Eco. Env. & Cons. 27 (August Suppl. Issue) : 2021; pp. (S165-S177)

ISSN 0971–765X

Diversity of metabolites produced by White Rot Fungi possess different biological properties: A review

Sanam Kundu[1] and Minhaj Ahmad Khan*[2]

Department of Microbiology[1], Department of Biochemistry[2]
School of Bioengineering and Biosciences, Lovely Professional University,
Phagwara 144 411, Panjab, India

(Received 12 March, 2021; Accepted 26 April, 2021)

ABSTRACT

White rot fungi is a well known wood decaying macro-fungi being studied for many years for the potential applications in the bio-degradation of environmental pollutants because they produces a varieties of enzyme primarily responsible for the degradation of complex organic polymers. Along with these white rot fungi produces a vast number of cellular and extracellular metabolites having significant biological properties like antimicrobial, antioxidant, immunomodulatory, and nutritional properties. Because of these properties white rot fungi are being used in many field of science like Environmental Biotechnology, Bio-remediation technology, dye decolourization technology, Pharmaceutical industries, Nutritional researches etc. Aim of the study is to find out the different types of metabolites they produce, in which bio-synthetic pathways and their significant biological properties.

Key words: *White rot fungi, Wood decay, Enzymes, Metabolites, Pathways, Biotechnology.*

Introduction

White rot fungi belongs to a large group of phylum Basidiomycota that contains nearly 30-32% of entire fungal diversity and comprising about 30,000 different species having cosmopolitan distribution in nature and involved in a varieties of relationships like, pathogenic, mutualistic, parasitism and symbiosis etc (Riley *et al*., 2014; Webster and Weber, 2007). They are heterogenous group of saprophytic Fungi can grow everywhere on different organic substrates like lignocellulosic polymers of wood, waste organic materials, dead organisms and other biological substrates (Tuomela and Hatakka, 2019, Goyal *et al*., 2016; Magan, 2008).

In a forest ecosystem, the saprotrophic wood decomposing fungi plays an important role in Earth's carbon cycle (Hatakka and Hammel, 2011). Certain basidiomycetes, specially the white-rot fungal group, have the ability of degrading complex cell wall polymers of plants such as cellulose, hemicellulose and lignin and other organic materials including carbohydrates, polysaccharides and other biopolymeric substances thus release carbon di-oxide and water into the environment that plays an significant role in Earth's ecosystem (Goodell *et al*., 2020; Fukushima, 2020; Baldrian, 2008; Hatakka and Hammel, 2011). This ability due to production of a varieties of different cellular and extracellular enzymes like hydrolytic enzymes, cellulases, hemicellulose, laccases, peroxidases and others (Wang *et al*., 2018; Glazunova *et al*., 2018). As a result of degradation wood became pale and white spongy fibres and cause rot on wood (Abdel *et al*., 2013; Gao *et al*., 2010). Around 90% of wood rotting fungi are reported to white rot types and they are the only organism can efficiently degrade and mineralize the complex polymer lignin (Tuomela and Hatakka, 2019; Fernando *et al*., 2016; Hatakka and Hammel, 2011). Based on the nature of action of wood degradation a group of basidiomycetes have been classified into brown rot and white rot and sometimes cause soft rot where, brown rot and soft rot fungi are responsible for degrading cellulosic and hemicellulosic materials (Yilkal, 2015; Schu and Anke, 2009) and white rot fungi is responsible for the degradation of lignin by producing extracellular enzyme lignin peroxidase (Sevindik, 2018).

Beside these white rot fungi possess a wide range of biological properties like they can be poisonous, edible with degrading, nutritional and therapeutic properties (Ukwuru *et al*., 2018; Remya *et al*., 2019; Swann and Hibbett, 2007). Some white rot basidiomycetes are known for producing fruiting bodies called as mushrooms (Swann and Hibbett, 2007). Since past centuries mushroom is being considered as functional food as they are contains nutrition rich compounds such as lipids, proteins, fat, carbohydrates, fibres, vitamins and minerals (Sevindik 2018). The mycelium and fruiting body consists of a wide range of metabolites with biologically active compounds that helps them to survive in nature by competing with other organisms for colonization, growth and nutritions (Wang *et al*., 2018). A large no of enzymes along with others secondary metabolites are produced by white rot fungi have high therapeutic, nutritional, medicinal and degradation capabilities (Gebreyohannes *et al*., 2019; Chowdhury *et al*., 2015; Rodriguez, 2017). Those bioactive compounds such as cellular and extracellular components like enzymes and other metabolites are different in molecular weight such as phenolic compounds, high molecular weight polysaccharides, lipids, proteins, glycoproteins and tocopherols have shown bioactive properties in some isolated higher macro fungi. While secondary metabolites such as terpenoids, polyphenols, sterols, flavonoids, alkaloids, benzoic acid derivatives, quinolones, anthraquinones, lactones having bioactive properties mentioned by authors (Jaszek *et al*., 2013; Srikram and Supapvanich, 2016; Bains and Tripathi, 2016). White rot fungal metabolites having potential industrial, agricultural, environmental and biotechnological applications, in pharmaceutical industries, pulp industries such as bioleaching of pulp, in paper industries, waste water treatment, degradation and transformation of environmental pollutants, improvement of cellulose and lignin digestibility in animal, production of renewable raw materials from lignocellulosic materials, in bioremediation and bioaugmentation technology, agricultural wastes revalorization etc (De Jong, 1993; Wang *et al*., 2017; Rodriguez, 2017; Jurado *et al*., 2011).

The purpose of the study was to find out different types of bioactive metabolites produced by white rot fungi during their growth phase and developments, in which biosynthetic pathways the metabolites are produced and their biological properties including their degradation capabilities, antimicrobial properties, nutraceutical and health benefits. Various literatures data showed that the metabolites produced by white rot fungi having a lot of contributions in researches, and in biotechnological, Industrial and environmental applications.

Diversity of metabolites produced by white rot fungi

Metabolism is a biochemical process by which all the life processes are accomplished and it's a fundamental process for all cellular life. White Rot Fungi are one of the most beneficial organism on Earth due to the abilities of synthesizing numerous number of bioactive metabolites for survival in environment (Jaszek *et al*., 2013; Rodriguez, 2017). Mycelial structure and the fruiting bodies produces a vast number of metabolites having different biological properties (Schu and Anke, 2009, Xiao and Zhong, 2016, Wang *et al*., 2017). Their metabolites can be classified into two categories are primary and secondary metabolites.

Primary metabolites

The primary metabolites of white rot fungi are produced by different cellular metabolisms during the exponential growth phase that helps in their growth and development (Sanchez and Demain, 2008). The end products of metabolism are used by the cells as building blocks for the production of potential biomolecules are like amino acids and peptides such as lysine, methionine, phenyl alanine, tyrosine and repeated amino acid chain of leucine, valine (Lapadatescu *et al*., 2000; Beck, 1997; Stergiopoulos *et al*., 2013; Rahi and Malik, 2016), Some monomars or the subunits of nucleosides or nucleic acid derivatives like Eritadenine, Lentinacin and Clitocine were isolated from the white rot fungi species of *Lentinus edodes* and *Clitocybe inversa* (Fukushima, 2020, Rahi and Malik, 2016).

Organic acids such as oxalic acid, acetic acid, citric acid and malonic acids, fumaric acid, shikimic acid etc (Dashtban *et al*., 2010), carbohydrates and polysaccharides such as glucose, xylose, galactose, mannose and arabinose etc (Hatakka and Hammel, 2011). Vitamins a primary metabolite is very much needed for fungal growth and developments such as vitamin B12 or riboflavin, vitamin B1 or thiamine, niacin, biotin, ascorbic acid, pyridoxine, tocopherols etc have been reported to present in several white rot fungal mushroom (Ukwuru *et al*., 2018). The secretion of extracellular and hydrolytic enzymes such as pectinase, chitinase, cellulase, laccase, xylanase, manganese peroxidase (Tuomela and Hatakka, 2019; Abdel *et al*., 2013) lignin peroxides enzymes during their secondary metabolism while degradation of components polymer (Alves *et al*., 2012 a, Fonseca *et al*., 2015; Shu, 2007; Alves *et al*., 2013b, Rodriguez, 2017), some alcohols such as ethanol, benzyl alcohol and vanillyl alcohol (Lapadatescu *et al*., 2000; Dashtban *et al*., 2010; Mattila *et al*., 2020). It has been reported that various enzymes are involved in the degradations of complex polymers that results in the formation of biproducts for cellular metabolism (Goyal *et al*., 2016; Bezalel *et al*., 1996; Agrawal *et al*., 2016).

Secondary Metabolites

The synthesis of secondary metabolites basically involves with the polymerization of certain enzymes those referred to as the backbone of primary metabolisms and then secondary metabolites are produced by using the enzymes or intermediate byproducts of primary metabolisms (Keller *et al*., 2005). Though secondary metabolites are not very much essential for growth and development but they possess different biological properties such as antimicrobial, anti-parasites, insecticides, microbial interactions, such as competition and symbiosis, production of important enzymes for biodegradations (Schu and Anke, 2009; Thirumurugan *et al*., 2018; Verduzco and Gutierrez, 2020). Some important types of secondary metabolites are Terpenoids such as Taxol, lanosterol, pleuromutilin and illudin, ganoderic acid, hirsutane and ergosterols etc (Schu and Anke, 2009; Kuhnert *et al*., 2018; Rahi and Malik, 2016). Phenols and phenolic compounds such as flavonoids, quinones, tannins, cinnamic acids, coumarins, gallic acid, p-hydroxybenzoic, ferulic acid, syringic acid, Tyrosol and hydroquinone (Gan *et al*., 2019; Jong, 2010, Osinka *et al*., 2015). Polyketides, Alkaloids and fatty acid such as sterenins, orsellinic acid, Pestalachloride, Terphenyl, and Strobilurin (Jong, 2010; Tian *et al*., 2020; Nofiani *et al*., 2018), non-ribosomal peptides etc (Keller *et al*., 2005). Carbohydrates and Polysaccharides such as 5-d-glucans, glucose, mannose, galactose (Hatakka and Hammel, 2011; Keller *et al*., 2005; Wang *et al*., 2017). Proteins and Glycoproteins such as lectins, pectin, heme peroxidase like manganese, lignin and versatile peroxidase, anthraquinones etc (Schu and Anke, 2009; Jaszek *et al*., 2013; Thirumurugan *et al*., 2018; Dashtban *et al*., 2010; Jong, 2010). Veratryl alcohol is also a secondary metabolite that produce lignin peroxidase important enzymes for lignin polymer degradations (Jensen *et al*., 1994). Several colorless fungal secondary metabolites are considered to be the pigments The genus Thelephora and Hypoxylon has shown to be rich sources of pigment p-terphenyl (Chen and Liu, 2017) on the other hand an extracellular metabolite melanin pigment is produced from white rot fungus *Schizophyllum commune* (Arun and Gunasekaran, 2015).

Metabolic biosynthesis

Fungi are the most ubiquitous organism in nature as they are capable to synthesize broad range of compounds naturally from simple molecules which referred to as primary metabolites to the complex molecules are called secondary metabolites (Rahi and Malik, 2016). Although the commercial production of fungal metabolites depends on the amount of nutrients, its growth environments and culture conditions that promotes metabolite biosynthesis (Bills *et al*., 2008, Moreira *et al*., 2003; Barberel and Walker, 2000). Different chemicals or substrates are generally used to transform the actions of cellular enzymes by the organisms for the production of bioactive metabolites that might be used as building blocks for the production of secondary metabolites (Nielsen, 2018, Bezalel *et al*., 1996; Agrawal *et al*., 2016). Naturally so many cellular and extracellular enzymes are involved in the degradations of various compounds or polymers in the environment by cellular metabolisms results in the formations of cellular biproducts (Goyal *et al*.,2016; Bezalel *et al*., 1996; Agrawal *et al*., 2016). Secondary metabolites are produced by using those biproducts of primary metabolism as building blocks (Nord, 2014) and are well known bioactive compounds with structural diversities are synthesized in various metabolic pathways with the actions of various enzymes or intermediates (Goyal *et al*., 2016; Lin *et al*., 2019).

White Rot Fungal Metabolites

Primary Metabolites

1. **Carbohydrates** – Glucose, Xylose, Arabinose, Manose, Galactose etc.
2. **Cellular Enzymes**- Cellulose, hemi-cellulose, laccase, Lignin peroxidase, Manganese peroxidase, xylanase, etc.
3. **Nucleotides and nucleosides-** Eritadenine, Lentinacin and Clitocine and nucleotides bases etc.
4. **High molecular weight compounds -**like amino acids and peptides such as Tyrosine, Leucine, Phenyl alanine.
5. **Organic Acids-** Acetic acid, malic acid, citric acid, oxalic acid etc.
6. **Vitamins –** Tocopherols, pyridoxine, riboflavin, thiamine, niacin, biotin, ascorbic acid etc.

Secondary Metabolites

1. **Terpenoids** – Taxol, Lanosterol, Ergosterol, Ganoderic acid, Hirsutane etc
2. **Phenolic components-** Flavonoids, Tannins, cinnamic acids, gallic acid, parahydroxybenzoic, ferulic acid, syringic acid, Tyrosol.
3. **Polysaccharides**- β d-Glucan, galactose, arabinose.
4. **Polyketides and alkaloids**- Pestalachloride, Strobilurin, sterenins etc.
5. **Glycoproteins**- lectins, pectins, Cellular enzymes, hem peroxidase etc.
6. **Anthraquinones**- Erythroglaucin, Physcion and Emodin, Hydroquinone etc
7. **Pigments-** Melanin, p-terphenyl

Fig. 1. Types of metabolic components produced by White Rot fungi

Biosynthetic pathways are involved like

i. Mevalonic acid pathway

It is a common pathway of many plants and including fungi (Hansson, 2013). Several class of terpenoids like sesquiterpenoids, diterpenoids and triterpenoids, steroids secondary metabolites of white rot fungi are synthesized by following the mevalonic acid pathway by integration of primary and secondary metabolic products (Goyal *et al.*, 2016; Kaller *et al.*, 2005; Thirumurugan *et al.*, 2018). White rot fungi mostly follows this mevalonic acid pathway for the synthesis of several classes of terpenoids and its derivatives (Hansson, 2013).

ii. Shikimic acid pathway

Shikimic acid pathway is a biosynthesis pathway for the production of various aromatic amino acids and organic compounds like L-phenylalanine, L-tryptophan and L-tyrosine, glycine, various proteins and sterols etc (Goyal *et al.*, 2016; Moore *et al.*, 2020). The shikimic acid pathway involved with the carbohydrate metabolisms and pentose phosphate pathway to produce shikimic acids and other by products (Hansson, 2013). Shikimic acid phosphorylated with a Phosphoenol pyruvate molecules an important compounds of Krebs cycle and attached to another group of shikimic acid and helps in the formation of many other important compounds such as aromatic amino acids such as Benzoic acid derivates and phenolic compounds are originated from this pathway and tannic acid is formed by the reaction of glucose and shikimic acids following the shikimic acid pathway (Goyal *et al.*, 2016; Kojima *et al.*, 2015; Thirumurugan *et al.*, 2018; Hansson 2013; Nowicka and Kruk, 2010).

iii. Acetic acid pathway

The Fungal polyketides are generally synthesized by polyketide synthases an enzyme is composed of a multi domain proteins and non-ribosomal peptide synthase following by the polyketide and non-ribosomal peptide synthesis pathways (Kaller *et al*., 2005; Nielsen, 2018; Valiante, 2017). These two enzymes contain short chain of carboxylic acids such as acetyl CoA and malonyl Co-A are two important by-products of Krebs cycle or Tri carboxylic Acid cycle are involved in polyketide and fatty acid biosynthesis those are produced by the acetic acid pathway and β oxidation of fatty acids (Moore *et al*., 2020; Kaller *et al*., 2005; Collemare and Seidl, 2019). Polyketide synthase simulates other intermolecular reactions where anthraquinones are synthesised in this pathway (Hansson, 2013; Nowicka and Kruk, 2010).

iv. Biosynthesis of carbohydrates and polysaccharides

The biosynthetic pathway of carbohydrates are common in all fungi in compared with the other organisms (Deveau *et al.*, 2008). Polysaccharides are composed of long chain of carbohydrate molecules joined together by galactosidase bonds are essential components for all living organisms produced by both primary and secondary metabolism (Kaller *et al*., 2005; Hansson, 2013). Examples of carbohydrates and polysaccharides are glucose, mannose, galactose and glucan are produced via several reverse pathways are like glycolytic, gluconeogenesis, pentose phosphate pathway and krebs cycle from non-carbohydrate sources (Deveau *et al*., 2008;, Deacon, 2013).

Biological properties of white rot fungal metabolites

White rot fungi is one of the most beneficial organism on earth easily available in nature as they grows naturally in the environment produces unlimited no of metabolites and compounds possess different varieties of bioactive properties, some wild white rot basidiomycetes are not edible because of the presence of toxins might cause harm to human health and on the other hand wild edible white rot fungi has an importance in every aspects of life, from their nutritional properties to their potential applications in various field of science has increased based on their biological properties (Table 1).

Degradation properties

White rot fungi is a type of fungi having the capability to degrade and mineralize the most abundant complex polymer lignin of wood or plants along with other lignocellulosic biomass and various organic pollutants that could be a possible way to degrade a wide varieties of environmental pollutants and chemicals that are insoluble and very recalcitrant in nature are easily mineralized by that fungi (Aust, 1995; Shah *et al*., 1992; Abdel *et al*., 2013). Although the capability of Lignin degradation by white rot fungi is being studied from last 30 years and it widely applied for its biotechnical applications in pulp mills and paper industries, bleaching processes, dyes decolorization in textile industries for removal of environmental chemicals and other xenobiotic pollutants (Tuomela and Hatakka, 2019; Aust 1995; Boer, 2018; Jaszek *et al*., 2006; Zuleta *et al*., 2016). The xenobiotic compounds such as some organochlorinated and other pesticides with diverse chemical classes, some of important chemicals are diuron, Linuron, metalaxyl, lindane, metribuzin, chlorpyrifos, atrazine or terbuthylazine, DDT or 1,1,1-trichloro-2,2-bis (4-chlorophenyl)ethane, TCDD or 2,3,7,8- tetrachlorodibenzo-p-dioxin, benzo (a) pyrene, polyaromatic hydrocarbons or PAHs, polychlorinated biphenyls, pentachlorophenol and various groups of pesticides (Magan 2008; Aust, 1995, Shah *et al*., 1992; Bending *et al.*, 2002; Mohapatra *et al*., 2018; Gouma *et al*., 2019).

Their ability of degradation might be for the action of producing extracellular non-specific oxidative and hydrolytic enzymes during metabolisms that composed of cellulase, hemicellulose, lignin peroxidase, manganese peroxidase and laccase that allows the organisms to mineralize the cellulosic polymers, lignin and xenobiotics pollutants persistent in soil and water in the environment (Tuomela and Hatakka, 2019; Jaszek *et al*., 2013; Chaturvedi *et al*., 2018; Dewick, 2009). The ligninolytic system of white rot fungi have a great complexity involved with the varieties of non-specific enzymes those cleaves the carbon-carbon and carbon-oxygen bonds in the lignocellulosic recalcitrant polymers results in the depolymerisation of lignin and thus degrades varieties of aromatic and aliphatic groups containing xenobiotic compounds (Tuomela and Hatakka, 2019; Magan, 2008).

The most unique feature of the fungi are, they occurs naturally having the ability of degradation with the degradative peroxidase enzymes are produced in response to differences in carbon nitrogen ratio or the presence of organic polymers, xenobiotics and heavy metals through various metabolic pathways in natural or artificial environment (Tuomela and Hatakka, 2019; Shah *et al*., 1992).

Antioxidant properties

At present scenario unhealthy food habits, hypertensions, climate conditions, ultraviolet radiations and other environmental factors responsible for oxidative damage or stress, free radicals, and numerous health diseases (Roman *et al*., 2020) Numerous no of bioactive properties of secondary metabolites produced by Fungi have been described extensively in many studies with their antioxidant properties also reported is an important features could be used as natural source antioxidants where now a days doctors are suggesting natural food sources those posses antioxidants to prevent oxidative damages in the body (Fernando *et al*., 2016). Oxidative stress is a condition of damage that is a vital problem for human and all living organisms including is basically caused by the uncontrolled formations of reactive oxygen species or ROS including free radicles having one or more unpaired electrons are generated during normal cellular metabolism that consequently exposed to stress factors, such as changes in temperature, environmental pollution, change in climates (Fernando *et al*., 2016; Jaszek *et al*., 2013; Rezaeian *et al*., 2016).

An uncontrolled increase of level of free radicals can cause oxidative damage to cellular components including DNA, proteins, membrane lipids that leads to serious degenerative human diseases such as coronary heart disease, impaired immune functions, aging, cancer, cardiovascular disease, brain disfunctions and atherosclerosis (Fernando *et al*., 2016; Jaszek *et al*., 2013; Jain and Choudhary, 2012). Various authors have done antioxidant activity of different white rot fungi and other higher fungi and reported that the secondary metabolites produced from white rot basidiomycetes posses strong antioxidative mechanism that can protect mammalian cells against free radicals mediated toxicity generated in human body (Fernando *et al*., 2016; Jaszek *et al*., 2013, Rezaeian *et al*., 2016).

Antimicrobial properties

Several antimicrobial screening has been done to know about antimicrobial properties of white rot fungal metabolites and a large number of bioactive components both cellular, extracellular components and secondary metabolites have shown to be effective against pathogenic microorganisms that could be used to treat variety of disease (Wang *et al*., 2018; Jaszek *et al*., 2013). From literature studies some bioactive compounds have been identified, including cellular and extracellular low and high molecular weight compounds are mainly secondary metabolites like some lipids, glycoproteins, peptides, terpenes, carbohydrates, pigment such as melanin (Arun and Gunasekaran, 2015), polysaccharides, alkaloids, sterols, polyphenols (Jaszek *et al*., 2013) and flavonoid derivatives, anthraquinones, benzoic acid derivatives, and quinolines responsible for showing antimicrobial activity from different extracts of white rot basidiomycetes against both gram-positive and gram negative pathogenic bacteria (Wang *et al*., 2018; Sharma *et al*., 2017; Sevindik, 2018; Akyuz *et al*., 2010; Jaszek *et al*., 2013).

Nutraceutical benefits

Some edible white rot fungi are able to produces fruiting bodies also referred as mushroom that is being consumed as prominent food from several centuries in many countries traditionally called as "Food of the Gods" to ancient Greeks because the fruiting bodies of edible white rot fungi or mushrooms were very good in taste with aroma and flavours (Rahi and Malik, 2016; Jennison *et al*., 1957; Kandeler, 2007). As many as researches are being conducted with mushrooms and macro fungi several informations are being reported in literatures. Scientists have reported that all edible mushrooms including white rot fungi contains a large number of bioactive components are very much beneficial to human health (Rezaeian *et al*., 2016; Dewick, 2009). Some white rot fungal species are *Agaricus campestris, Lentinula edodes, Cyclocybe aegerita, Pleurotus* sp (Yogita *et al*., 2010) are composed of high content of carbon and nitrogenous components, dietary fibers, water composition, low fat and low-calorie protein content including the essential amino acids along with numerous no of minerals and vitamins B12 or riboflavin, B3, B5 and vitamin C and D, Copper, Selenium, Potassium, carbohydrates and nitrogen rich compounds, lipids etc (Ukwuru *et al*., 2018, Remya *et al*., 2019; Rahi and Malik, 2016; Xiao and Zhong, 2016, Yogita *et al*., 2010). The bioactive compounds polyphenols and flavonoid components produced by some white rot fungal species are used as a functional food source having nutraceutical benefits with dietary components (Fernando *et al*., 2016).

Table 1. Bioactive metabolites produced by white rot fungi and their biological properties:

Diversity of Metabolites	White Rot Fungal Species	Significant Features	References
1. Nucleosides and nucleotide derivatives	*Lentinus edodes* *Clitocybe inversa*	Nucleosides and nucleotide derivatives serves the energy within the cell in the form of the nucleoside triphosphates like ATP, GTP, CTP, and UTP and also play central roles in cellular metabolisms.	Fukushima, 2020; Rahi and Malik, 2016
2. Laccase and laccase type of enzyme named phenol oxidases	*Crassostrea gigas* *Cerrena unicolor*	Antimicrobial activities and immune defence mechanisms Degradation of lignin polymers, Antioxidative properties	Tuomela and Hatakka, 2019; Luna *et al*., 2011 Rodríguez, 2017
3. Lignin peroxidase, Manganese peroxidase and other enzymes	*Trametes versicolor* *Phanerochaete chrysosporium* *Pleurotus ostreatus* *Pleurotus sajor-caju* *Ganoderma lucidun* *Trametes sp*	Degradation of lignin, cellulose and hemicellulose Degradation of xenobiotics including pesticides, aromatic hydrocarbons, Industrial dyes decolourization, Acts as antioxidants.	Tuomela and Hatakka, 2019; Jaszek *et al*., 2013; Koroleva *et al*., 2015, Rodríguez, 2017
4. Phenolic compounds and Flavonoids	*Pestalotiopsis* sp. *Stereum sp.* *Ganoderma lucidum* *Phellinus linteus* *Agaricus campestris* *Lentinus edodes* *Agaricus blazei* *Pleurotus ostreatus* *Flavodon flavus* *Xylaria feejeensis* *Schizophyllum sp.*	Antioxidant activities, Oxidative stress reduction Nutraceutical properties Antimicrobial activities against MRSA Cytotoxic and Scavenging activity in human body.	Fernando *et al*., 2016; Ukwuru *et al*., 2018; Sharma *et al*., 2017; Rahi and Malik, 2016; Verduzco and Gutierrez, 2020; Tian *et al*., 2020; Rezaeian *et al*., 2016 Jain and Choudhary, 2012
5. Veratryl alcohol	*Phanerochaete chrysosporium*	This compound stabilizes the lignin peroxidase enzymes to promote oxidation of a variety of lignocellulosic and recalcitrant substrates, Acts as antioxidant	Jennison *et al*., 1957; Morales *et al*., 2010
6. Terpenoids and Several Lipids	*Cystoderma sp.* *Conocybe sp* *Pestalotiopsis spp* *Ganoderma lucidum* *Stereum hirsutum* *Clitocybe illudens* *Coprinus sp.* *Limacella illinita* *Fomitella fraxinea* *Clavariadelphus truncates* *Grifola frondosa* *Ganoderma lucidum*	Antitumor properties, Anticancer, Neurotrophic Anti-infectious and anti-inflammatory activities Cytotoxic activity Fungicidal and Antibacterial and Nematocidal activities Acts against gram positive methicillin resistant *staphylococcus aureus* or MRSA	Schu and Anke 2009, Zhong and Xiao 2009, Rahi and Malik 2016, Jong 2010; Farhat *et al*., 2018

Table 1. *Continued ...*

Diversity of Metabolites	White Rot Fungal Species	Significant Features	References
7. Sterols	*Stereum hirsutum* *Lentinula edodes* *Cordyceps sinensis* *Tricholomopsis rutilans*	Acts against both Gram positive and negative bacteria, Antioxidant properties	Jaszek *et al*., 2013; Rahi and Malik 2016; Kandeler 2007
8. Polyketides, Alkaloids and Fatty acid derivatives	*Stereum* sp. *Pestalotiopsis adusta* *Ceriporia subvermispora* *Strobilurus tenacellus*	Antibacterial, Antifungal, Anticancer and Immunosuppressive properties	Schu and Anke, 2009; Jaszek *et al*., 2013, Rahi and Malik, 2016; Jong 2010; Nofiani *et al*., 2018
9. Glycoproteins	*Agaricus campestris* *Tricholoma* *Mongolicum* *Phallus* sp. *Lactarius* sp.	Cellular mechanisms like Cellular transport, Adhesions of cell to cell, Cellular Recognition, Cell Differentiation, Growth regulation in living organisms	Schu and Anke, 2009; Rahi and Malik, 2016; Elisashvili, 2012
10. Polysaccharides	*Stereum* sp. *Ganoderan* sp. *Lentinan* sp. *Grifolan* sp. *Schizophyllan commune* *Trametes villosa*	Anti- Cancer Anti-Tumor, Immuno-Modulatory Properties, Antiviral Activities, Antimicrobial Properties,Anti-Inflammatory, Hypoglycaemic Activities, Antioxidative, Hepatoprotective Effects	Wang *et al*., 2018; Jaszek *et al*., 2013, Rahi and Malik 2016, Elisashvili 2012, Rajasekar *et al*.,2008, Osinka *et al*.,2015
11. Anthraquinones	*Lentinus* sp. *Cortinarius* sp.	Antimicrobial and antioxidant activities.	Fernando *et al*., 2016; Zahmatkesh *et al*., 2018
12. Pigments	*Thelephora* sp *Hypoxylon* sp. *Schizophyllan commune*	Nutraceuticals Antimicrobial properties	Chen and Liu 2017Arun and Gunasekaran, 2015
13. Vitamins and minerals	*Pleurotus spp.*, *Lentinus edodes*	Vitamins regulate the growth of body. Selenium is an mineral antioxidant that prevents cell damage and reducing the risk of cancer and other diseases. Potassium is an extremely important mineral that regulates blood pressure.	Rahi and Malik, 2016

Literatures data shown that the bioactive compounds such as polysaccharides, proteins, glycoproteins, unsaturated fatty acids, phenolic compounds, tocopherols, ergosterols, lectins etc produced by white rot fungi having therapeutic properties like antidiabetic, anti-obesity, antioxidants, anticancer, antimicrobial and immunomodulatory properties, hypocholesteraemia and anti-aging along with they lowering the cholesterols, hypertensions and stress factors in human body (Rahi and Malik, 2016; Xiao and Zhong, 2016; Sevindik, 2019). Numerous no of investigations shown different bioactive molecules obtained from white rot fungi by different screening methods and the studies revealed that white rot fungi could be an alternative and natural source of bioactive compounds with therapeutic and nutraceutical benefits.

Conclusion

From the study we have got to know about varieties of primary and secondary metabolites including cellular enzymes white rot fungi produces during their growth and metabolisms. Moreover they are composed of varieties of nutritional components and due to the presence of those components some edible white rot fungi or mushrooms are being considered as functional food and dietary supplements. Beside nutritional properties they possess significant biological properties as they are well known macro fungi having great potential in the field of bioremediation technology and other biotechnological industrial applications, their antioxidant and antimicrobial properties. Various studies have been done with white rot fungi, some authors applied them into biotechnological applications while, other authors only focused on their antimicrobial and medicinal properties. In this review we have found different biologically active metabolites produced by white rot fungi, the metabolites produced in which biosynthetic pathways, their biodegradation capabilities towards complex organic polymers and environmental pollutants, then their nutritional properties to human health and diseases. So it's been concluded that white rot fungi not only will lead to the contribution in biotechnological applications and bioremediation technology but also could make some significant contributions in pharmaceutical industries, nutritional and biomedical research field.

Acknowledgement

Author is thankful to the Department of Microbiology and Biochemistry for all the supports provided during performing review analysis.

References

Abdel-Hamid, A. M., Solbiati, J. O. and Cann, I. K. 2013. Insights into lignin degradation and its potential industrial applications. *Advances in Applied Microbiology*. 82: 1-28.

Agrawal, N., Verma, P. and Shahi, S. K. 2018. Degradation of polycyclic aromatic hydrocarbons (phenanthrene and pyrene) by the ligninolytic fungi Ganoderma lucidum isolated from the hardwood stump. *Bioresources and Bioprocessing*. 5(1), 1-9.

Akyuz, M., Onganer, A. N., Erecevit, P. and Kirbag, S. 2010. Antimicrobial activity of some edible mushrooms in the eastern and southeast Anatolia region of Turkey. *Gazi University Journal of Science.* 23(2).

Alves, M. J., Ferreira, I. C., Dias, J., Teixeira, V., Martins, A. and Pintado, M. 2012. A review on antimicrobial activity of mushroom (Basidiomycetes) extracts and isolated compounds. *Planta Medica*. 78(16) : 1707-1718.

Arun, G., Eyini, M. and Gunasekaran, P. 2015. Characterization and biological activities of extracellular melanin produced by *Schizophyllum commune* (Fries).

Aust, S. D. 1995. Mechanisms of degradation by white rot fungi. *Environmental Health Perspectives*. 103(suppl 5), 59-61.

Bains, A. and Tripathi, A. 2016. Antibacterial Activity And Phytochemical Screening Of Wild Edible Mushroom Pleurotus Ostreatus collected From Himachal Pradesh. *International Journal*. 4(4) : 467-474.

Baldrian, P. 2008. Enzymes of saprotrophic basidiomycetes. *In British mycological society symposia series* (Vol. 28, pp. 19-41). Academic Press.

Barberel, S. I. and Walker, J. R. 2000. The effect of aeration upon the secondary metabolism of microorganisms. *Biotechnology and Genetic Engineering Reviews*. 17(1): 281-326.

Barros-Filho, B. A., de Oliveira, M. C., Mafezoli, J., Barbosa, F. G. and Rodrigues-Filho, E. 2012. Secondary metabolite production by the basidiomycete, Lentinus strigellus, under different culture conditions. *Natural Product Communications*. 7(6).

Beck, H. C. 1997. Biosynthetic pathway for halogenated methoxy benzaldehyde in the white rot fungus Bjerkandera adusta. *FEMS Microbiology Letters*. 149(2) : 233-238.

Bending, G. D., Friloux, M. and Walker, A. 2002. Degradation of contrasting pesticides by white rot fungi and its relationship with ligninolytic potential. *FEMS Microbiology Letters.* 212(1) : 59-63.

Bezalel, L. E. A., Hadar, Y., Fu, P. P., Freeman, J. P. and Cerniglia, C. E. 1996. Metabolism of phenanthrene by the white rot fungus Pleurotus ostreatus. *Applied and Environmental Microbiology*. 62(7) : 2547-2553.

Bills, G. F., Platas, G., Fillola, A., Jiménez, M. R., Collado, J., Vicente, F. and Peláez, F. 2008. Enhancement of antibiotic and secondary metabolite detection from filamentous fungi by growth on nutritional arrays. *Journal of Applied Microbiology*. 104(6) : 1644-1658.

Boer, D. 2018. White-rot fungi as potential bioremediators of endocrine dusrupting compounds-a mini review (Doctoral dissertation, MSc thesis. Wageningen University).

Chaturvedi, V. K., Agarwal, S., Gupta, K. K., Ramteke, P. W. and Singh, M. P. 2018. Medicinal mushroom: boon for therapeutic applications. *3 Biotech.* 8(8): 334.

Chen, H. P. and Liu, J. K. 2017. Secondary metabolites from higher fungi. *Progress in the Chemistry of Organic Natural Products*. 106 : 1-201.

Chowdhury, M. M. H., Kubra, K. and Ahmed, S. R. 2015. Screening of antimicrobial, antioxidant properties and bioactive compounds of some edible mushrooms cultivated in Bangladesh. *Annals of clinical*

Microbiology and Antimicrobials. 14(1) : 8.
Christian, V., Shrivastava, R., Shukla, D., Modi, H. A. and Vyas, B. R. M. 2005. Degradation of xenobiotic compounds by lignin-degrading white-rot fungi: enzymology and mechanisms involved.
Collemare, J. and Seidl, M. F. 2019. Chromatin-dependent regulation of secondary metabolite biosynthesis in fungi: is the picture complete?. *FEMS Microbiology Reviews*. 43(6): 591-607.
Dashtban, M., Schraft, H., Syed, T. A. and Qin, W. 2010. Fungal biodegradation and enzymatic modification of lignin. *International Journal of Biochemistry and Molecular Biology*. 1(1) : 36.
De Boer, W., Folman, L. B., Klein Gunnewiek, P. J., Svensson, T., Bastviken, D., Öberg, G. and Boddy, L. 2010. Mechanism of antibacterial activity of the white-rot fungus Hypholoma fasciculare colonizing wood. canadian *Journal of Microbiology*. 56(5) : 380-388.
De Jong, E. 1993. Physiological roles and metabolism of fungal aryl alcohols. De Jong.
Deacon, J. W. 2013. *Fungal biology*. John Wiley & Sons. USA: Blackwell.
Deveau, A., Kohler, A., FreyKlett, P. and Martin, F. 2008. The major pathways of carbohydrate metabolism in the ectomycorrhizal basidiomycete Laccaria bicolor S238N. *New Phytologist*. 180(2) : 379-390.
Dewick, P. M. 2009. Medicinal plants Ichinose, H. and Kitaoka, T. 2018. Insight into metabolic diversity of the brownrot basidiomycete Postia placenta responsible for sesquiterpene biosynthesis: semicomprehensive screening of cytochrome P450 monooxygenase involved in protoilludene metabolism. *Microbial biotechnology*. 11(5) : 952-965.
Elisashvili, V. I. 2012. Submerged cultivation of medicinal mushrooms: bioprocesses and products. *International Journal of Medicinal Mushrooms*. 14(3).
Farhat, F., Tariq, A., Zikrea, A. and Fatima, R. N. 2018. Diterpenes from Different Fungal Sources and Their. Terpenes and Terpenoids, 111.
Fernando, M. D. M., Wijesundera, R. L. C., Soysa, S. S. B. D. P., de Silva, E. D. and Nanayakkara, C. M. 2016. Antioxidant potential and content of the polyphenolic secondary metabolites of white rot macrofungi; Flavodon flavus (Klotzsch.) and Xylaria feejeensis (Berk.). *SDRP Journal of Plant Science.* 1(1).
Fernando, M., Adhikari, A., Senathilake, N., Silva, E., Nanayakkara, C., Wijesundera, R., Soysa, P. and Silva, B. 2019 In Silico Pharmacological Analysis of a Potent Anti-Hepatoma Compound of Mushroom Origin and Emerging Role as an Adjuvant Drug Lead. *Food and Nutrition Sciences*. 10(11): 1313-1333.
Fonseca, M. I., Zapata, P. D., Villalba, L. L. and Fariña, J. I. 2015. Characterization of the oxidative enzyme potential in wild white rot fungi from the subtropical forest of Misiones (Argentina). *Acta Biològica Colombiana*. 20(1) : 47-56.
Fukushima-Sakuno, E. 2020. Bioactive small secondary metabolites from the mushrooms Lentinula edodes and Flammulina velutipes. *The Journal of Antibiotics*. 73(10) : 687-696.
Gan, R. Y., Chan, C. L., Yang, Q. Q., Li, H. B., Zhang, D., Ge, Y. Y. and Corke, H. 2019. Bioactive compounds and beneficial functions of sprouted grains. *In Sprouted grains* (pp. 191-246). AACC International Press.
Gao, D., Du, L., Yang, J., Wu, W. M. and Liang, H. 2010. A critical review of the application of white rot fungus to environmental pollution control. *Critical Reviews in Biotechnology*. 30(1) : 70-77.
Gasecka, M., Magdziak, Z., Siwulski, M. and Mleczek, M. 2018. Profile of phenolic and organic acids, antioxidant properties and ergosterol content in cultivated and wild growing species of Agaricus. *European Food Research and Technology*. 244 (2) : 259-268.
Gebreyohannes, G., Nyerere, A., Bii, C. and Sbhatu, D. B. 2019. Investigation of antioxidant and antimicrobial activities of different extracts of auricularia and Termitomyces species of mushrooms. *The Scientific World Journal*, 2019.
Glazunova, O. A., Shakhova, N. V., Psurtseva, N. V., Moiseenko, K. V., Kleimenov, S. Y. and Fedorova, T. V. 2018. White-rot basidiomycetes Junghuhnia nitida and Steccherinum bourdotii: Oxidative potential and laccase properties in comparison with *Trametes hirsuta* and *Coriolopsis caperata*. *PloS one*. 13(6): e0197667.
Goodell, B., Winandy, J. E. and Morrell, J. J. 2020. Fungal Degradation of Wood: Emerging Data, New Insights and Changing Perceptions. *Coatings*. 10(12) : 1210.
Gouma, S., Papadaki, A. A., Markakis, G., Magan, N. and Goumas, D. 2019. Studies on pesticides mixture degradation by white rot fungi. *Journal of Ecological Engineering*, 20(2).
Goyal, S., Ramawat, K.G. and Mérillon, J.M. 2016. Different shades of fungal metabolites: an overview. *Fungal Metabolites*. 1: p.29.
Hansson, D. 2013. Structure and biosynthesis of fungal secondary metabolites (Vol. 2013, No. 63).
Hatakka, A. and Hammel, K. E. 2011. Fungal biodegradation of lignocelluloses. *In Industrial applications* (pp. 319-340). Springer, Berlin, Heidelberg.
Heleno, S. A., Ferreira, R. C., Antonio, A. L., Queiroz, M. J. R., Barros, L. and Ferreira, I. C. 2015. Nutritional value, bioactive compounds and antioxidant properties of three edible mushrooms from Poland. *Food Bioscience*. 11 : 48-55.
Hibbett, D.S., Binder, M., Bischoff, J.F., Blackwell, M., Cannon, P.F., Eriksson, O.E., Huhndorf, S., James, T., Kirk, P.M., Lücking, R. and Lumbsch, H.T. 2007. A higher-level phylogenetic classification of the Fungi. *Mycological Research*. 111(5) : 509-547.

Jain, P. and Choudhary, S. 2012. Evaluation of antimicrobial and antioxidant activities and phytochemical analysis of white button mushroom Agaricus bisporus. *Int. J. Pharm. Sci. Rev. Res.* 15(2) : 85-89.

Jaszek, M., Osińska-Jaroszuk, M., Janusz, G., Matuszewska, A., Stefaniuk, D., Sulej, J. and Jarosz-Wilkolazka, A. 2013. New bioactive fungal molecules with high antioxidant and antimicrobial capacity isolated from Cerrena unicolor idiophasic cultures. *BioMed Research International*, 2013.

Jaszek, M., Zuchowski, J., Dajczak, E., Cimek, K., Graz, M., and Grzywnowicz, K. 2006. Ligninolytic enzymes can participate in a multiple response system to oxidative stress in white-rot basidiomycetes: Fomes fomentarius and Tyromyces pubescens. *International Biodeterioration & Biodegradation*. 58(3-4) : 168-175.

Jennison, M. W., Richberg, C. G. and Krikszens, A. E. 1957. Physiology of Wood-rotting Basidiomycetes: II. Nutritive Composition of Mycelium Grown in Submerged Culture1, 2. *Applied Microbiology*. 5(2) : 87.

Jensen, K. A., Evans, K. M., Kirk, T. K. and Hammel, K. E. 1994. Biosynthetic pathway for veratryl alcohol in the ligninolytic fungus Phanerochaete chrysosporium. *Applied and Environmental Microbiology*. 60(2): 709-714.

Jose Alves, M., CFR Ferreira, I., Dias, J., Teixeira, V., Martins, A. and Pintado, M. 2013. A Review on Antifungal Activity of Mushroom (Basidiomycetes) Extracts and Isolated Compounds. *Current Topics in Medicinal Chemistry*. 13(21) : 2648-2659.

Jurado, M., Martinèz, À. T., Martinez, M. J. and Saparrat, M. C. N. 2011. Application of white-rot fungi in transformation, detoxification, or revalorization of agriculture wastes. *Comprehensive Biotechnology*. 6: 595-603.

Kandeler, E. 2007. Physiological and biochemical methods for studying soil biota and their function. In *Soil Microbiology, Ecology and Biochemistry* (pp. 53-83). *Academic Press*.

Keller, N. P., Turner, G. and Bennett, J. W. 2005. Fungal secondary metabolism—from biochemistry to genomics. *Nature Reviews Microbiology*. 3(12) : 937-947.

Kojima, M., Kimura, N. and Miura, R. 2015. Regulation of primary metabolic pathways in oyster mushroom mycelia induced by blue light stimulation: accumulation of shikimic acid. *Scientific Reports*. 5(1) : 1-7.

Koroleva, O. V., Zherdev, A. V. and Kulikova, N. A. 2015. The Role of White-rot Fungi in Herbicide Transformation. Herbicides, *Physiology of Action, and Safety*. Price A., Kelton J., Sarunaite L., InTechOpen, 187-221.

Kuhnert, E., Li, Y., Lan, N., Yue, Q., Chen, L., Cox, R. J. and Bills, G. F. 2018. Enfumafungin synthase represents a novel lineage of fungal triterpene cyclases. *Environmental Microbiology*. 20(9) : 3325-3342.

Lapadatescu, C., Giniès, C., Le Quéré, J. L. and Bonnarme, P. 2000. Novel Scheme for Biosynthesis of Aryl Metabolites from l-Phenylalanine in the FungusBjerkandera adusta. *Applied and Environmental Microbiology*. 66(4) : 1517-1522.

Lee, M. K. 2005. Application of White-rot Fungi for the biodegradation of natural organic matter in wastes (Doctoral dissertation, RMIT University, Victoria).

Lee, S. Y., Kim, M., Kim, S. H., Hong, C. Y., Ryu, S. H. and Choi, I. G. 2016. Transcriptomic analysis of the white rot fungus Polyporus brumalis provides insight into sesquiterpene biosynthesis. *Microbiological Research*. 182 : 141-149.

Lima, C. U., Gris, E. F. and Karnikowski, M. G. 2016. Antimicrobial properties of the mushroom Agaricus blazei–integrative review. *Revista Brasileira de Farmacognosia*. 26(6) : 780-786.

Lin, H. C., Hewage, R. T., Lu, Y. C. and Chooi, Y. H. 2019. Biosynthesis of bioactive natural products from Basidiomycota. *Organic & Biomolecular Chemistry*. 17(5) : 1027-1036.

Luna-Acosta, A., Saulnier, D., Pommier, M., Haffner, P., De Decker, S., Renault, T., & Thomas-Guyon, H. 2011. First evidence of a potential antibacterial activity involving a laccase-type enzyme of the phenol oxidase system in Pacific oyster Crassostrea gigas haemocytes. *Fish & Shellfish Immunology*. 31(6): 795-800.

Magan, N. 2008. Ecophysiology: impact of environment on growth, synthesis of compatible solutes and enzyme production. *Ecology of Saprotrophic Basidiomycetes.* 63-78.

Mattila, H. K., Mäkinen, M. and Lundell, T. 2020. Hypoxia is regulating enzymatic wood decomposition and intracellular carbohydrate metabolism in filamentous white rot fungus. *Biotechnology for Biofuels*. 13(1): 1-17.

Matuszewska, A., Stefaniuk, D., Jaszek, M., Piêt, M., Zaj¹c, A., Matuszewski, L. and Bancerz, R. 2019. Antitumor potential of new low molecular weight antioxidative preparations from the white rot fungus Cerrena unicolor against human colon cancer cells. *Scientific Reports*. 9(1): 1-10.

Mohapatra, D., Rath, S. K. and Mohapatra, P. K. 2018. Bioremediation of insecticides by white-rot fungi and its environmental relevance. *In Mycoremediation and Environmental Sustainability* (pp. 181-212). Springer, Cham.

Moore, D., Robson, G. D. and Trinci, A. P. 2020. *21st century guidebook to fungi*. Cambridge University Press.

Morales, J. C. and Lucas, R. 2010. Structure–Activity relationship of phenolic antioxidants and olive components. *In Olives and olive oil in health and disease prevention* (pp. 905-914). Academic Press.

Moreira, M. T., Feijoo, G. and Lema, J. M. 2003. Fungal bioreactors: applications to white-rot fungi. *Reviews* *in Environmental Science and Biotechnology*. 2(2-4), 247-259.

Nielsen, J. C. 2018. Systems Biology of the Secondary Metabolism in Filamentous Fungi. Chalmers Tekniska Hogskola (Sweden).

Nofiani, R., de Mattos-Shipley, K., Lebe, K. E., Han, L. C., Iqbal, Z., Bailey, A. M. and Cox, R. J. 2018. Strobilurin biosynthesis in Basidiomycete fungi. *Nature Communications*. 9(1) : 1-11.

Nord, C. 2014. Secondary metabolites from the saprotrophic fungus Granulobasidium vellereum (Vol. 2014, No. 88).

Nowicka, B. and Kruk, J. 2010. Occurrence, biosynthesis and function of isoprenoid quinones. *Biochimica et Biophysica Acta (BBA)-Bioenergetics*. 1797(9) : 1587-1605.

Osinka-Jaroszuk, M., Jarosz-Wilko³azka, A., Jaroszuk-Œcise³, J., Sza³apata, K., Nowak, A., Jaszek, M. and Majewska, M. 2015. Extracellular polysaccharides from Ascomycota and Basidiomycota: production conditions, biochemical characteristics, and biological properties. *World Journal of Microbiology and Biotechnology*. 31 (12) : 1823-1844.

Rahi, D. K. and Malik, D. 2016. Diversity of mushrooms and their metabolites of nutraceutical and therapeutic significance. *Journal of Mycology*. 2016.

Rajasekar, S., Selvakumar, P., Periasamy, K. and Raaman, N. 2008. Polysaccharides from Basidiomycetes: A promising Source for Immunostimulating and Anticancerous activity. Biotechnology: Concepts and Applications, *Narosa Publishing House*, 232-269.

Remya, V. R., Chandra, G. and Mohanakumar, K. P. 2019. Edible Mushrooms as Neuro-nutraceuticals: Basis of Therapeutics. *In Medicinal Mushrooms* (pp. 71-101). Springer, Singapore.

Rezaeian, S., Saadatmand, S., Sattari, T. N. and Mirshamsi, A. 2016. Antioxidant potential and other medicinal properties of edible mushrooms naturally grown in Iran.

Riley, R., Salamov, A. A., Brown, D. W., Nagy, L. G., Floudas, D., Held, B. W. and Lindquist, E. A. 2014. Extensive sampling of basidiomycete genomes demonstrates inadequacy of the white-rot/brown-rot paradigm for wood decay fungi. *Proceedings of the National Academy of Sciences*. 111(27) : 9923-9928.

Rodríguez-Couto, S. 2017. Industrial and environmental applications of white-rot fungi. *Mycosphere*, 8(3), 456-466.

Roman, M. P. G., Mantilla, N. B., Florez, S. A. C., De Mandal, S., Passari, A. K., Ruiz-Villáfan, B. and Sánchez, S. 2020. Antimicrobial and Antioxidant Potential of Wild Edible Mushrooms. *In An Introduction to Mushroom*. Intech Open.

Sanchez, S. and Demain, A. L. 2008. Metabolic regulation and overproduction of primary metabolites. *Microbial Biotechnology*. 1(4) : 283-319.

Schu, A. and Anke, T. 2009. 10 Secondary Metabolites of Basidiomycetes. *The Mycota*, 209.

Sevindik, M. 2018. Investigation of antioxidant/oxidant status and antimicrobial activities of Lentinus tigrinus. *Advances in Pharmacological Sciences*. 2018.

Sevindik, M. 2019. Antioxidant and antimicrobial activity of Cerrena unicolor. *Mycopath*. 16(1).

Shah, M. M., Barr, D. P., Chung, N. and Aust, S. D. 1992. Use of white rot fungi in the degradation of environmental chemicals. *Toxicology Letters*. 64 : 493-501.

Sharma, D., Pramanik, A. and Agrawal, P. K. 2016. Evaluation of bioactive secondary metabolites from endophytic fungus Pestalotiopsis neglecta BAB-5510 isolated from leaves of Cupressus torulosa *D. Don. 3 Biotech*. 6(2): 210.

Sharma, J., Tripathi, A., Kumar, P., Sharma, I., Thakur, M., Thakur, N. and Singh, S. 2017. Study Of Antibacterial And Phytochemical Properties Of White Rot Fungi Collected From North Western Region Of Himachal Pradesh.

Shu, C. H. 2007. Fungal fermentation for medicinal products. In Bioprocessing for Value-Added Products from Renewable Resources (pp. 447-463). Elsevier.

Smith, H. A. 2014. Production of antimicrobials and antioxidants from filamentous fungi (Doctoral dissertation, National University of Ireland Maynooth).

Srikram, A. and Supapvanich, S. 2016. Proximate compositions and bioactive compounds of edible wild and cultivated mushrooms from Northeast Thailand. *Agriculture and Natural Resources*. 50(6) : 432-436.

Stergiopoulos, I., Collemare, J., Mehrabi, R. and De Wit, P. J. 2013. Phytotoxic secondary metabolites and peptides produced by plant pathogenic Dothideomycete fungi. *FEMS Microbiology Reviews*. 37(1) : 67-93.

Swann, E. and Hibbett, D. S. 2007. Basidiomycota. *The Club Fungi*.

Thirumurugan, D., Cholarajan, A., Raja, S. S. and Vijayakumar, R. 2018. An introductory chapter: secondary metabolites. *Second metab—sources Appl*, 1-21.

Tian, M., Zhao, P., Li, G. and Zhang, K. 2020. In Depth Natural Product Discovery from the Basidiomycetes Stereum Species. *Microorganisms*. 8(7) : 1049.

Tisma, M., Zelic, B. and Vasic-Racki, Đ. 2010. White-rot fungi in phenols, dyes and other xenobiotics treatment–a brief review. *Croatian Journal of Food Science and Technology*. 2(2.): 34-47.

Titas, G., Aparajita, S. and Arpita, D. 2019. Nutrition, Therapeutics and Environment Impact of Oyster Mushrooms: A Low Cost Proteinaceous Source. *J Gynecol Women's Health*. 14(1): 555876.

Tolera, K. D. and Abera, S. 2017. Nutritional quality of Oyster Mushroom (Pleurotus Ostreatus) as affected by osmotic pre-treatments and drying methods. *Food Science & Nutrition*. 5(5) : 989-996.

Tuomela, M. and Hatakka, A. 2019. Oxidative fungal enzymes for bioremediation. In Comprehensive Biotechnology: *Environmental and Related Biotechnologies* (pp. 224-239). Elsevier.

Ukwuru, M. U., Muritala, A. and Eze, L. U. 2018. Edible and non-edible wild mushrooms: Nutrition, toxicity and strategies for recognition. *J. Clin. Nutr. Metab.* 2.

Valiante, V. 2017. The cell wall integrity signaling pathway and its involvement in secondary metabolite production. *Journal of Fungi*. 3(4): 68.

Valverde, M. E., Hernández-Pérez, T. and Paredes-López, O. 2015. Edible mushrooms: improving human health and promoting quality life. *International Journal of Microbiology*, 2015.

Verduzco-Oliva, R. and Gutierrez-Uribe, J. A. 2020. Beyond Enzyme Production: Solid State Fermentation (SSF) as an Alternative Approach to Produce Antioxidant Polysaccharides. *Sustainability*. 12(2) : 495.

Wang, Q., Qian, Y., Ma, Y. and Zhu, C. 2018. A Preliminary Study on the Newly Isolated High Laccase-producing Fungi: Screening, Strain Characteristics and Induction of Laccase Production. *Open Life Sciences*. 13(1) : 463-469.

Wang, Q., Wang, F., Xu, Z. and Ding, Z. 2017. Bioactive mushroom polysaccharides: a review on monosaccharide composition, biosynthesis and regulation. *Molecules*. 22(6) : 955.

Webster, J. and Weber, R. 2007. *Introduction to fungi*. Cambridge University Press.

Xiao, H. and Zhong, J. J. 2016. Production of useful terpenoids by higher-fungus cell factory and synthetic biology approaches. *Trends in Biotechnology*. 34(3) : 242-255.

Xu, J. 2010. Secondary metabolites from the endophytic fungus Pestalotiopsis sp. JCM2A4 and its microbe-host relationship with the mangrove plant Rhizophora Mucronata (Doctoral dissertation).

Yaoita, Y., Kikuchi, M. and Machida, K. 2015. Terpenoids and sterols from mushrooms. *In Studies in Natural Products Chemistry* (Vol. 44, pp. 1-32). Elsevier.

Yilkal, T. 2015. Role of White Rot Fungi as a Biological Treatment of Low Quality Animal Feeds: Review. *Scholarly Journal of Agricultural Science*. 5(7): 247-255.

Yogita, R., Simanta, S., Aparna, S., Shraddha, G. and Kamlesh, S. 2011. Screening for exopolysaccharide production from basidiomycetes of chhattisgarh. *Current Botany*.

Zahmatkesh, M., Spanjers, H. and van Lier, J. B. 2018. A novel approach for application of white rot fungi in wastewater treatment under non-sterile conditions: immobilization of fungi on sorghum. *Environmental Technology*. 39(16) : 2030-2040.

Zhong, J. J. and Xiao, J. H. 2009. Secondary metabolites from higher fungi: discovery, bioactivity, and bioproduction. *In Biotechnology in China* I (pp. 79-150). Springer, Berlin, Heidelberg.

Zuleta-Correa, A., Merino-Restrepo, A., Hormaza-Anaguano, A. and Gallo, S. A. C. 2016. Use of white rot fungi in the degradation of an azo dye from the textile industry. *Dyna*. 83(198) : 128-135.