Wood Rotting Fungi

S.K. Srivastava

Associate Professor, Dept. of Botany, Lal Bahadur Shastri PG College, Gonda, UP-271003

ABSTRACT

A wood-rotting or xylophagous fungus is any species of fungus that digests moist wood, causing it to rot. Some species of wood-decay fungi attack dead wood, such as brown rot, and some, such as Armillaria (honey fungus), are parasitic and colonize living trees. Excessive moisture above the fibre saturation point in wood is required for fungal colonization and proliferation. Fungi that not only grow on wood but permeate its fibrous structure and actually cause decay, are called lignicolous fungi. In nature, this process causes the breakdown of complex molecules and leads to the return of nutrients to the soil.

Wood decay by fungi is typically classified into three types: soft rot, brown rot and white rot. The wood decayed by brown rot fungi is typically brown and crumbly and it is degraded via both non-enzymatic and enzymatic systems. A series of cellulolytic enzymes are employed in the degradation process by brown rot fungi, but no lignin degrading enzymes are typically involved. White rot fungi are typically associated with hardwood decay and their wood decay patterns can take on different forms. White rotted wood normally has a bleached appearance and this may either occur uniformly, leaving the wood a spongy or stringy mass, or it may appear as a selective decay or a pocket rot. White rot fungi possess both cellulolytic and lignin degrading enzymes and these fungi therefore have the potential to degrade the entirety of the wood structure under the correct environmental conditions. Soft rot fungi typically attack higher moisture, and lower lignin content wood and can create unique cavities in the wood cell wall. Less is known about the soft rot degradative enzyme systems, but their degradative mechanisms are reviewed along with the degradative enzymatic and nonenzymatic systems known to exist in the brown rot and white rot fungi. As we learn more about the non-enzymatic systems involved in both brown and white rot degradative systems, it changes our perspective on the role of enzymes in the decay process. This in turn is affecting the way we think about controlling decay in wood preservation and wood protection schemes, as well as how we may apply fungal decay mechanisms in bio-industrial processes.

Keywords: wood rotting, fungi, white, soft, brown, cellulolytic, enzymes, decay, degradative, bio-industrial

I. Introduction

Wood is among the most durable cellulosic materials, but it can be degraded by a number of biotic and abiotic agents. These agents often act simultaneously making it difficult to completely separate causal agents. This review will concentrate on the role of fungi in degradation but will also discuss other agents as they relate to the overall process. Our discussion will focus on those fungi capable of degrading the primary cell wall polymers of cellulose, hemicellulose and lignin, but will also touch on the many mold and stain fungi that not only cause aesthetic concerns and disfigure coatings but can digest the stored compounds in the parenchyma cells and the pit membranes while promoting more limited damage to the structural elements of wood.

Some common wood-rotting fungi. a, *Auriculariaauricula;* b, *Daldiniaconcentrica;* c, *Ganodermaapplanatum;* d, *Hexagoniatenius;* e, *Microporusxanthopus;* f, *Schizophyllum commune;* g, *Steccherinumochraceum;* h, *Trameteshirsutum;* i, *T. versicolor*

Wood poses a major challenge to organisms seeking to extract the energy from its polymeric structure. While the stored compounds in parenchyma cells are digestible by many organisms, accessing the more complex polymers is a key challenge. The chemistry and arrangement of the cellulose and lignin polymers in the wood cell wall sharply reduces the number of agents capable of causing damage. Many fungi are cellulolytic but are unable to unlock the chemistry of the lignin polymer that both enrobes and is interspersed with the cellulosic components of the lignocellulosic matrix. Only those fungi that have developed strategies to surmount the recalcitrance of lignin are able to fully extract the embodied energy of the lignocellulose cell wall. Wood decay is largely caused by fungi that fall into categories depending on the appearance of the degraded wood which is, in turn, related to polymeric materials that are degraded. Brown rot decay is an informal name for the most common type of decay occurring in timber products. [1,2]

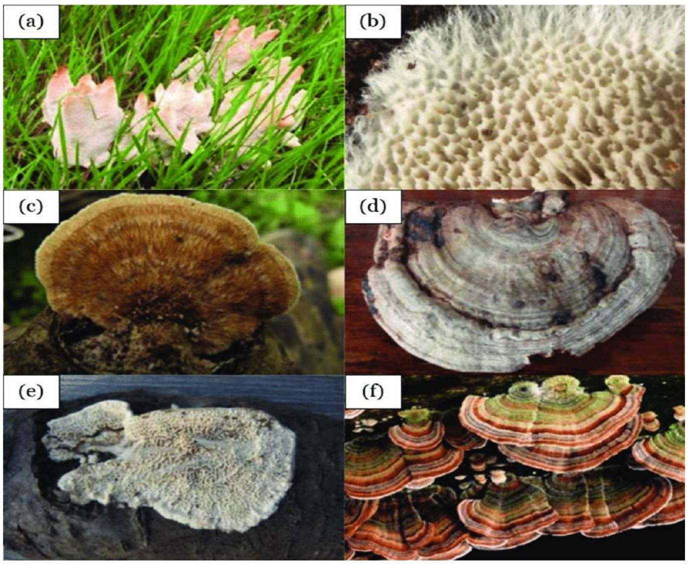
Brown rot fungi

a. *Buglossoporuseucalypticola* (Dai 13660); **b**. *Buglossoporusmalesianus* (RSNB 5747); **c**. *Buglossoporusquercinus* (Vlasák 0906/15-J); **d,** **e**. *Daedaleaallantoidea* (Dai 13612A); **f**. *Fomitopsisbetulina* (Dai 1953); **g**. *Fragifomesniveomarginatus* (Dai 9175); **h**. *Niveoporofomesspraguei* (Dai 9260); **i**, **j**. *Piptoporellushainanensis* (Dai 13714); **k**. *Piptoporellustriqueter* (Dai 13121); **l**. *Piptoporellussoloniensis* (Cui 11390); **m**. *Rhodofomescajanderi* (Dai 9024); **n**. *Rhodofomescarneus* (Ryvarden 10118); **o**. *Rhodofomesincarnatus* (Cui 10348); **p**. *Rhodofomesrosea* (Cui 9278); **q**. *Rhodofomessubfeei* (Uotila 42928); **r**. *Rhodofomitopsiscupreorosea* (Ryvarden 44394); **s**. *Rhodofomitopsisfeei* (Uotila 42928); **t**, **u**. *Rhodofomitopsislilacinogilva* (Ratkowsky 0562); **v**. *Rubellofomescystidiatus* (Dai 10355); **w**. *Rubellofomesminutisporus* (Rajchenberg 10666); **x**. *Ungulidaedaleafragilis* (Cui 10919).

Fungi that cause brown rot depolymerize cellulose and hemicellulose (holocellulose) for digestion, while lignin is also depolymerized and modified before being rapidly repolymerized. The general categories of white rot fungi and soft rot fungi are the other major types of decay, and these are covered later in this review, as these fungal decays can be quite important in certain environments. Fungi are Eukaryotic organisms that are in the same Domain in the Tree of Life as plants and animals. Species within other Domains in the tree of life comprising the Bacteria and Archaea can also live in wood. Some species of Bacteria have been shown to cause limited wood deterioration over long periods of time (several centuries), resulting in mechanical property loss in wood. Because of their minor importance in deterioration of structures, these microorganisms will not be considered further in this chapter, although we recognize that they are almost always present and have been suggested to play supporting roles in the degradation process including pre-conditioning of wood, and extractives detoxification. Bacteria are also active in long-term degradation of submerged wooden foundation piling, which typically occurs over many centuries . Insects and some types of marine boring animals also can cause significant biodeterioration of wood under some circumstances, but deterioration by these animals is reviewed elsewhere . For all fungi, spores (microscopic seeds) or other small fragments of the fungi must be produced and be transported either in the air, water or on other organisms (such as insects) to other pieces of wood where a new fungal colonization can initiate.[3,4]

II. Discussion

White-rot fungi are the most effective for delignification due to production of ligninolytic extracellular oxidative enzymes.



White-rot fungi of species (a) Abortiporusbiennis, (b) Ceriporiopsissubvermispora, (c) Coriolopsistrogii, (d) Ganodermaapplanatum, (e) Irpexlacteus and (f) Trametesversicolor

Lignin degradation by several white-rot fungi, such as *Phanerochaete chrysosporium*, *Pleurotus ostrea tus*, *Coriolusversicolor*, *Cyathus stercoreus*, and *Ceriporiopsissubvermispora*, have been studied . White-rot fungi degrade lignin leaving decayed wood whitish in color and fibrous in texture. Some white-rot fungi such as *C. subvermispora*, *Phellinus pini*, *Phlebia* spp., and *Pleurotus* spp. delignify wood by preferentially attacking lignin more readily than hemicellulose and cellulose, leaving enriched cellulose. However, other white-rot fungi such as *Trametes versicolor*, *Heterobasidionannosum*, and *Irpexlacteus* degrade the cell wall components simultaneously . White rot fungi (WRF) play an important role in the global carbon cycle, and are most effective in lignin degradation, while growing on woody substrates. Their unique extracellular nonspecific ligninolytic system, as well as intracellular oxidizing enzymes, enable WRF to metabolize and degrade a wide variety of aromatic toxic pollutants, including polycyclic aromatic hydrocarbons, polychlorinated biphenyls, azo-dyes, pesticides, and pharmaceuticals. Numerous studies provide data on the chemistry, biochemistry, physiology, toxicology genetics, and genomics of the degradation mechanisms of these compounds by WRF. This knowledge will lead to practical mycoremediation processes of polluted environments.[5,6]

Rotting of wood

After the initial colonization stages, brown rot fungi primarily utilize the carbohydrate polymers of the wood cell wall, although they affect all three polymers. Brown rot fungi are considered to be more commercially important from a structural damage perspective because they tend to attack softwoods which represent the bulk of timber used in North American and European construction. However, they can also attack hardwoods and will readily do so in some environments . The resulting decayed wood has a brownish, fractured appearance . The most important aspect of brown rot decay is the tendency for these fungi to produce degradation far in advance of the point of hyphal growth at the cellular level, and to depolymerize the carbohydrates much faster than they can be utilized. This results in very dramatic changes in many timber properties even when the macroscopic visual appearance of the wood is little changed. The result is very rapid losses in properties such as tension or bending at very low mass losses . [7,8]

Brown rot fungi have a more limited suite of enzymes involved in the depolymerization and deconstruction of cellulose compared to white rot fungi, and they possess no peroxidase enzymes for lignin depolymerization. However, brown rot fungi rapidly attack and degrade cellulose while also using a non-enzymatic mechanism to depolymerize lignin to allow access to the cellulosic components. The lignin then rapidly repolymerizes, leaving a modified lignin that long led researchers to conclude that brown rot fungi had little effect on this polymer. This unique oxygen radical-based chemistry known as the “chelator-mediated Fenton” (CMF) system functions in advance of enzymatic action to deconstruct wood polymers. CMF chemistry is more complex than conventional Fenton chemistry and allows brown rot fungi to generate powerful hydroxyl radicals within the wood cell wall rather than next to the fungal hyphae (which would kill the fungus). CMF chemistry causes lignin to depolymerize and then repolymerize as small, discrete irregular masses, separate from the cellulose, thereby opening the wood cell wall to further deconstruction. This type of chemistry is being studied as an efficient mechanism for lignin processing in future biorefineries. This later aspect may be of importance for modifying lignin for use in polymeric coatings and is reviewed further in the section on biotechnological applications.[9,10]

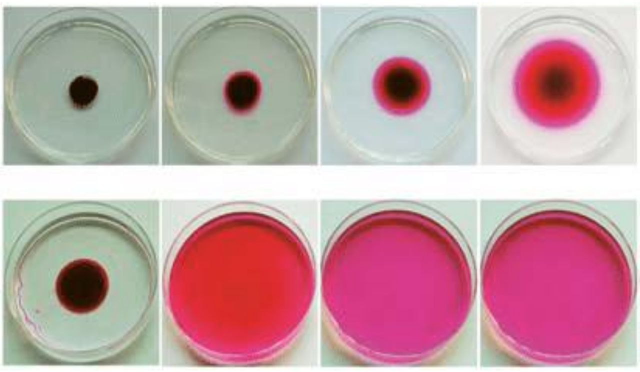
Soft rot fungi-Although soft rot damage of wood was first observed in the 1860s, soft rot fungi were not classified as a decay type until the 1950s .

Soft rot-mould, yeast fungi

Most soft rot fungi are Ascomycota species. There are two types of soft rot attack. Type 1 soft rot involves formation of diamond-shaped cavities aligned with the cellulose microfibril angle within the S-2 cell wall layer, while Type 2 is a more generalized erosion of the S-2 cell wall layer from the lumen outward . Type 2 attack is more prevalent, but some species can produce both types of damage depending on the timber as well as environmental conditions . Soft rot fungi are often found in more extreme, and wetter conditions that are less suitable for traditional white and brown rot fungi .Their damage tends to be confined to the external few mm of wood that is exposed to the environment, possibly because oxygen levels are too low in interior wood below ground to support more aggressive Basidiomycota fungal species. However, particularly in Scandinavian reports, soft rot has been observed to extend more deeply in some products such as utility poles. Soft rot damage presents an interesting mixture of white and brown rot characteristics in that these fungi utilize both cellulose and hemicellulose, but they can clearly degrade lignin as evidenced by the cavities and erosion they cause. Several soft rot fungi are known to produce laccase which is also involved in lignin degradation by white rot fungi . Soft rot fungi tend to have very large, but localized effects on wood properties and these effects are magnified because the damage tends to be on the exterior of the timber where flexural properties for products such as utility poles become more important. In other products, such as boards that will be used for paneling, soft rot fungi can impart an appearance that some people consider as desirable for rustic interiors, and because only the surface wood is degraded, these fungi can sometimes be considered as enhancing the properties of certain wood products.[11,12]

III. Result

Among the main categories of wood-rotting fungi, white rot and brown rot fungi and their enzymes are being increasingly used in a variety of biotechnological applications, some of which include wood and pulping, textile, bioenergy/biofuel and bioremediation (decolourization of synthetic dyes, wastewater treatment, detoxification/removal of toxic substances, including wood preservatives).



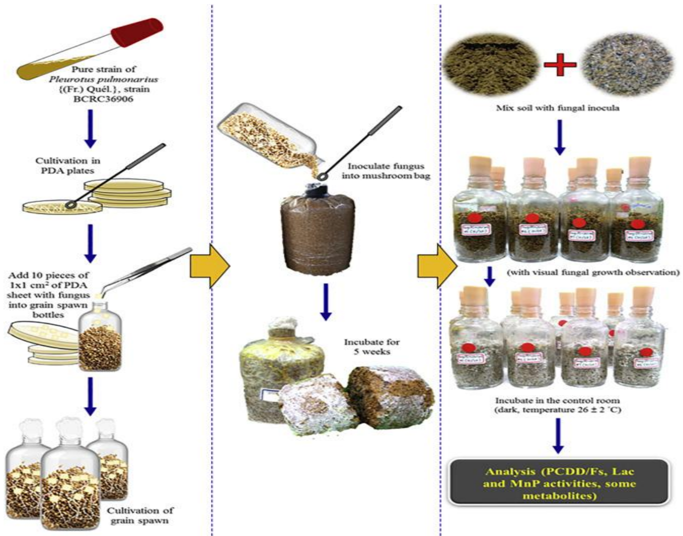
Wood rotting fungal degradation of dyes

The various biotechnological applications of wood-rotting fungi and their key enzymes, laccase and peroxidases, and outlines future prospects where technological developments can lead to their more efficient and economic industrial uses and can create opportunities to expand applications. With increasing awareness among the general public of the problems of water pollution has come a realization among effluent dischargers that the colour in effluents represents a problem in itself. Colourlesseffiuents are less visible, attract less attention and cause less concern than colouredeffiuents. This is despite the fact that often chromophores may be present in very small amounts and may pose no significant threat to the environment, other than turning a river red or purple! Having said this, there can be significant problems of toxicity associated with some chromophores , and many coloured effluents contain damaging materials in addition to chromophores. The focus of this contribution is the removal of colour from effluents, and in particular how wood-rotting fungi can be used for this purpose. It is perhaps useful to consider briefly what alternative processes are available before examining the possible roles of fungi.[13,14]

The main processes used for colour removal are physicochemical and chemical treatments , all of which have some drawbacks. Physicochemical treatments include flocculation and coagulation, adsorption, ion exchange, ultrafiltration and reverse osmosis. These processes (apart from expense) have the problem that contaminant chemicals are not destroyed; they are simply removed from effluents and relocated elsewhere – usually disposed of to landfill or by incineration. Chemical processes mainly involve bleaching using chlorine-based chemicals, ozone or peroxides.

Conclusion

White-rot fungi are chief agents of biodegradation of ligninnous material in nature which contribute in the global carbon recycling.



Wood rotting fungal bioremediation process

Endocrine disrupting chemicals (EDCs) and TrOCs such as pharmaceuticals and personal care products (PPCPs) which can result in effects such as bioaccumulation, acute and chronic toxicity to aquatic organisms, and possible adverse effects on human health have generated a lot of interest with reference to their degradation by white-rot fungi. Majority of the studies have demonstrated the bioremediation potential of white-rot fungi; *Phanerochaetechysosporium*, *Trametesversicolor*, *Bjerkanderaadjusta* and *Pleurotus* sp., by virtue of producing different ligninolytic enzymes such as laccases and peroxidases [19]. The ligninolytic enzymes from white-rot fungi have been applied for transformation of variety of organic pollutants such as pesticides from contaminated wastewaters by promoting microbial activity using a biopurification system (BPS) [20]. Owing to restricted access of ligninolytic enzymes to lignin granules which are deposited on the surface of lignocellulosicfibres, pressure refining was applied for separation of fibres of lignocellulosic materials. This strategy enhanced the accessibility of ligninolytic enzymes from white-rot fungus *Ceriporiopsissubvermispora* which showed higher delignification from pressure refined *Miscanthus* than milled *Miscanthus* [15]. Extracellular ligninolytic enzymes also have capacity for adsorption of dyes which has made white-rot fungi, a dominating force in the area of dye degradation or decolourization as demonstrated in case of decolorization of Direct Blue 14 by various species of *Pleurotus* [18] and Remazol Brilliant Blue-R by *Agaricomycete*, a white-rot fungus from Amazon forest [19].

Wood decay fungi

Diverse fungal groups such as *Coriolusversicolor*, *Hirschioporuslarincinus*, *Inonotushispidus*, *Phanerochaetechrysosporium*, *Phlebiatremellosa* have been reported for decolourization of dye effluent [14] while 38 species of white-rot fungi were shown to cause reduction in total phenolics (>60 %) and color (≤70 %) from olive-mill wastewater [11]. Similarly, white-rot fungi have been applied for remediation of cresolate contaminated soil with bioaugmentation of two strains—*T. versicolor* and *Lentinustigrinus* [19]. The cresolate-polluted soil was contaminated with residual recalcitrant petroleum hydrocarbons and high molecular weight PAH fraction remaining after a biopiling treatment. Significant degradation of the residues could be achieved by biostimulation with lignocellulosic substrate along with bioaugmentation of fungi.[17]

However, there was always a possibility that this type of treatment could promote the growth of local microbes which might subsequently dominate the augmented organism thereby stressing the need for validating such types of studies at a small scale before field applications. In addition to above applications of ligninolytic enzymes for bioremediation of variety of compounds, other features such as laccasses have also been employed by white-rot fungi for degradation of substituted organic compounds at enhanced removal efficiencies [11-15]. Considering the significance of such features in bioremediation, attempts have been made for increasing the laccase production in white-rot fungi, *T. versicolor* and *P. ostreatus* by solid state fermentation on orange peels followed by further testing of its capacity for bioremediation of PAHs such as phenanthrene and pyrene [18]. Laccase production from *T. versicolor* cultures was 3000 U/L and though, *P. ostreatus* produced 2700 U/L laccase, it showed better removal of phenanthrene and pyrene. For a better understanding and exploitation of bioremediation potential of fungi to the fullest, there is a need for studying these fungi at genomic level.[16]

References

[1] Albert Leo N. dela Cruz, William Gehling, SlawomirLomnicki, Robert Cook, and Barry Dellinger . Detection of Environmentally Persistent Free Radicals at a Superfund Wood Treating Site. Environmental Science & Technology 2011, 45 (15) , 6356-6365. https://doi.org/10.1021/es2012947

[2] Adam C. Gusse,, Paul D. Miller, and, Thomas J. Volk. White-Rot Fungi Demonstrate First Biodegradation of Phenolic Resin. Environmental Science & Technology 2006, 40 (13) , 4196-4199. https://doi.org/10.1021/es060408h

[3] Rimko ten Have and, Pauline J. M. Teunissen. Oxidative Mechanisms Involved in Lignin Degradation by White-Rot Fungi. Chemical Reviews 2001, 101 (11) , 3397-3414. https://doi.org/10.1021/cr000115l
[4] Aditya Khindaria, David P. Barr, and Steven D. Aust. Lignin peroxidases can also oxidize manganese. Biochemistry 1995, 34 (23) , 7773-7779. https://doi.org/10.1021/bi00023a025
[5] Venkata Krishna Bayineni. Bioremediation of Toxic Dyes for Zero Waste. 2012,,, 47-66. https://doi.org/10.1002/9783527832064.ch4
[6] Harris, Samuel Y. (2001). Building Pathology: Deterioration, Diagnostics, and Intervention. John Wiley & Sons. p. 106. ISBN 978-0-471-33172-8.
[7] "Wood Decay in Living and Dead Trees: A Pictorial Overview" (PDF).
[8] Viitanen, T. et al. (2010). Towards modelling of decay risk of wooden materials. European Journal of Wood and Wood Products 68:303-313.
[9] J. Deacon, Wood decay and wood-rotting fungi. University of Edinburgh (2005?).
[10] Microorganisms causing decay in trees and wood. University of Minnesota.
[11] Vane, C. H., et al. (2005). "Decay of cultivated apricot wood (Prunusarmeniaca) by the ascomycete Hypocreasulphurea, using solid state 13C NMR and off-line TMAH thermochemolysis with GC–MS." International Biodeterioration& Biodegradation 55(3): 175-185.
[12] Stamets, Paul (2005). Mycelium running: how mushrooms can help save the world. Random House, Inc. pp. 83–84. ISBN 978-1-58008-579-3.
[13] Vane, C. H., et al. (2001). "The effect of fungal decay (Agaricusbisporus) on wheat straw lignin using pyrolysis–GC–MS in the presence of tetramethylammonium hydroxide (TMAH)." Journal of Analytical and Applied Pyrolysis 60(1): 69-78.
[14] Ryvarden, Leif (1993). "Tropical polypores". In Isaac, Susan (ed.). Aspects of Tropical Mycology. British Mycological Society. Symposium. Cambridge University Press. p. 159. ISBN 978-0-521-45050-8.
[15] Vane, C. H., et al. (2006). "Bark decay by the white-rot fungus Lentinula edodes: Polysaccharide loss, lignin resistance and the unmasking of suberin." International Biodeterioration& Biodegradation 57(1): 14-23.
[16] "Wood Decay Fungi in Landscape Trees Management Guidelines--UC IPM". www.ipm.ucdavis.edu. Retrieved 24 February 2010.
[17] Cohen, R.; Persky, L.; Hadar, Y. (2002). "Biotechnological applications and potential of wood-degrading mushrooms of the genus Pleurotus" (PDF). Applied Microbiology and Biotechnology. 58 (5): 582–94. doi:10.1007/s00253-002-0930-y. PMID 11956739. S2CID 45444911.
[18] Vane, C. H., et al. (2003). "Biodegradation of Oak (Quercus alba) Wood during Growth of the Shiitake Mushroom (Lentinula edodes): A Molecular Approach." Journal of Agricultural and Food Chemistry 51(4): 947–956.
[19] Vane, C. H., et al. (2001). "Degradation of Lignin in Wheat Straw during Growth of the Oyster Mushroom (Pleurotusostreatus) Using Off-line Thermochemolysis with Tetramethylammonium Hydroxide and Solid-State 13C NMR." Journal of Agricultural and Food Chemistry 49(6): 2709–2716.