecosyst. Environ., 107:151–165.
[40] Mar'in, A., Conti, C. and Gobbi, G. 1997. Sorption of lead and caesium by mushrooms grown in natural conditions. Res. Environ. Biotechnol., 2:35–49.
[41] Mclean, R.I. and Abbe, G.R. 2008. Characteristics of *Crassostrea ariakensis* (Fujita 1913) and *Crassostrea virginica* (Gmelin 1791) in the discharge area of a nuclear power plant in central Chesapeake Bay. J. Shellfish. Res., 27(3):517–523.
[42] Novotný, C., Svobodová, K., Erbanová, P., Cajthaml, T., Kasinath, A., Lang, E. and Šašeka, V. 2004. Ligninolytic fungi in bioremediation: extracellular enzyme production and degradation rate. Soil Biol. Biochem., 36:1545–1551, doi:10.1016/j.soilbio.2004.07.019
[43] Nyanhongo, G.S., Gübitz, G., Sukyai, P., Leitner, C., Haltrich, D. and Ludwig, R. 2007. Oxidoreductases from *Trametes* spp. in biotechnology: A wealth of catalytic activity. Food Technol. Biotechnol., 45:250–268.
[44] Obire, O. and Anyanwu, E.C.2009. Impact of various concentrations of crude oil on fungal populations of soil. Int. J. Environ. Sci. Technol., 6: 211-218.

[45] Oerke, E.C.and Dehne, H.W.2004. Safeguarding production–losses in major crops and the role of crop protection. Crop. Prot., 23, 275–285. [CrossRef]

[46] Ojumu, T.V., Bello, O.O., Sonibare, J.A. and Solomon, B.O. 2004. Evaluation of microbial systems for bioremediation of petroleum refinery effluents in Nigeria. Afr. J. Biotechnol., 4: 31-35.

[47] Ollikka, P., Alhonmäki, K., Leppänen, V.M., Glumoff, T., Raijola, T. and Suominen, I. 1993. Decolorization of azo, triphenylmethane, heterocyclic, and polymeric dyes by lignin peroxidase isoenzymes from *Phanerochaete chrysosporium*. Appl. Environ. Microbiol., 59:4010–4016.

[48] Propst, T.L., Lochmiller, R.L., Qualls Jr., C.W. and McBee, K. 1999. *In situ* (mesocosm) assessment of immunotoxicity risks to small mammals inhabiting petrochemical waste sites. Chemosphere, 38: 1049-1067.

[49] Purnomo, A.S., Mori, T., Putra, S.R. and Kondo, R. 2013. Biotransformation of heptachlor and heptachlor epoxide by white-rot fungus *Pleurotus ostreatus*.Int Biodeterior Biodegrad 82:40–44, doi:10.1016/j.ibiod.2013.02.013.

[50] Ramwell, C.T.; Johnson, P.D.; Boxall, A.B.A.; Rimmer, D.A.2004. Pesticide residues on the external surfaces of field-crop sprayers: Environmental impact. Pest Manag. Sci., 60, 795–802. [CrossRef] [PubMed]

[51] Robinson, C., Bro¨mssen, M.V., Bhattacharya, P., Ha¨ller, S., Bive´n, A., Hossain, M., Jacks, G., Ahmed, K.M., Hasan, M.A. and Thunvik, R. (2011).Dynamics of arsenic adsorption in the targeted arsenic-safe aquifers in Matlab, south-eastern Bangladesh: insight from experimental studies. Appl. Geochem., 26:624–635.

[52] Rodríguez-Salgado, I.; Paradelo-Pérez, M.; Pérez-Rodríguez, P.; Cutillas-Barreiro, L.; Fernández-Calviño, D.; Nóvoa-Muñoz,J.C.and Arias-Estévez, M.2014. *Cyprodinil* retention on mixtures of soil and solid wastes from wineries. Effects of waste dose and ageing. Environ. Sci. Pollut. Res., 21, 9785–9795. [CrossRef] [PubMed]

[53] Romero, M.C., M.I. Urrutia, H.E. Reinoso and M.M. Kiernan, 2010. Benzo[*a*]pyrene degradation by soil filamentous fungi. J. Yeast Fungal Res., 1: 25-29.

[54] Saraswathy, A. and R. Hallberg, 2002. Degradation of pyrene by indigenous fungi from a former gasworks site. FEMS Microbiol. Lett., 210: 227-232.

[55] Singhal, V., Kumar,, A. and Rai, J.P. 2005. Bioremediation of pulp and paper mill effluent with Phanerochaete chrysosporium. J. Environ. Biol., 26:525–529.

[56] VanAcken, L.M., Godefroid, C.M., Peres, H. and Naveau, A.S.N. 1999. Mineralization of 14C-U ring labeled 4-hydroxylamino-2, 6-dinitrotoluene by manganesedependent peroxidase of the white-rot basidiomycete *Phlebia radiate*. J. Biotech., 68:159–169.

[57] Yateem, A., Balba, M.T. and Al-Awadhi, N. 1998. White rot fungi and their role in remediating oil contaminated soil. Environ. Int., 24: 181-187.

[58] Zhu, M.J., Du, F., Zhang, G.Q., Wang, H.X. and Ng, T.B. 2013. Purification a laccase exhibiting dye decolorizing ability f rom an edible mushroom Russula virescens. Int Biodeterior Biodegrad., 82:33–39, doi:10.1016/j.ibiod.2013.02.010