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Review

Green Biotechnology of Oyster Mushroom (*Pleurotus ostreatus* L.): A Sustainable Strategy for Myco-Remediation and Bio-Fermentation

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Abstract: The field of biotechnology presents us with a great chance to use many organisms, such as mushrooms, to find suitable solutions for issues that include the accumulation of agro-wastes in the environment. The green biotechnology of mushrooms (*Pleurotus ostreatus* L.) includes the myco-remediation of polluted soil and water as well as bio-fermentation. The circular economy approach could be effectively achieved by using oyster mushrooms (*Pleurotus ostreatus* L.), of which the substrate of their cultivation is considered as a vital source for producing biofertilizers, animal feeds, bioenergy, and bio-remediators. Spent mushroom substrate is also considered a crucial source for many applications, including the production of enzymes (e.g., manganese peroxidase, laccase, and lignin peroxidase) and bioethanol. The sustainable management of agro-industrial wastes (e.g., plant-based foods, animal-based foods, and non-food industries) could reduce, reuse and recycle using oyster mushrooms. This review aims to focus on the biotechnological applications of the oyster mushroom (*P. ostreatus* L.) concerning the field of the myco-remediation of pollutants and the bio-fermentation of agro-industrial wastes as a sustainable approach to environmental protection. This study can open new windows onto the green synthesis of metal-nanoparticles, such as nano-silver, nano-TiO_2 and nano-ZnO. More investigations are needed concerning the new biotechnological approaches.

Keywords: agro-industrial residues; waste recycling; pollutants; bio-fermenter; myco-remediator; white-rot fungi

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1. Introduction

Green biotechnology is the use of scientific techniques and tools, including molecular markers, genetic engineering, molecular diagnostics and tissue culture, on plants; it is called red biotechnology in the medical field and white biotechnology in the industrial field [1]. Fungi have several applications in agricultural and environmental sustainability, which can support the growth of plants, such as mycorrhizal association [2], for human nutrition, including edible mushrooms [3,4]. Arbuscular mycorrhizal fungi can also be utilized to sustain and improve soil health [5]. Fungi, such as mushrooms, are important plants, which can be consumed due to their nutritional benefits (as edible mushrooms) and their medicinal values (as medicinal mushrooms) since time immemorial [6]. Many applications of mushrooms were confirmed by researchers, such as their valuable biotechnological properties [7,8], the sustainability of the mushroom industry through a zero waste and circular bioeconomy [9], and myco-remediation [10].

The genus *Pleurotus* is considered as the second most cultivated and distributed edible mushroom all over the world after the champignon mushroom (*Agaricus bisporus*), because of its adaptation capability [11–13]. The mushrooms of *Pleurotus* are characterized by several valuable medical, biotechnological, and nutritional attributes. Numerous studies have reported the many relevant features of the *Pleurotus* genus, which confirmed their attractive low-cost industrial tools that resolve the pressure of ecological issues [7,11,12,14–17]. These issues may include the production of enzymes (oxidases and hydrolases) and biomass from fruit residues using *Pleurotus* spp. [18], bioethanol production [19], the biodegradation of pollutants [20,21], and medicinal attributes [6]. This genus is also characterized by its high content of fatty acids, steroids, and polysaccharides, which can produce a lot of bioactive molecules and has become a popular functional food [15]. Additionally, a number of *Pleurotus* species are highly adaptive, possess specific resistance to pests and polluted diseases, and they do not require any specific conditions for their growth [7]. *P. ostreatus* is an important member of the *Pleurotus* species, which has significant medicinal importance and nutritional values [22] due to its anti-oxidative, anti-carcinogenic, anti-inflammatory, anti-hypercholesteremic, anti-viral, and immune-stimulating properties [11].

Therefore, this review is an attempt to highlight *Pleurotus* as an important genus of mushrooms. Different features of *Pleurotus* genus are discussed with special focus on *Pleurotus ostreatus*. Many biotechnological features of *P. ostreatus* are debated, including its role as a myco-remediator, a bio-degrader of organic solid wastes, and its use in bioethanol and enzyme production.

2. Methodology

The present review was created by collecting the required information from different databases, including ScienceDirect, Springer link, and PubMed. The strategy for this review depended on the collection of information from different databases during certain periods, especially during the last 15 years, for obtaining the latest information. To obtain the required information, we selected the suitable keywords, which we inserted into the website of each database, and then selected the suitable literatures based on three criteria: the high-impacted journals, the up-to-date publications (with a preference for the publication years of 2022, 2021, and 2020), and the reputation of the scientist or researcher of the published materials. The most important aim of the present review is to create a strong and attractive table of contents (TOC), which mainly depends on the main objective of this review. After preparing the TOC, which can be changed according the availability of information, different sections of the review can be created. The main keywords depend on the section, for example, for the section titled "Food importance of *Pleurotus genus*", the key words are "food", "*Pleurotus*", and "nutritional value". The second aim in editing the review is the presence of Tables and Figures, which need the precise evaluation of the information, summaries, and presentation of the output of the authors. A significant amount of experience is needed to edit the review, as well as the knowledge of how to support the perspectives of the readers using the correct arguments. Harmony between the structure of the review's TOC is also needed. The building of survey tables for discussing the ideas presented in the review is also required. The review should depend on all published materials, including original articles, reviews and book chapters. The total number of cited literatures should be significant, and some journals require at least 50 references in a review, but a larger quantity is preferable.

3. The Genus *Pleurotus* and Its Potential Uses

3.1. Taxonomy and Botanical Description

The Pleurotus species belongs to the Kingdom of Fungi, Phylum of Basidiomycota, Class of Agaricomycetes, Order of Agaricales, Family of Pleurotaceae, and the Genus of Pleurotus [23] (Figure 1). Pleurotus species, such as many species of mushrooms, include cultivated and wild mushrooms, which are dominant in many forests worldwide. *Pleurotus* was first scientifically described in 1775 and, in 1871, the German mycologist Paul Kummer transferred the oyster mushroom to the genus *Pleurotus.* This is a new genus defined by Kummer himself in 1871 and is the currently accepted scientific name. Pleurotus ostreatus grows throughout the United Kingdom, Ireland, and most parts of Europe. It is also widely distributed in many parts of Asia, including Japan, and is located in parts of North America [24].

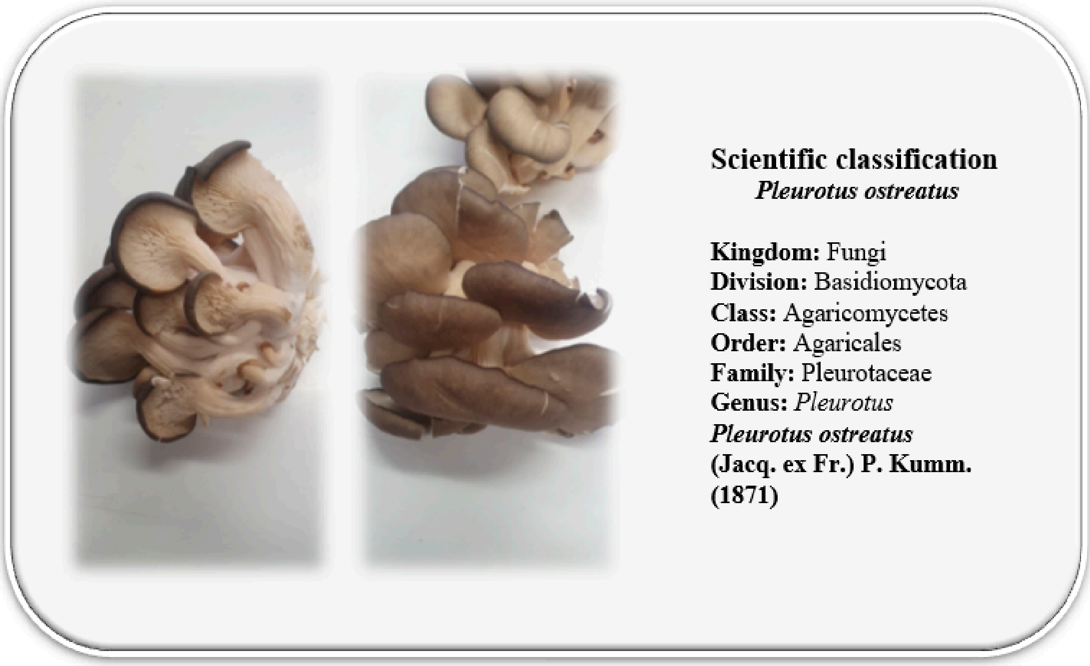

Figure 1. Photos of *Pleurotus ostreatus* and the scientific classification of this mushroom. (Photos were taken by Gréta Törős, Debrecen University, Hungary).

3.2. Food Importance of the Pleurotus Genus

The genus *Pleurotus* includes more than 200 species, which are consumed worldwide as edible mushrooms with an annual increase of 15%, and *Pleurotus* is considered as the second most commonly consumed mushrooms [25]. Some representatives of this genus (e.g., the oyster mushroom or *P. ostreatus*) are well known for their odor, flavor, nutraceutical value, and gastronomic properties, which are important to several consumers [26]. Thus, the edible mushroom of *P. ostreatus* has been used as a source of food additives due to its high content of antioxidants, bioactives, and β-glucans [25,27]. Due to their contents of minerals, fibers, lipids, and vitamins, *Pleurotus* mushrooms have become increasingly appealing as functional foods [16]. Different species of *Pleurotus* mushrooms and the chemical composition of their nutritional values, including moisture, proteins, carbohydrates, fats, ash and fiber, are presented in Table 1. Based on this Table, the highest content of crude proteins (30 and 35.5%, respectively) was recorded for the *Pleurotus citrinopileatus* and *P. djamor var. roseus* mushrooms, whereas the *P. eryngii* mushroom had the highest fiber content (28.29%).

Table 1. The nutritional content (as % or g/100 g of dried mushrooms) of some *Pleurotus* spp. mushrooms from different sources.

Pleurotus spp.	Moisture (%)	Proteins (%)	Carbohydrates (%)	Fats (%)	Ash (%)	Fiber (%)	Refs.
Pleurotus ostreatus	90.7	18.3	71.25	2.58	7.82	14.31	[28]
Pleurotus eryngii	91.0	11.9	39.85	7.50	4.89	28.29	[29]
Pleurotus eryngii	88	20	53	2.8	7.5	7.5	[30]
Pleurotus eryngii	88	18.8	57	2.3	5.5	10	[31]
P. citrinopileatus	88.9	30.0	42.50	3.90	7.65	20.78	[32]
Pleurotus flabellatus	91.0	21.6	57.40	1.80	10.7	11.90	[33]
P. djamor var. roseus	79.5	35.5	44.75	1.72	5.90	14.60	[34]
Pleurotus pulmonarius	78.8	20.3	34.00	2.62	7.33	9.00	[35]
Pleurotus djamor	86.8	24.1	45.59	4.73	9.84	15.91	[36]
Pleurotus tuber-regium	87.1	22.1	63.03	1.06	2.97	10.86	[37]
Pleurotus florida	87.5	20.5	42.83	2.31	9.02	11.50	[38]
Pleurotus sajor-caju	87.0	24.6	39.82	2.29	8.28	10.90	[39]
Pleurotus cystidiosus	91.1	15.6	55.92	2.05	6.30	20.05	[22]

In 2017, the world production of *P. ostreatus* was approximately 4.1 million tons. Similar to many oyster mushrooms, *P. ostreatus* is cultivated for foods and medicinal purposes. It can be cultivated on different lignocellulosic substrates, including maize cobs, wheat straw, sawdust, or cotton waste [40]. *Pleurotus* spp. can colonize and bio-degrade a large variety of lignocellulosic wastes, as a result of their ability to produce many ligninolytic enzymes [40]. *Pleurotus* mushrooms have been used for their high nutritive content and their potential biotechnological and environmental applications.

3.3. Medicinal Importance of the Pleurotus Genus

This genus includes more than 40 species, commonly referred to as the "Oyster mushroom", including *P. ostreatus* and *P. eryngii*, which has attracted special attention because of its high nutritional values and medicinal attributes [11,12]. It is well known for its anti-oxidative, anti-carcinogenic, anti-inflammatory, anti-viral, anti-hypercholesteremic, and immune-stimulating properties, as well as its ability to regulate glucose levels and blood lipids [11,12]. Table 2 lists the bioactive compounds and their activities, which are dominant in *Pleurotus ostreatus* and their mode of actions or mechanisms [41].

Table 2. Different bioactive compounds of *Pleurotus ostreatus* and their mode of actions.

Activity	Bioactive Compound	Mode of Action	Refs.
Anti-oxidative	Lectins	The dendritic cells were activated using the pathway of "Toll-like receptor 6 signal"	[42]
	Polysaccharides	Increasing the activities of SOD, CAT, GST, GR, APx and reducing superoxide radicals, and the activity of GPx	[43]
	Phenols	Inhibits the growth of HL-60 cells by inducing apoptosis	[44]
	Flavonoids, ascorbic acid and β-carotene	Induces apoptosis by inhibiting HL-60 cell growth	[44]
	Vitamin E	Lipid peroxidation is prevented in cell membranes	[43]
Immuno-modulatory	Polysaccharides	The toxicity of cyclophosphamide in mice was decreased due to the immune-modulatory activity	[43]
Anti-inflammatory	Polysaccharides (β-glucans)	Methotrexate may have a synergistic effect on the arthritis of rats	[45]

Table 2. *Cont.*

Activity	Bioactive Compound	Mode of Action	Refs.
Anti-hypercholesterolemic	Statins (lovastatin)	In the cholesterol synthesis pathway, 3-hydroxy-3-methyl-glutaryl coenzyme A reductase is inhibited due to the conversion of enzymes to mevalonic acid	[46]
	Flavons (chrysin)	Non-enzymatic antioxidant parameters in hypercholesterolemic rats, the blood/serum levels of lipid profile parameters and hepatic marker enzymes decreased	[47]
Anti-cancer and anti-tumor	Polysaccharides	In HeLa cell lines, cytotoxic activity inhibited the development of Ehrlich Tumor and Sarcoma 180 (S-180)	[45,48]
	Pleuran (β-glucan)	Anti-neoplastic properties of different cells (breast, colorectal and prostate cancers)	[48]
	Proteins	In cell line SW 480, therapeutic effects on colorectal cancer and monocytic leukemia by inducing apoptosis	[48]
	Lectins	Tumor burden in Sarcoma S180 reduced by 88.4% and hepatoma H-22 by 75.4% in mice; increase in survival time	[45]
Anti-viral and anti-microbial	Laccase	Anti-viral effects against hepatitis C	[48]
	Ubiquitin-like protein	Anti-viral effects in human immunodeficiency viruses, such as HIV-1	[45]
	Nanoparticles mixed with aqueous extract	Inhibiting the growth of Gram-negative bacteria	[45]
	Ribonucleases	Degradation of viral genetic materials to neutralize HIV	[49]
Hepatoprotective	Poly-saccharopeptides	Thioacetamide is alleviated, inducing alterations in inflammation, steatosis, fibrosis and necrosis	[49]
Anti-aging	Mushroom powder	Significant bifidogenic and then strong lactogenic effects	[50]

Abbreviations: HIV-1 (human immunodeficiency viruses), SOD (superoxide dismutase), CAT (catalase), APX (ascorbate peroxidase), GR (glutathione reductase), GST (glutathione S-transferases).

4. General Features of *Pleurotus ostreatus*

Pleurotus ostreatus is found in dead and living tree branches, especially hornbeam (*Carpinus* sp.), beech (*Fagus* sp.), willow (*Salix* sp.), poplar (*Populus* sp.), birch (*Betula* sp.) and the common walnut (*Juglans regia*) trees [51]. This species produces grouped fruiting bodies of various sizes, similar to oyster mushroom colonies. The fruiting body is pink, gray-to-dark brown, and is 4 to 15 cm in size. In the wild, its offspring generally appear between October and November (Figure 2). However, they can be encountered in mild winters or in early, warm springs. Their cap is 3–15 cm in diameter; broadly convex, flat or depressed flat; kidney shaped-to-fan shaped in outline, or nearly spherical when growing on tree trunks; young and fresh and somewhat greasy; bald; pale-to-dark brown; fade to buff; sometimes slowly fading and becoming two-toned; and the edge is slightly curled when young [52]. Gills can run down the trunk (or pseudo stem); close, short gills are common; and can be whitish or grayish, turning yellowish with age and sometimes with brownish edges [52]. A salient feature of these gilled mushrooms is their ability to capture and feed nematodes to the gills using a "lasso" made of hyphae. Their stem is whitish, hairy to velvety, and hard. Moreover, their flesh is thick, white and unchanging when cut.

These mushrooms are edible, in addition to having several important applications in biotechnological [7], nutraceutical [15,22,53], medicinal [54–57], and environmental fields [12,58]. Due to their exceptional ligninolytic attributes, the *Pleurotus* genus is considered as one of the most extensively investigated types of white-rot fungi. These species also have a significant role in the global initiative towards the "zero waste economy", as a result of their ability to convert or biodegrade waste for biomass production using various enzyme properties, such as endoglucanase and laccase [12]. This distinguished role of *Pleurotus* spp. in the biodegradation of agro-industrial residues has been confirmed by many published reports, such as those published by Kumla et al. [59], Mahari et al. [60], Durán-Aranguren et al. [18], Ogidi et al. [61], Caldas et al. [15], and Melanouri et al. [11,12,30,31,62].

Figure 2. The cultivation of oyster (*Pleurotus ostreatus*) mushrooms, the mushroom-fruiting basic processes, and how to produce a *Pleurotus* inoculant on a millet substrate are presented in photos 1 to 6. The mushroom fungi (*Pleurotus ostreatus*) culture should first be ready on the surface of the agar plate (photo 1); the cultivation substrates of oyster mushrooms are ready (photo 2); tools for the propagation of the mushroom and poured media (heat treated at 95 °C for 1 day); inoculant should be prepared, and a jar with boiled millet and oyster culture (photo 3); the millet spawn in the jar and culture media (photos 4 and 5); and finally we obtain the oyster mushroom. (These steps were photographed in the factory of "Magyar Gomba Kertész Kft.", whereas all photos were taken by Gréta Törős, Debrecen University, Hungary).

In the *Pleurotus* mushroom cultivation industry, it is important to meet the increased demands of human consumption of *Pleurotus* mushrooms, for which new methods of mushroom cultivation are needed to reduce global waste and increase mushroom productivity [34,60]. The cultivation of *Pleurotus* mushrooms depends on both intrinsic factors (i.e., substrate type, pH, C:N ratio, levels of spawning, surfactants, the content of N, C and moisture) and extrinsic factors, which include temperature, relative humidity, luminosity, air composition, and light [30,31,36,58,60,62,63]. The growth and cultivation of mushrooms can be achieved using growth media or substrates, which have a vital impact on the functional, chemical, and sensorial characteristics of mushrooms [58,64,65]. Solid substrates can be used traditionally in cultivating many species of mushrooms for fruiting body formation, which usually needs several months with a non-stable quality of harvested materials [66]. The technology of solid phase cultivation in the bioreactors of mushrooms can reduce the required time for producing the biomass, depending on the control of several physical process parameters, such as the aeration temperature and pH [66]. This technology may include the production of mushrooms in submerged liquid culture or sterilized solid substrates inside static or mixed chambers with a reduced amount of water, compared to submerged liquid cultivations, which allows for a nature-like growth of mycelium on the substrate [66].

5. Myco-Remediation by *Pleurotus ostreatus*

Environmental pollution is a global unsolved health issue, which requires advanced strategies through the remediation of soil, water, sediment, and air. This pollution can result from organic pollutants, such as petroleum [67], or inorganic pollutants, such as metal/metalloids (i.e., lead) [68]. These pollutants represent a potential threat to human health, which needs bioremediation by micro-organisms (bacterial, fungi, and algae), phytoremediation by plants, or nano-bioremediation by micro-organisms in the presence of nanoparticles. Myco-remediation is the process that can remediate or bio-degrade pollutants using fungi, such as mushrooms, through many mechanisms, such as biosorption, bioaccumulation, bioconversion, and biodegradation. Myco-remediation is also eco-efficient and an ecologically sound approach to counter the escalating crisis of terrestrial and aquatic pollution [69]. Myco-remediation has many advantages of biodegradation, such as the ability to oxidize pollutants, a safe and low cost, the production of diverse coupling products, the efficient production of biodiesel, and a tolerance under conditions of salinity, whereas the disadvantages include the necessity for nutrient addition, its inability to remove toxicity, its long depletion period, and the necessity for immobilization [70]. The previous advantages of mushrooms are mainly to the result of their immense hyphal networks, which strengthen growth through the production of multi-purpose extracellular enzymes, increasing the surface area-to-volume ratio, increasing the capabilities towards complex contaminants, enhancing the adaptability to fluctuating temperatures and pH, and possessing a metal-binding protein [71]. It is worth mentioning that the myco-remediation of different environmental pollutants can be applied for the removal or biodegradation of polluted soil and water via certain mechanisms, including biodegradation, biosorption, biotransformation, bioaccumulation, bioconversion, precipitation, and surface sequestration [69,72,73]. More details concerning these mechanisms and a comparison between them is presented in Table 3.

Table 3. A comparison between the different myco-remediation mechanisms.

Approach or Mechanism	Kinds of Pollutants	Advantages	Disadvantages	Refs.
Biosorption	Mainly metal pollutants	Simple process; highly cost-effective way to produce biomass; removes various HMs at the same time without using chemicals	Many adsorbent types are required; reversible sorption of metals on biomass; suffers from the saturation and clogging of reactors; expensive regeneration	[74]
Bioaccumulation or precipitation	All pollutants	To remediate wastewater, it is the simplest and cheapest method; very efficient for removing sulfides and metals; non-selective of metals; does not require chemicals	A difficult method to maintain; the key for success by precipitation is the genetic engineering; the oxidation step is required for complex metals	[75]
Biotransformation or bioconversion	Agro-industrial wastes by biological catalysts	It is a time-saving technology and has low operational control; produces biodegradable compounds by green chemistry	Depending on enzymes (high cost), biocatalysts require narrow operation parameters, which are susceptible to the inhibition of products or substrates	[76]
Biodegradation	Pollutants from human activities	High reduction pollutant rate; can be used in entirely polluted areas depending upon its characteristics; economically viable; can clean-up with time	Removing other beneficial elements during the natural attenuation of pollutants, the mobility and toxicity of pollutants may be too high; monitoring and groundwater controls are required	[77]

Source: extracted from Kumar et al. [69] and Yadav et al. [72].

Several studies reported about the myco-remediation of the *Pleurotus* genus for different pollutants, such as petroleum solid wastes [78], industrial wastes [79], perfluoroalkyl substances, pharmaceuticals [80], chlorinated pesticides [81], and sulfonamides by myco-degradation [82]. Several mushrooms as fungi have the ability to bioremediate the polluted environments through their ubiquitous nature and their efficient enzymatic machinery for the biodegradation and biotransformation of toxic pollutants [81]. Furthermore, myco-remediation can be achieved by biosorption through the removal of dyes, metals, or organic pollutants by the process presented in [81]. The ability of *Pleurotus ostreatus* in the myco-remediation of pollutants in different media has been reported in many studies, as presented in Table 4. Different factors controlling myco-remediation by *Pleurotus ostreatus* are presented in this table, including the substrate, growth conditions, and the kinds of pollutants, and their concentrations. The biodegradation of pollutants by *Pleurotus ostreatus* mainly depends on many factors, including the growth conditions and the kinds of pollutants, and the mechanism of this process is linked to certain enzymes, such as manganese peroxidase, lignin peroxidase, and laccase [21] Many studies discussed the role of *Pleurotus ostreatus* in the myco-remediation process via the consideration of different perspectives, such as the myco-remediation of chlorinated pesticides [81], the accumulation of metals in fruiting bodies [83], and the biodegradation of decabromodiphenyl ethane [21], as well as including some reviews that include those published by Akhtar and Mannan [84], Pini and Geddes [85], Kumar and Dwivedi [86], and Yadav et al. [72].

Table 4. The myco-remediation of pollutants by the fungi of *Pleurotus ostreatus* in different media.

Pollutant Details	Growth Conditions	The Main Findings or the Mechanism	Refs.
Decabromo-diphenyl ethane (5, 20 mg L^{-1})	Biodegradation after 120 h	Biodegradation of pollutants by enzyme P450, manganese peroxidase, lignin peroxidase, and laccase	[21]
Cytostatic drugs include vincristine and bleomycin (5, 10 and 15 mg L^{-1})	Cultivated in liquid medium for 30 days before the test	Studied drugs as anticancer treatments can be removed by biosorption on fungal biomass during wastewater treatment	[87]
Sulfonamide antibiotics (0.1 mM)	Biodegradation after 14 d in polluted wastewater	Mushrooms as biofilters removed sulfonamides by up to 83–91% of the applied doses over 14 d from polluted wastewater	[88]
Cadmium at doses ranging from 0.5 to 20 mg L^{-1} Cd	Removal rate up to 54.6% for 7 days	Cd detoxification pathways included 26 enzymes, including catalase, superoxide dismutase, and peroxisomal enzymes	[89]
Petroleum hydrocarbons in soils (339 g kg^{-1} dry weight) for 90 days	Mushroom spawn (10 g) added to pot (1.5 kg soil)	Myco-remediation efficiency was 85% from polluted soil, depending on the type of substrates and application method	[90]
Organic micro-pollutants, such as diclofenac and bicalutamide	Substrate content was 200 g L^{-1} during 14 and 36 d	Removal efficiency of bicalutamide, lamotrigine, and metformin was 43%, 73%, and 59%, respectively, from water	[91]
Chloro-hydroxyl-actones	Culture medium for 72 h	Mushroom bio-transformed bicyclic halolactones to chlorolactones	[92]
Triclosan (5, 10, 20, 30, and 50 mg L^{-1})	Biodegradation at 4, 7, and 10 days in liquid medium	Complete biodegradation within the first day of sampling through manganese peroxidase and laccase activity	[93]
Pesticide of carbendazim residue (up to 25 days) using wheat straw	Biodegradable in spawned bags (at 22–26 °C)	Mushroom can bioremediate both thiophanate-methyl (up to 60 ppm) and fungicides with a similar chemistry	[94]
Polychlorinated biphenyls (PCBs at 0.1–1.0 µg L^{-1})	Contaminated groundwater for 30–71 days	Spent oyster substrate degraded PCBs and aerobic and/or anaerobic bacteria (87 %)	[95]
Lamotrigine, $C_9H_7Cl_2N_5$ (100 mg L^{-1})	Transformation on culture medium within 20 days	Oxidation of cytochrome P450, where, after 10 days, ~50% of the pollutant was removed	[96]
Polycyclic aromatic hydrocarbons (50 mg L^{-1})	Biodegradative effect up to 14 d in liquid medium	Naphthalene was completely degraded within 5 days (86.47%) by laccase or dioxygenase and ligninolytic enzymes	[97]
Applied cobalt (Co) of up to 20 mg kg^{-1} to the soil	Spent mushroom substrate for 30 d in fluvo-aquic soil	Mushroom reduced Co phyto-availability if added to cultivated soil at a range of 8.86 to 9.51 g kg^{-1} with pakchois plants	[98]
Lead (Pb) from liquid media	Removal rate of Pb was 53.7%	Mushroom removed Pb by biosorption, precipitation, and bioaccumulation	[99]

6. Recycling of Organic Solid Wastes by *Pleurotus ostreatus*

Agro-industrial wastes are defined as any residue that results from the agricultural and industrial activities. These wastes have been successfully used as growth substrates in the cultivation of mushrooms. Several agro-industrial wastes have low N-content materials, which represents an important factor in the growth and cultivation of mushrooms on these wastes [59]. The protein content in a mushroom-fruiting body depends upon both the C:N ratio of the substrates and the chemical composition, in addition to the mushroom species that is being cultivated [59,100,101]. This group of mushrooms could also be artificially cultivated in different phenolic wastes and lignocellulosic substrates (under both the solid-state and liquid-submerged fermentation processes) through their complex enzymatic system, which includes cellulolytic (e.g., cellulase and xylanase) and ligninolytic (e.g., laccase, lignin peroxidase, manganese peroxidase, and versatile peroxidase) enzymes, which have different applications in the beverage and food industry [12]. Several fermentation factors can control the activity of these lignocellulolytic enzymes, such as the pH, medium composition, C:N ratio, air composition, and temperature [58]. The C:N ratio that is required for the substrate to obtain the highest yield of *Pleurotus ostreatus* should be (40:1) at the minimum, (45–60:1) as the optimum, and (90:1) at the maximum, as reported by Kumla et al. [59]. The chemical composition and biological efficiency of *Pleurotus ostreatus* grown on different kinds of agro-industrial wastes are presented in Table 5. It is evident from Table 5 that the chemical composition of harvested mushrooms on agro-wastes mainly depends on the type of waste; the highest biological efficiency was recorded for soy stalks (85.2%).

Table 5. Chemical composition and biological efficiency of *Pleurotus ostreatus* grown on different kinds of agro-industrial waste (as % or g 100 g^{-1} dry weight).

Agro-Industrial Wastes	Biological Efficiency (%)	Crude Proteins (%)	Carbohydrates (%)	Fats (%)	Fiber (%)	Ash (%)	Refs.
I. ***Applied individual agro-industrial waste***							
Wheat straw	37.6	13.6	60.5	2.3	22.7	10.3	[102]
Barley straw	21.3	12.8	54.7	29.9	0.90	1.2	[103]
Rice straw	55.6	17.9	56.4	8.4	4.30	9.6	[104]
Maize cob	46.4	23.4	50.8	3.1	22.0	7.6	[105]
Soya stalk	85.2	24.7	53.2	2.8	7.2	6.7	[104]
Cotton stalk	44.3	30.1	40.2	2.1	17.2	8.4	[106]
Cotton seed hull	8.9	17.5	65.9	1.2	10.2	5.2	[107]
Rice husk	9.5	5.9	48.5	30.9	0.3	14.3	[103]
Sugarcane bagasse	65.7	27.1	34.9	2.0	29.3	6.7	[105]
Sugarcane bagasse	52.3	17.1	-	1.18	12.1	4.5	[108]
Cassava peel	25.1	10.6	73.7	2.2	8.7	7.6	[109]
Acacia sawdust	46.4	19.5	51.3	1.3	22.0	5.9	[105]
Beech sawdust	46.8	16.1	73.6	3.5	15.8	6.2	[102]
Birch sawdust	42.5	21.0	67.6	1.0	6.4	6.4	[110]
II. ***Applied combined agro-industrial wastes***							
Soya stalk + rice straw	81.7	23.0	50.5	2.7	7.7	6.4	[111]
Soya stalk + wheat straw	77.7	21.1	52.0	2.6	7.4	6.2	[111]
Wheat and rice straw	71.8	20.3	56.0	2.6	7.5	5.9	[111]
Cotton stalk + cottonseed hull	20.2	22.8	58.0	2.9	10.8	5.5	[107]
Acacia sawdust + maize cob	58.8	18.7	46.9	3.3	24.5	6.7	[105]
Acacia sawdust + sugarcane bagasse	58.9	24.2	37.8	2.5	28.8	6.7	[105]
Wheat straw + olive pruning residues	56.8	19.9	71.7	1.9	16.5	6.5	[111]
Cassava peel + maize cobs	32.4	10.7	73.8	2.2	8.7	7.6	[109]

Source: extracted from Kumla et al. [59] and the ratio of the combined agro-industrial wastes is 50% for each one or (1:1).

Many reports have discussed the many purposes of oyster mushrooms through their cultivation on agro-wastes or agro-industrial wastes, which include mushroom production, and the biodegradation of agro-wastes, producing many bioactive compounds and creating a healthy environment for humans, as well as these mushrooms possessing pharmaceutical attributes for medical applications, such as anti-diabetic, anti-carcinogenic, anti-oxidative, and immune suppressor attributes (e.g., [11,12,61,112–114]. Furthermore, oyster mushrooms have a great ability to convert the agro-wastes into bioenergy, bio-compost and biofertilizers [60,115]. The cultivation of oyster mushrooms can be also carried out on coffee waste substrates or spent coffee grounds [116].

7. Enzyme Production by *Pleurotus ostreatus*

The mushrooms of genus *Pleurotus* have a great tolerance to diverse conditions, such as high temperatures or growing on hard woods in their natural ecosystem or forests [11]. The distinguished feature of these fungi is represented in their ability to cultivate on different lignocellulosic agro-industrial by-products, as a result of their complex enzymatic system [11]. The cultivation of *Pleurotus ostreatus* and the collection of spent mushroom substrates following cultivation have attracted great attention due to their potential applications in the production of enzymes, biomass, bioethanol, feed ingredients, and functional foods, such as xylo-oligosaccharides [117]. Table 6 presents the different applications of *Pleurotus ostreatus* in the production of some cellulolytic enzymes and other by-products. Three main factors are responsible for controlling this production process, including the media, the source of carbon used in the substrate, and the solid-state fermentation conditions and its purpose, as listed in Table 6.

Table 6. Some applications of solid-state fermentation using *Pleurotus ostreatus* and the used substrate for the production of some cellulolytic enzymes and other by-products.

Media	Fermentation Conditions and Its Purpose	Substrate (Source of Carbon)	Refs.
Malt extract agar (up 36 days) 26 °C, RH 75%	Production of laccases and endoglucanases were recorded for oat straw, rice bark, and poplar wood sawdust (26–51 days)	Oat straw, rice bark, poplar wood sawdust, olive pulp, and wheat straw	[12]
Malt extract agar (up to 36 days) 25 °C, RH 80%	Rice bark presented the highest productivity, with the highest biological efficiency > 70% (during a cropping period of 51 days)	Rice bark, wheat straw, coffee residue, barley and oat straw	[11]
Potato dextrose agar for 5 days	Incubated at 25 °C and sampled after 77 days for improved ruminant animal feed	Maize stover and kudzu (*Pueraria montana*)	[118]
Potato dextrose agar for 7 days	Incubated at 27 °C for 15 days to produce phenolics and flavonoids	Cocoa pod husk and kolanut pod	[61]
Fungi stock culture for 12 days	Inoculation at 25°C and 60% humidity for 12 d for proteinaceous animal feed	Brewer's spent grain	[119]
Bacteriological agar for 5 days	Solid culture media at 30 °C, carbon source (sugarcane bagasse), to produce cellulases, pectinases, and xylanase	Pineapple wastes (fruits, leaves, and stalks)	[120]
Potato dextrose agar for 28 days	Inoculated straw with fungus at 28 °C, humidity 80% for rumen degradability	Naked oat straw	[121]
Potato extract for 5 days	Produce exopoly-galacturonases after 7 or 10 days at 30 °C	Peel of pomelo (*Citrus maxima*)	[122]
Potato dextrose agar for 8 days	Production at 28–32 °C of cellulases, hemi-cellulases, and reducing sugars	Leaf-and-stem mixture of *Alstroemeria* sp.	[123]
Potato dextrose broth for 6 days	Incubated at 28 °C to produce lovastatin at a rate of 34.97 mg g^{-1}	Barley, wheat bran, rice husk, and oat grains	[124]
Culture media (50 °C for 72 h)	Butanol production through treatment by laccase (saccharification yield 99%)	Brewer's spent grain	[125]

The cultivation of *Pleurotus ostreatus* and its benefits can be explained from different studies as follows:

1. Studies on the role of spent mushroom substrates after this cultivation produces many important materials, such as enzymes [12,19,126,127], biomass [118,128,129], bioethanol [19,127,130], feed ingredients, and functional foods [61,131,132]. Spent mushroom substrates can be recycled as a substrate for the "new cultivation cycle" of mushrooms, a feedstock for producing the second generation of biofuels, a bio-control agent, a biofertilizer, and for soil amendment [133–135];
2. Studies on the biodegradation of agro-wastes or agro-industrial by-products through the solid-state fermentation or submerged fermentation by *P. ostreatus*, such as (a) using the deinking sludge as a substrate to produce lignocellulolytic enzymes (Vodovnik et al. [136], (b) producing exo-polygalacturonases using pomelo peel powder under submerged fermentation by *P. ostreatus* [122], and (c) producing laccases by white-rot fungi under solid-state fermentation conditions [137];
3. Studies on the production of ligninolytic enzymes and their potential [129,138–140]. The most important ligninolytic enzymes, which can be produced by *Pleurotus* include manganese peroxidase, laccase, and lignin peroxidase through biodegradation, which varied from species to species. The main factors controlling the *Pleurotus* species and their ability to produce enzymes or to degrade wastes or pollutants include the pH, pollutant/waste concentration, and C:N ratio of the substrate [141];
4. Studies on the role of nano-mycology, including the applications of *Pleurotus* spp. to the green or myco-synthesis of nano-silver [142–144], nano-TiO_2 [145,146], nano-ZnO [147], and the production of fluorescent carbon quantum dots as a C-based nanomaterial [148]. The myco-synthesis of nano-nutrients (nano-Ag, nano-TiO_2, and nano-ZnO) has been investigated for medical attributes, such as controlling mosquito larvae, and anti-cancer activities [145–147]. Nanomaterials conjugated lignocellulosic wastes for producing biofuels using immobilized enzymes [149];
5. Sustainable management of agro-industrial wastes could be achieved by the reduction and conservation of wastes as well as different utilizations of wastes, including reuse and recycling [132,150]. The main agro-based industries that produce large amounts of waste may include plant-based foods (e.g., cereals, fermentation, sugar, food and fruit processing), animal-based foods (e.g., milk, dairy, fish and poultry products), and non-food industries, such as paper and textiles [132].

8. Bioethanol Production by *Pleurotus ostreatus*

Bioethanol is considered an important source of bio-based fuel, which has the ability to mitigate global warming and conserve fossil fuels [151]. Nowadays, the production of bioethanol is manufactured by fermenting different agro-industrial wastes. These substrates may include fermentable sugars (mainly sugarcane or by-products of the sugar industry), amylaceous feedstocks (e.g., maize, barley, potatoes, and wheat), and cellulosic substrates, such as bagasse, post-harvest agricultural residues, and wood wastes [151]. In other words, biofuel is a type of fuel of which the energy is derived from biological C-fixation via different processes, including gasification, liquefaction, pyrolysis, supercritical fluid extraction, supercritical water liquefaction, and biochemical processes [152]. Therefore, there is an urgent need for more intensive research to be conducted on the utilization of waste and agricultural biomass to produce the required energy for the following generations. The sustainable production of bioethanol can be achieved using fermentable sugars without decomposition through a pretreatment technology [153]. The correct selection of this pretreatment technology has a vital role in determining the cost of the whole technology, which contributes to about 30–35% of the overall production costs [153]. In general, the main production techniques of oyster mushrooms may include both solid substrate fermentation and submerged liquid fermentation using solid and liquid spawn [154]. The different species of mushrooms are listed in Table 7, which have the ability to produce bioethanol compared to the *Pleurotus ostreatus* mushroom and used substrate.

Table 7. The role of different kinds of fungi in the production of bioethanol compared to the *Pleurotus ostreatus* mushroom and used substrate.

Fungi Species	Fermentation Conditions	Biofuel Production	Refs.
Pleurotus florida	Cotton-spinning waste mixture using solid-state cultivation for 14 d; hydrolysis at 32 °C for 72 h	Ethanol at 1.18 g L^{-1} (64 % at 60 h)	[19]
Pleurotus ostreatus	Mushroom compost derived from millet and sorghum produced ethanol by saccharification and fermentation (applied substrate at 5–30% *w*/*v*)	Ethanol at 45.8 g L^{-1} dry weight (70%)	[155]
Pleurotus ostreatus	Rice straw was biodegraded by ligninolytic enzymes (cellulase and xylanase) up to 45 days	Biomethane yield 269 mL·g^{-1} (at 25 d)	[156]
Pleurotus ostreatus	Using 181 g of mushrooms per wet 2 kg waste of banana leaves with a biological efficiency of 37%	Biogas yield (282 mL g^{-1} VS^{-1})	[157]
Pachysolen tannophilus	Spent mushroom substrate of *Agaricus bisporus* was enzymatic hydrolysis (30 °C after 48 h) incubation	Ethanol at 6.41 g L^{-1} (76.13%)	[156]
Saccharomyces cerevisiae	Spent mushroom substrate of *Pleurotus forida* was enzymatic hydrolysis (30 °C after 48 h) incubation	Ethanol yield was 5.8 g L^{-1} (58.12%)	[158]
Saccharomyces cerevisiae	Cultivation wastes of *Aspergillus tubingensis*, which produced cellulolytic enzymes (at 30 °C for 10 days)	Ethanol yield was 17.3 g L^{-1} (48 h)	[159]
Saccharomyces cerevisiae	Rice straw was biodegraded by *Trichoderma reesei* and mushroom for 7 days and incubated at 32 °C	Bioethanol produced by *S. cerevisiae*	[160]
Kluyveromyces marxianus	Pine needle wastes were catalyzed by xylanase from *Bacillus* sp., fermented by fungi (at 40 °C for 96 h)	Bioethanol was 5.34 g L^{-1} (3.89% yield)	[161]
Ganoderma lucidum	Substrate of old newspapers was alkali (4% NaOH) or enzymatic fermented using *Trichoderma harzianum* (30 °C for 5 d)	Ethanol production: 17.8 and 20.4 g L^{-1}, respectively, for 2 methods	[162]
Aspergillus niger and *Saccharomyces cerevisiae*	Rice straw was pretreated (4% NaOH; incubated 40 °C for 24 h), saccharified, and fermented at 37 °C by *S. cerevisiae*	Ethanol yield was 31.9 g L^{-1} after the incubation	[163]
Aspergillus niger and *Saccharomyces cerevisiae*	Potato wastes were pretreated, saccharified, and fermented at pH 5.8, 35 °C, and no-aeration by co-cultures of *A. niger* and *S. cerevisiae*	Ethanol yield was 37.93 g L^{-1}	[163]
Saccharomyces cerevisiae	Maize husks, peanut husks, and husks of coffee cherry were pretreated using 3 methods (acid or H_2SO_4, alkaline or NaOH and steam)	Ethanol yield was 20.61, 18.21 and 6.86 g L^{-1}, respectively, for each one	[164]
Ganoderma lucidum	Spent substrate of *G. lucidum* was acid-pretreated by H_2SO_4 using *Saccharomyces cerevisiae* (30 °C for 5 d)	Ethanol yield was 0.91 g L^{-1}	[165]

Abbreviation: volatile solids (VSs).

It is well known that the production of bioethanol from wastes or non-crop-based lignocellulosic materials attracted a lot of attention on a commercial scale, as a possible sustainable solution for "the decarbonization of the transport sector" [166]. The world is facing a great challenge to save enough fuel for transport by the exploitation of global crop residues. Instead of being burnt, which can pollute the environment and increase global warming [158], crop residual wastes are important sources that can be used to produce bioenergy or bioactive compounds. These crop residues can also be exploited for producing several value-added products, such as lignocellulolytic enzymes, biogas, bioethanol, biohydrogen, and biofertilizers [158]. Mushrooms and their waste may be considered as a suitable source for bioethanol production. Mushrooms of *Pleurotus* can produce many ligninolytic enzymes (laccase, lignin peroxidase, manganese peroxidase, and versatile peroxidase) during the biodegradation of agro-industrial wastes through solid-state or submerged-state fermentation. Therefore, bioethanol can be produced from the lignocellulosic biomass and/or spent mushroom substrate [158].

Many studies reported the production of bioethanol using the mushrooms of *Pleurotus ostreatus*, which can be highlighted as follows:

1. The chemical composition of agro-wastes (cellulose, hemicellulose, and lignin) or spent mushroom substrates (SMSs) is considered an important factor controlling the biodegradation of these wastes, as reported in Table 5. Every 1 kg of grown mushroom generates nearly 5 kg of SMSs, establishing a promising industry for SMSs [158]. The biodegradation mechanism of these SMSs by mushrooms (e.g., *Pleurotus* spp.) may include the enzymatic degradation of various substrates (mainly cellulose, hemicellulose, and lignin) into soluble compounds of a low molecular weight. A partial degradation of the lignocellulosic biomass by saccharification during the pre-treatment is needed;
2. The condition of fertilization and its kind (solid-state fermentation or submerged), using media are the substrates as a source of carbon, and are the main factors that control the applications of *Pleurotus ostreatus* for the production of some cellulolytic enzymes and other by-products, such as reducing sugars, biofertilizers, and animal feeds, as reported in Table 6;
3. The production of biofuel from saccharification and/or fermentation in the presence or absence of *Pleurotus ostreatus* or other mushrooms depends on the kind of applied substrate, mushroom species, and the oxidation or fermentation conditions, as reported in Table 7;
4. Based on about 998 million tons of agro-wastes produced per year from agricultural practices [167], new approaches are needed to overcome the resistant nature of lignocellulosic wastes, to convert them into valuable products in an economical and eco-friendly manner [168];
5. The general structure of the lignocellulosic agro-wastes includes cellulose (30–50%), lignin (10–20%), and hemicelluloses (15–35%), in addition to some components, including minerals, extractives, and ash, in tiny amounts [167]. These agro-wastes are still underutilized, especially in developing countries. The unwise utilization of these wastes (mainly the burning of them) causes many environmental crises, such as global warming due to an increase in the emissions of gases, particularly carbon dioxide and sulfur dioxide, as well as underground water pollution [169];
6. It is evident from Table 7 that the oyster mushroom (*Pleurotus ostreatus*) is a mushroom distinguished for its ability to produce of bioethanol compared to other mushrooms, even in the case of the genus *Pleurotus*. This rate of production is higher in *Pleurotus ostreatus* (up to 46 g L^{-1} with efficiency up to 70%), which is higher than *Pleurotus florida* or other species, such as *Ganoderma lucidum*.

9. General Discussion

In this general discussion, it is necessary to present the answers, in brief, for the main following questions:

What is the importance or potential of this study?

This central aim of the present review concerns the genus *Pleurotus* and more details about the most famous mushroom in this genus (*Pleurotus ostreatus*). This species of mushroom has brilliant features, which appear in their applications in several fields, including food, myco-remediation, the production of bioethanol and enzymes, as well as bio-degradation and the conversion of agro-industrial wastes into organic fertilizers.

What are the main ideas presented in this review?

The main points presented in this review include the many biotechnological applications of *Pleurotus ostreatus* in several fields, such as the food sector, pollution and the remediation of polluted environments, agro-industrial wastes and their recycling, the production of enzymes and bio-organic fertilizers from the biodegradation of different wastes, the cultivation and production of mushrooms for human foods, the energy sector, and the production of bioethanol.

Why is this work important for readers?

This work is important for the readers because it includes information concerning an important source of human food and an alternative form of energy production and enzyme. These aspects are crucial to our lives, and they especially help to sustain our activities as well.

What are the open questions that still need to be answered?

The relationship between the *Pleurotus ostreatus* mushroom and nanotechnology can lead to many questions, which need to be investigated in the future, and this will be the subject of our next review.

10. Conclusions

Mushrooms are fungal plants that represent an important source of human foods because of their high nutritional value, bioactive compounds, and many medicinal uses. Recently, these mushrooms have new applications, particularly in the biotechnology sector. These applications mainly depend on the plant of mushrooms and their green biotechnological tools in the field of myco-remediation, bio-fermentation, bioethanol, and enzyme production. The use of oyster mushrooms is considered a sustainable strategy in the bioremediation of polluted environments, the biodegradation of agro-wastes or agro-industrial wastes, and the bio-fermentation of ligninolytic wastes to produce enzymes. The oyster mushroom (*Pleurotus ostreatus* L.) can also be applied to produce biomass, feed ingredients, and functional foods. The spent substrate of the oyster mushroom has multiple benefits, which include recycling as a substrate for the new cultivation cycle of mushrooms, producing biofuels, a bio-control agent, a biofertilizer, and soil amendment. The oyster mushroom has also penetrated the field of nanotechnology through the myco-synthesis of nano-silver, nano-TiO_2, and nano-ZnO. Therefore, several environmental problems can include the issue of sustained management concerning the use of oyster mushrooms, especially the accumulation of large amounts of agro-industrial waste, removing the bioremediation or the bio-degradation of pollutants, cultivating nutritive mushrooms for the purpose of human nutrition Similar to any scientific topic, many questions are still require an answer, including "what is the expected role of oyster mushrooms in producing other nanoparticles of different nutrients in addition to Ag, Ti, and Zn?"; "to what extent can these nano-nutrients be used in the agricultural sector?"; and "is there any possibility to establish a global standard criterion for the toxic levels of nutrients or other toxic nutritional compounds of oyster mushrooms (*Pleurotus ostreatus* L.) and other species?".

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References

1. Gullino, M.L. Green Biotechnologies. In *Spores*; Springer International Publishing: Cham, Switzerland, 2021; pp. 253–257. ISBN 978-3-030-69994-9.
2. Chaurasia, P.K.; Bharati, S.L. Applicability of Fungi in Agriculture and Environmental Sustainability. In *Microbes in Land Use Change Management*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 155–172. ISBN 978-0-12-824448-7.
3. Mleczek, M.; Budka, A.; Siwulski, M.; Mleczek, P.; Budzyńska, S.; Proch, J.; Gąsecka, M.; Niedzielski, P.; Rzymski, P. A Comparison of Toxic and Essential Elements in Edible Wild and Cultivated Mushroom Species. *Eur. Food Res. Technol.* **2021**, *247*, 1249–1262. [CrossRef]
4. Zhang, Y.; Mo, M.; Yang, L.; Mi, F.; Cao, Y.; Liu, C.; Tang, X.; Wang, P.; Xu, J. Exploring the Species Diversity of Edible Mushrooms in Yunnan, Southwestern China, by DNA Barcoding. *J. Fungi* **2021**, *7*, 310. [CrossRef] [PubMed]
5. Gujre, N.; Soni, A.; Rangan, L.; Tsang, D.C.W.; Mitra, S. Sustainable Improvement of Soil Health Utilizing Biochar and Arbuscular Mycorrhizal Fungi: A Review. *Environ. Pollut.* **2021**, *268*, 115549. [CrossRef] [PubMed]
6. Mwangi, R.W.; Macharia, J.M.; Wagara, I.N.; Bence, R.L. The Antioxidant Potential of Different Edible and Medicinal Mushrooms. *Biomed. Pharmacother.* **2022**, *147*, 112621. [CrossRef] [PubMed]
7. Sekan, A.S.; Myronycheva, O.S.; Karlsson, O.; Gryganskyi, A.P.; Blume, Y.B. Green Potential of *Pleurotus* spp. in Biotechnology. *PeerJ* **2019**, *7*, e6664. [CrossRef]
8. Xiao, P.; Wu, D.; Wang, J. Bibliometric Analysis of Global Research on White Rot Fungi Biotechnology for Environmental Application. *Environ. Sci. Pollut. Res.* **2022**, *29*, 1491–1507. [CrossRef]
9. Khoo, S.C.; Ma, N.L.; Peng, W.X.; Ng, K.K.; Goh, M.S.; Chen, H.L.; Tan, S.H.; Lee, C.H.; Luang-In, V.; Sonne, C. Valorisation of Biomass and Diaper Waste into a Sustainable Production of the Medical Mushroom Lingzhi *Ganoderma lucidum*. *Chemosphere* **2022**, *286*, 131477. [CrossRef] [PubMed]
10. Sithole, S.C.; Agboola, O.O.; Mugivhisa, L.L.; Amoo, S.O.; Olowoyo, J.O. Elemental Concentration of Heavy Metals in Oyster Mushrooms Grown on Mine Polluted Soils in Pretoria, South Africa. *J. King Saud Univ. Sci.* **2022**, *34*, 101763. [CrossRef]
11. Melanouri, E.-M.; Dedousi, M.; Diamantopoulou, P. Cultivating *Pleurotus ostreatus* and *Pleurotus eryngii* Mushroom Strains on Agro-Industrial Residues in Solid-State Fermentation. Part II: Effect on Productivity and Quality of Carposomes. *Carbon Resour. Convers.* **2022**, *5*, 52–60. [CrossRef]
12. Melanouri, E.-M.; Dedousi, M.; Diamantopoulou, P. Cultivating *Pleurotus ostreatus* and *Pleurotus eryngii* Mushroom Strains on Agro-Industrial Residues in Solid-State Fermentation. Part I: Screening for Growth, Endoglucanase, Laccase and Biomass Production in the Colonization Phase. *Carbon Resour. Convers.* **2022**, *5*, 61–70. [CrossRef]
13. Prokisch, J.; Törős, G.; El-Ramady, H. Edible Mushroom of *Pleurotus* spp.: A Case Study of Oyster Mushroom (*Pleurotus ostreatus* L.). *EBSS* **2021**, *5*, 1–2. [CrossRef]
14. Bains, A.; Chawla, P.; Tripathi, A.; Sadh, P.K. A Comparative Study of Antimicrobial and Anti-Inflammatory Efficiency of Modified Solvent Evaporated and Vacuum Oven Dried Bioactive Components of *Pleurotus floridanus*. *J. Food Sci. Technol.* **2021**, *58*, 3328–3337. [CrossRef]
15. Caldas, L.A.; Zied, D.C.; Sartorelli, P. Dereplication of Extracts from Nutraceutical Mushrooms Pleurotus Using Molecular Network Approach. *Food Chem.* **2022**, *370*, 131019. [CrossRef]
16. Corrêa, R.C.G.; Brugnari, T.; Bracht, A.; Peralta, R.M.; Ferreira, I.C.F.R. Biotechnological, Nutritional and Therapeutic Uses of *Pleurotus* spp. (Oyster Mushroom) Related with Its Chemical Composition: A Review on the Past Decade Findings. *Trends Food Sci. Technol.* **2016**, *50*, 103–117. [CrossRef]
17. Kapahi, M.; Sachdeva, S. Mycoremediation Potential of *Pleurotus* Species for Heavy Metals: A Review. *Bioresour. Bioprocess.* **2017**, *4*, 32. [CrossRef]
18. Durán-Aranguren, D.D.; Meléndez-Melo, J.P.; Covo-Ospina, M.C.; Díaz-Rendón, J.; Reyes-Gutiérrez, D.N.; Reina, L.C.; Durán-Sequeda, D.; Sierra, R. Biological Pretreatment of Fruit Residues Using the Genus *Pleurotus*: A Review. *Bioresour. Technol. Rep.* **2021**, *16*, 100849. [CrossRef]
19. Ranjithkumar, M.; Uthandi, S.; Senthil Kumar, P.; Muniraj, I.; Thanabal, V.; Rajarathinam, R. Highly Crystalline Cotton Spinning Wastes Utilization: Pretreatment, Optimized Hydrolysis and Fermentation Using *Pleurotus florida* for Bioethanol Production. *Fuel* **2022**, *308*, 122052. [CrossRef]
20. Kaewlaoyoong, A.; Cheng, C.-Y.; Lin, C.; Chen, J.-R.; Huang, W.-Y.; Sriprom, P. White Rot Fungus *Pleurotus pulmonarius* Enhanced Bioremediation of Highly PCDD/F-Contaminated Field Soil via Solid State Fermentation. *Sci. Total Environ.* **2020**, *738*, 139670. [CrossRef]
21. Wang, S.; Li, W.; Liu, L.; Qi, H.; You, H. Biodegradation of Decabromodiphenyl Ethane (DBDPE) by White-Rot Fungus *Pleurotus ostreatus*: Characteristics, Mechanisms, and Toxicological Response. *J. Hazard. Mater.* **2022**, *424*, 127716. [CrossRef]
22. Raman, J.; Jang, K.-Y.; Oh, Y.-L.; Oh, M.; Im, J.-H.; Lakshmanan, H.; Sabaratnam, V. Cultivation and Nutritional Value of Prominent *Pleurotus* spp.: An Overview. *Mycobiology* **2021**, *49*, 1–14. [CrossRef]
23. Ghosh, T.; Sengupta, A.; Das, A. Nutrition, Therapeutics and Environment Impact of Oyster Mushrooms: A Low Cost Proteinaceous Source. *J. Gynecol. Women's Health* **2019**, *14*, 555876. [CrossRef]
24. CABI Invasive Species Compendium: Datasheet. Pleurotus ostreatus (Oyster Mushroom). Available online: https://www.cabi.org/isc/datasheet/42037 (accessed on 8 February 2022).

25. Espinosa-Páez, E.; Hernández-Luna, C.E.; Longoria-García, S.; Martínez-Silva, P.A.; Ortiz-Rodríguez, I.; Villarreal-Vera, M.T.; Cantú-Saldaña, C.M. Pleurotus ostreatus: A Potential Concurrent Biotransformation Agent/Ingredient on Development of Functional Foods (Cookies). *LWT* **2021**, *148*, 111727. [CrossRef]
26. Menolli, N.; Breternitz, B.S.; Capelari, M. The Genus *Pleurotus* in Brazil: A Molecular and Taxonomic Overview. *Mycoscience* **2014**, *55*, 378–389. [CrossRef]
27. Dicks, L.; Ellinger, S. Effect of the Intake of Oyster Mushrooms (*Pleurotus ostreatus*) on Cardiometabolic Parameters—A Systematic Review of Clinical Trials. *Nutrients* **2020**, *12*, 1134. [CrossRef] [PubMed]
28. Jacinto-Azevedo, B.; Valderrama, N.; Henríquez, K.; Aranda, M.; Aqueveque, P. Nutritional Value and Biological Properties of Chilean Wild and Commercial Edible Mushrooms. *Food Chem.* **2021**, *356*, 129651. [CrossRef] [PubMed]
29. Gąsecka, M.; Mleczek, M.; Siwulski, M.; Niedzielski, P. Phenolic Composition and Antioxidant Properties of *Pleurotus ostreatus* and *Pleurotus eryngii* Enriched with Selenium and Zinc. *Eur. Food Res. Technol.* **2016**, *242*, 723–732. [CrossRef]
30. Sardar, H.; Ali, M.A.; Anjum, M.A.; Nawaz, F.; Hussain, S.; Naz, S.; Karimi, S.M. Agro-Industrial Residues Influence Mineral Elements Accumulation and Nutritional Composition of King Oyster Mushroom (*Pleurotus eryngii*). *Sci. Hortic.* **2017**, *225*, 327–334. [CrossRef]
31. Sardar, H.; Anjum, M.A.; Hussain, S.; Ali, S.; Shaheen, M.R.; Ahsan, M.; Ejaz, S.; Ahmad, K.S.; Naz, S.; Shafique, M. Deciphering the Role of Moringa Leaf Powder as a Supplement in the Cotton Waste Substrate for the Growth and Nutrition of King Oyster Mushroom. *Sci. Hortic.* **2022**, *293*, 110694. [CrossRef]
32. Singh, M.; Singh, V. Yield Performance and Nutritional Analysis of Pleurotus Citrinopileatus on Different Agrowastes and Vegetable Wastes. 2011. Available online: https://www.semanticscholar.org/paper/Yield-performance-and-nutritional-analysis-of-on-Singh-Singh/39e9fd8541f30a60aa6909903f881caa4266def3 (accessed on 10 February 2022).
33. Mshandete, A.M.; Cuff, J. Cultivation of Three Types of Indigenous Wild Edible Mushrooms: *Coprinus cinereus*, *Pleurotus flabellatus* and *Volvariella volvocea* on Composted Sisal Decortications Residue in Tanzania. *Afr. J. Biotechnol.* **2008**, *7*. [CrossRef]
34. Jegadeesh, R.; Lakshmanan, H.; Kab-Yeul, J.; Sabar, V.; Raaman, N. Cultivation of Pink Oyster Mushroom *Pleurotus Djamor Var. Roseus* on Various Agro-Residues by Low Cost Technique. *J. Mycopathol. Res.* **2018**, *56*, 213–220.
35. Silva, S.O.; Costa, S.M.G.D.; Clemente, E. Chemical Composition of *Pleurotus pulmonarius* (Fr.) Quél., Substrates and Residue after Cultivation. *Braz. Arch. Biol. Technol.* **2002**, *45*, 531–535. [CrossRef]
36. Bumanlag, C.; Kalaw, S.; Dulay, R.; Reyes, R. Optimum conditions for mycelia growth and basidiocarp production of *Pleurotus djamor* on corn based media. *Int. J.Biol. Pharm. Allied Sci.* **2018**, *7*, 558–575. [CrossRef]
37. Ijeh, I.I.; Okwujiako, I.A.; Nwosu, P.C.; Nnodim, H.I. Phytochemical Composition of *Pleurotus Tuber Regium* and Effect of Its Dietary Incorporation on Body /Organ Weights and Serum Triacylglycerols in Albino Mice. *J. Med. Plants Res.* **2009**, *3*, 939–943.
38. Ahmed, S.; Kadam, J.; Mane, V.; Patil, S.; Mmv, B. Biological Efficiency and Nutritional Contents of *Pleurotus florida* (Mont.) Singer Cultivated On Different Agro-Wastes. *Nat. Sci. Sleep* **2008**, *7*, 44–48.
39. Rajak, S.; Mahapatra, S.C.; Basu, M. Yield, Fruit Body Diameter and Cropping Duration of Oyster Mushroom (*Pleurotus Sajor Caju*) Grown on Different Grasses and Paddy Straw as Substrates. *Eur. J. Med. Plants* **2011**, *1*, 10–17. [CrossRef]
40. Hřebečková, T.; Wiesnerová, L.; Hanč, A. Change in Agrochemical and Biochemical Parameters during the Laboratory Vermicomposting of Spent Mushroom Substrate after Cultivation of Pleurotus ostreatus. *Sci. Total Environ.* **2020**, *739*, 140085. [CrossRef]
41. Cateni, F.; Gargano, M.L.; Procida, G.; Venturella, G.; Cirlincione, F.; Ferraro, V. Mycochemicals in Wild and Cultivated Mushrooms: Nutrition and Health. *Phytochem. Rev.* **2021**. [CrossRef]
42. Ma, G.; Yang, W.; Zhao, L.; Pei, F.; Fang, D.; Hu, Q. A Critical Review on the Health Promoting Effects of Mushrooms Nutraceuticals. *Food Sci. Hum. Wellness* **2018**, *7*, 125–133. [CrossRef]
43. Islam, T.; Ganesan, K.; Xu, B. New Insight into Mycochemical Profiles and Antioxidant Potential of Edible and Medicinal Mushrooms: A Review. *Int. J. Med. Mushrooms* **2019**, *21*, 237–251. [CrossRef]
44. Vamanu, E. In Vitro Antimicrobial and Antioxidant Activities of Ethanolic Extract of Lyophilized Mycelium of *Pleurotus ostreatus* PQMZ91109. *Molecules* **2012**, *17*, 3653–3671. [CrossRef]
45. Carrasco-González, J.A.; Serna-Saldívar, S.O.; Gutiérrez-Uribe, J.A. Nutritional Composition and Nutraceutical Properties of the *Pleurotus* Fruiting Bodies: Potential Use as Food Ingredient. *J. Food Compos. Anal.* **2017**, *58*, 69–81. [CrossRef]
46. Talkad, M.S.; Das, R.K.; Bhattacharjee, P.; Ghosh, S.; Shivajirao, U.P. Establishment of Enzyme Inhibitory Activities of Lovastatin, Isolated From *Pleurotus ostreatus*. *Int. J. Appl. Sci. Biotechnol.* **2015**, *3*, 408–416. [CrossRef]
47. Anandhi, R.; Annadurai, T.; Anitha, T.S.; Muralidharan, A.R.; Najmunnisha, K.; Nachiappan, V.; Thomas, P.A.; Geraldine, P. Antihypercholesterolemic and Antioxidative Effects of an Extract of the Oyster Mushroom, *Pleurotus ostreatus*, and Its Major Constituent, Chrysin, in Triton WR-1339-Induced Hypercholesterolemic Rats. *J. Physiol. Biochem.* **2013**, *69*, 313–323. [CrossRef] [PubMed]
48. Golak-Siwulska, I.; Kałużewicz, A.; Spiżewski, T.; Siwulski, M.; Sobieralski, K. Bioactive Compounds and Medicinal Properties of Oyster Mushrooms (*Pleurotus* sp.). *Folia Hortic.* **2018**, *30*, 191–201. [CrossRef]
49. Patel, Y.; Naraian, R.; Singh, V. Medicinal Properties of *Pleurotus* Species (Oyster Mushroom): A Review. *World J. Fungal Plant Biol.* **2012**, *3*, 1–12.

50. Mitsou, E.K.; Saxami, G.; Stamoulou, E.; Kerezoudi, E.; Terzi, E.; Koutrotsios, G.; Bekiaris, G.; Zervakis, G.I.; Mountzouris, K.C.; Pletsa, V.; et al. Effects of Rich in Β-Glucans Edible Mushrooms on Aging Gut Microbiota Characteristics: An In Vitro Study. *Molecules* **2020**, *25*, 2806. [CrossRef]
51. Piska, K. Edible Mushroom Pleurotus ostreatus (Oyster Mushroom)—Its Dietary Significance and Biological Activity. *Acta Sci. Pol. Hortorum Cultus* **2017**, *16*, 151–161.
52. Kuo, M. Pleurotus ostreatus (MushroomExpert.Com). Available online: https://www.mushroomexpert.com/pleurotus_ostreatus.html (accessed on 9 February 2022).
53. Włodarczyk, A.; Krakowska, A.; Sułkowska-Ziaja, K.; Suchanek, M.; Zięba, P.; Opoka, W.; Muszyńska, B. *Pleurotus* spp. Mycelia Enriched in Magnesium and Zinc Salts as a Potential Functional Food. *Molecules* **2020**, *26*, 162. [CrossRef]
54. Elhusseiny, S.M.; El-Mahdy, T.S.; Awad, M.F.; Elleboudy, N.S.; Farag, M.M.S.; Aboshanab, K.M.; Yassien, M.A. Antiviral, Cytotoxic, and Antioxidant Activities of Three Edible Agaricomycetes Mushrooms: *Pleurotus columbinus, Pleurotus sajor-caju*, and Agaricus Bisporus. *J. Fungi* **2021**, *7*, 645. [CrossRef]
55. Elhusseiny, S.M.; El-Mahdy, T.S.; Awad, M.F.; Elleboudy, N.S.; Farag, M.M.S.; Yassein, M.A.; Aboshanab, K.M. Proteome Analysis and In Vitro Antiviral, Anticancer and Antioxidant Capacities of the Aqueous Extracts of *Lentinula Edodes* and *Pleurotus ostreatus* Edible Mushrooms. *Molecules* **2021**, *26*, 4623. [CrossRef]
56. Krakowska, A.; Zięba, P.; Włodarczyk, A.; Kała, K.; Sułkowska-Ziaja, K.; Bernaś, E.; Sękara, A.; Ostachowicz, B.; Muszyńska, B. Selected Edible Medicinal Mushrooms from *Pleurotus* Genus as an Answer for Human Civilization Diseases. *Food Chem.* **2020**, *327*, 127084. [CrossRef]
57. Mishra, V.; Tomar, S.; Yadav, P.; Singh, M.P. Promising Anticancer Activity of Polysaccharides and Other Macromolecules Derived from Oyster Mushroom (*Pleurotus* sp.): An Updated Review. *Int. J. Biol. Macromol.* **2021**, *182*, 1628–1637. [CrossRef]
58. Bellettini, M.B.; Fiorda, F.A.; Maieves, H.A.; Teixeira, G.L.; Ávila, S.; Hornung, P.S.; Júnior, A.M.; Ribani, R.H. Factors Affecting Mushroom *Pleurotus* spp. *Saudi J. Biol. Sci.* **2019**, *26*, 633–646. [CrossRef]
59. Kumla, J.; Suwannarach, N.; Sujarit, K.; Penkhrue, W.; Kakumyan, P.; Jatuwong, K.; Vadthanarat, S.; Lumyong, S. Cultivation of Mushrooms and Their Lignocellulolytic Enzyme Production Through the Utilization of Agro-Industrial Waste. *Molecules* **2020**, *25*, 2811. [CrossRef]
60. Wan Mahari, W.A.; Peng, W.; Nam, W.L.; Yang, H.; Lee, X.Y.; Lee, Y.K.; Liew, R.K.; Ma, N.L.; Mohammad, A.; Sonne, C.; et al. A Review on Valorization of Oyster Mushroom and Waste Generated in the Mushroom Cultivation Industry. *J. Hazard. Mater.* **2020**, *400*, 123156. [CrossRef]
61. Ogidi, C.O.; Abioye, S.A.; Akinyemi, D.D.; Fadairo, F.B.; Bolaniran, T.; Akinyele, B.J. Bioactivity Assessment of Ethanolic Extracts from *Theobroma cacao* and *Cola* spp. Wastes after Solid State Fermentation by Pleurotus ostreatus and Calocybe Indica. *Adv. Tradit. Med. (ADTM)* **2021**. [CrossRef]
62. Sardar, H.; Anjum, M.A.; Nawaz, A.; Ejaz, S.; Ali, M.A.; Khan, N.A.; Nawaz, F.; Raheel, M. Impact of various agro-industrial wastes on yield and quality of *Pleurotus sajor-caju*. *Pak. J. Phytopathol.* **2016**, *28*, 87–92.
63. Zawadzka, A.; Janczewska, A.; Kobus-Cisowska, J.; Dziedziński, M.; Siwulski, M.; Czarniecka-Skubina, E.; Stuper-Szablewska, K. The Effect of Light Conditions on the Content of Selected Active Ingredients in Anatomical Parts of the Oyster Mushroom (*Pleurotus ostreatus* L.). *PLoS ONE* **2022**, *17*, e0262279. [CrossRef]
64. Tagkouli, D.; Bekiaris, G.; Pantazi, S.; Anastasopoulou, M.E.; Koutrotsios, G.; Mallouchos, A.; Zervakis, G.I.; Kalogeropoulos, N. Volatile Profiling of *Pleurotus eryngii* and *Pleurotus ostreatus* Mushrooms Cultivated on Agricultural and Agro-Industrial By-Products. *Foods* **2021**, *10*, 1287. [CrossRef]
65. Ahmad Zakil, F.; Mohd Isa, R.; Mohd Sueb, M.S.; Isha, R. Growth Performance and Mineral Analysis of *Pleurotus ostreatus* (Oyster Mushroom) Cultivated on Spent Mushroom Medium Mixed with Rubber Tree Sawdust. *Mater. Today Proc.* **2022**, *in press*. [CrossRef]
66. Sandargo, B.; Chepkirui, C.; Cheng, T.; Chaverra-Muñoz, L.; Thongbai, B.; Stadler, M.; Hüttel, S. Biological and Chemical Diversity Go Hand in Hand: Basidiomycota as Source of New Pharmaceuticals and Agrochemicals. *Biotechnol. Adv.* **2019**, *37*, 107344. [CrossRef] [PubMed]
67. Hazaimeh, M.D.; Ahmed, E.S. Bioremediation Perspectives and Progress in Petroleum Pollution in the Marine Environment: A Review. *Environ. Sci. Pollut. Res.* **2021**, *28*, 54238–54259. [CrossRef] [PubMed]
68. Sevak, P.I.; Pushkar, B.K.; Kapadne, P.N. Lead Pollution and Bacterial Bioremediation: A Review. *Environ. Chem. Lett.* **2021**, *19*, 4463–4488. [CrossRef]
69. Kumar, A.; Yadav, A.N.; Mondal, R.; Kour, D.; Subrahmanyam, G.; Shabnam, A.A.; Khan, S.A.; Yadav, K.K.; Sharma, G.K.; Cabral-Pinto, M.; et al. Myco-Remediation: A Mechanistic Understanding of Contaminants Alleviation from Natural Environment and Future Prospect. *Chemosphere* **2021**, *284*, 131325. [CrossRef] [PubMed]
70. Ratnasari, A.; Syafiuddin, A.; Kueh, A.B.H.; Suhartono, S.; Hadibarata, T. Opportunities and Challenges for Sustainable Bioremediation of Natural and Synthetic Estrogens as Emerging Water Contaminants Using Bacteria, Fungi, and Algae. *Water Air Soil Pollut.* **2021**, *232*, 242. [CrossRef]
71. Kumar, V.; Kumar, P.; Singh, J.; Kumar, P. Kinetics of Nutrients Remediation from Sugar Industry Effluent-Treated Substrate Using *Agaricus Bisporus*: Mushroom Yield and Biochemical Potentials. *3 Biotech* **2021**, *11*, 164. [CrossRef]
72. Yadav, P.; Rai, S.N.; Mishra, V.; Singh, M.P. Mycoremediation of Environmental Pollutants: A Review with Special Emphasis on Mushrooms. *Environ. Sustain.* **2021**, *4*, 605–618. [CrossRef]

73. Boujelben, R.; Ellouze, M.; Tóran, M.J.; Blánquez, P.; Sayadi, S. Mycoremediation of Tunisian Tannery Wastewater under Non-Sterile Conditions Using Trametes Versicolor: Live and Dead Biomasses. *Biomass Conv. Bioref.* **2022**. [CrossRef]
74. Crini, G.; Lichtfouse, E. Advantages and Disadvantages of Techniques Used for Wastewater Treatment. *Environ. Chem. Lett.* **2019**, *17*, 145–155. [CrossRef]
75. Janyasuthwiong, S.; Rene, E. Bioprecipitation—A Promising Technique for Heavy Metal Removal and Recovery from Contaminated Wastewater Streams. *MOJCE* **2017**, *2*, 52. [CrossRef]
76. Prigione, V.; Spina, F.; Tigini, V.; Giovando, S.; Varese, G.C. Biotransformation of Industrial Tannins by Filamentous Fungi. *Appl. Microbiol. Biotechnol.* **2018**, *102*, 10361–10375. [CrossRef]
77. Zhang, H.; Yuan, X.; Xiong, T.; Wang, H.; Jiang, L. Bioremediation of Co-Contaminated Soil with Heavy Metals and Pesticides: Influence Factors, Mechanisms and Evaluation Methods. *Chem. Eng. J.* **2020**, *398*, 125657. [CrossRef]
78. Romero-Silva, R.; Sánchez-Reyes, A.; Díaz-Rodríguez, Y.; Batista-García, R.A.; Hernández-Hernández, D.; Tabullo de Robles, J. Bioremediation of Soils Contaminated with Petroleum Solid Wastes and Drill Cuttings by *Pleurotus* sp. under Different Treatment Scales. *SN Appl. Sci.* **2019**, *1*, 1209. [CrossRef]
79. Sharma, J.; Sharma, D.; Sharma, A.; Bansal, S. Thermo Stable Tyrosinase Purified from Pleurotus Djamor Grown in Biomimetic Calcium Carbonate: A Biological Strategy to Industrial Waste Remediation. *Environ. Technol. Innov.* **2021**, *21*, 101294. [CrossRef]
80. Golovko, O.; Kaczmarek, M.; Asp, H.; Bergstrand, K.-J.; Ahrens, L.; Hultberg, M. Uptake of Perfluoroalkyl Substances, Pharmaceuticals, and Parabens by Oyster Mushrooms (*Pleurotus ostreatus*) and Exposure Risk in Human Consumption. *Chemosphere* **2022**, *291*, 132898. [CrossRef]
81. Bokade, P.; Purohit, H.J.; Bajaj, A. Myco-Remediation of Chlorinated Pesticides: Insights into Fungal Metabolic System. *Indian J. Microbiol.* **2021**, *61*, 237–249. [CrossRef]
82. Baran, W.; Adamek, E.; Włodarczyk, A.; Lazur, J.; Opoka, W.; Muszyńska, B. The Remediation of Sulfonamides from the Environment by *Pleurotus eryngii Mycelium*. Efficiency, Products and Mechanisms of Mycodegradation. *Chemosphere* **2021**, *262*, 128026. [CrossRef]
83. Golian, M.; Hegedűsová, A.; Mezeyová, I.; Chlebová, Z.; Hegedűs, O.; Urminská, D.; Vollmannová, A.; Chlebo, P. Accumulation of Selected Metal Elements in Fruiting Bodies of Oyster Mushroom. *Foods* **2021**, *11*, 76. [CrossRef]
84. Akhtar, N.; Mannan, M.A. Mycoremediation: Expunging Environmental Pollutants. *Biotechnol. Rep.* **2020**, *26*, e00452. [CrossRef]
85. Pini, A.K.; Geddes, P. Fungi Are Capable of Mycoremediation of River Water Contaminated by *E. coli*. *Water Air Soil Pollut.* **2020**, *231*, 83. [CrossRef]
86. Kumar, V.; Dwivedi, S.K. Mycoremediation of Heavy Metals: Processes, Mechanisms, and Affecting Factors. *Environ. Sci. Pollut. Res.* **2021**, *28*, 10375–10412. [CrossRef] [PubMed]
87. Jureczko, M.; Przystaś, W. Removal of Two Cytostatic Drugs: Bleomycin and Vincristine by White-Rot Fungi—A Sorption Study. *J. Environ. Health Sci. Eng.* **2021**, *19*, 651–662. [CrossRef] [PubMed]
88. Mayans, B.; Camacho-Arévalo, R.; García-Delgado, C.; Antón-Herrero, R.; Escolástico, C.; Segura, M.L.; Eymar, E. An Assessment of *Pleurotus ostreatus* to Remove Sulfonamides, and Its Role as a Biofilter Based on Its Own Spent Mushroom Substrate. *Environ. Sci. Pollut. Res.* **2021**, *28*, 7032–7042. [CrossRef] [PubMed]
89. Xu, F.; Chen, P.; Li, H.; Qiao, S.; Wang, J.; Wang, Y.; Wang, X.; Wu, B.; Liu, H.; Wang, C.; et al. Comparative Transcriptome Analysis Reveals the Differential Response to Cadmium Stress of Two *Pleurotus* Fungi: *Pleurotus cornucopiae* and *Pleurotus ostreatus*. *J. Hazard. Mater.* **2021**, *416*, 125814. [CrossRef] [PubMed]
90. Dickson, U.J.; Coffey, M.; George Mortimer, R.J.; Smith, B.; Ray, N.; Di Bonito, M. Investigating the Potential of Sunflower Species, Fermented Palm Wine and *Pleurotus ostreatus* for Treatment of Petroleum-Contaminated Soil. *Chemosphere* **2020**, *240*, 124881. [CrossRef]
91. Hultberg, M.; Ahrens, L.; Golovko, O. Use of Lignocellulosic Substrate Colonized by Oyster Mushroom (*Pleurotus ostreatus*) for Removal of Organic Micropollutants from Water. *J. Environ. Manag.* **2020**, *272*, 111087. [CrossRef]
92. Grabarczyk, M.; Mączka, W.; Wińska, K.; Żarowska, B.; Maciejewska, G.; Gębarowska, E.; Jerzy Pietr, S. Antimicrobial Chloro-Hydroxylactones Derived from the Biotransformation of Bicyclic Halolactones by Cultures of Pleurotus ostreatus. *Bioorg. Chem.* **2020**, *104*, 104250. [CrossRef] [PubMed]
93. Maadani Mallak, A.; Lakzian, A.; Khodaverdi, E.; Haghnia, G.H.; Mahmoudi, S. Effect of Pleurotus ostreatus and Trametes Versicolor on Triclosan Biodegradation and Activity of Laccase and Manganese Peroxidase Enzymes. *Microb. Pathog.* **2020**, *149*, 104473. [CrossRef]
94. Sharma, V.P.; Kumar, A.; Kumar, S.; Barh, A.; Kamal, S. Substrate Sterilization with Thiophanate-Methyl and Its Biodegradation to Carbendazim in Oyster Mushroom (*Pleurotus ostreatus Var. Florida*). *Environ. Sci. Pollut. Res.* **2020**, *27*, 899–906. [CrossRef]
95. Šrédlová, K.; Škrob, Z.; Filipová, A.; Mašín, P.; Holecová, J.; Cajthaml, T. Biodegradation of PCBs in Contaminated Water Using Spent Oyster Mushroom Substrate and a Trickle-Bed Bioreactor. *Water Res.* **2020**, *170*, 115274. [CrossRef] [PubMed]
96. Chefetz, B.; Marom, R.; Salton, O.; Oliferovsky, M.; Mordehay, V.; Ben-Ari, J.; Hadar, Y. Transformation of Lamotrigine by White-Rot Fungus *Pleurotus ostreatus*. *Environ. Pollut.* **2019**, *250*, 546–553. [CrossRef]
97. Elhusseiny, S.M.; Amin, H.M.; Shebl, R.I. Modulation of Laccase Transcriptome during Biodegradation of Naphthalene by White Rot Fungus *Pleurotus ostreatus*. *Int. Microbiol.* **2019**, *22*, 217–225. [CrossRef]
98. Liu, B.; Huang, Q.; Su, Y.; Xue, Q.; Sun, L. Cobalt Speciation and Phytoavailability in Fluvo-Aquic Soil under Treatments of Spent Mushroom Substrate from *Pleurotus ostreatus*. *Environ. Sci. Pollut. Res.* **2019**, *26*, 7486–7496. [CrossRef]

99. Wang, Y.; Yi, B.; Sun, X.; Yu, L.; Wu, L.; Liu, W.; Wang, D.; Li, Y.; Jia, R.; Yu, H.; et al. Removal and Tolerance Mechanism of Pb by a Filamentous Fungus: A Case Study. *Chemosphere* **2019**, *225*, 200–208. [CrossRef]
100. Carrasco, J.; Zied, D.C.; Pardo, J.E.; Preston, G.M.; Pardo-Giménez, A. Supplementation in Mushroom Crops and Its Impact on Yield and Quality. *AMB Express* **2018**, *8*, 146. [CrossRef]
101. Mirabella, N.; Castellani, V.; Sala, S. Current Options for the Valorization of Food Manufacturing Waste: A Review. *J. Clean. Prod.* **2014**, *65*, 28–41. [CrossRef]
102. Pardo-Giménez, A.; Pardo, J.E.; Dias, E.S.; Rinker, D.L.; Caitano, C.E.C.; Zied, D.C. Optimization of Cultivation Techniques Improves the Agronomic Behavior of Agaricus Subrufescens. *Sci. Rep.* **2020**, *10*, 8154. [CrossRef]
103. Prasad, S.; Rathore, H.; Sharma, S.; Tiwari, G. Yield and Proximate Composition of *Pleurotus florida* Cultivated on Wheat Straw Supplemented with Perennial Grasses. *Indian J. Agric. Sci.* **2018**, *88*, 91–94.
104. Adenipekun, C.O.; Omolaso, P.O. Comparative Study on Cultivation, Yield Performance and Proximate Composition of *Pleurotus pulmonarius* Fries. (Quelet) on Rice Straw and Banana Leaves. *World J. Agric. Sci.* **2015**, *11*, 151–158.
105. Adedokun, O.M.; Akuma, A.H. Maximizing Agricultural Residues: Nutritional Properties of Straw Mushroom on Maize Husk, Waste Cotton and Plantain Leaves. *Nat. Resour.* **2013**, *4*, 534–537. [CrossRef]
106. Triyono, S.; Haryanto, A.; Telaumbanua, M.; Dermiyati; Lumbanraja, J.; To, F. Cultivation of Straw Mushroom (*Volvariella Volvacea*) on Oil Palm Empty Fruit Bunch Growth Medium. *Int. J. Recycl. Org. Waste Agric.* **2019**, *8*, 381–392. [CrossRef]
107. Iqbal, B.; Khan, H.; Saifullah; Khan, I.; Shah, B.; Naeem, A.; Ullah, W.; Khan, N.; Adnan, M.; Shah, S.R.A.; et al. Substrates Evaluation for the Quality, Production and Growth of Oyster Mushroom (*Pleurotus florida Cetto*). *J. Entomol. Zool. Stud.* **2016**, *4*, 98–107.
108. De Souza, D.F.; da Silva, M.D.C.S.; de Paula Alves, M.; Fuentes, D.P.; Porto, L.E.O.; de Oliveira, P.V.; Kasuya, M.C.M.; Eller, M.R. By-Products as Substrates for Production of Selenium-Enriched *Pleurotus ostreatus* Mushrooms. *Waste Biomass Valor.* **2022**, *13*, 989–1001. [CrossRef]
109. Sardar, A.; Satankar, V.; Jagajanantha, P.; Mageshwaran, V. Effect of Substrates (Cotton Stalks and Cotton Seed Hulls) on Growth, Yield and Nutritional Composition of Two Oyster Mushrooms (*Pleurotus ostreatus* and *Pleurotus florida*). *J. Cotton Res. Dev.* **2020**, *34*, 135–145.
110. Grimm, A.; Eilertsen, L.; Chen, F.; Huang, R.; Atterhem, L.; Xiong, S. Cultivation of *Pleurotus ostreatus* Mushroom on Substrates Made of Cellulose Fibre Rejects: Product Quality and Spent Substrate Fuel Properties. *Waste Biomass Valor.* **2021**, *12*, 4331–4340. [CrossRef]
111. Apetorgbor, M.M.; Apetorgbor, A.K. Comparative Studies On Yield Of Volvariella Volvacea Using Root And Tuber Peels For Improved Livelihood Of Communities. *J. Ghana Sci. Assoc.* **2015**, *16*, 34–43.
112. Chaturvedi, V.K.; Yadav, N.; Rai, N.K.; Ellah, N.H.A.; Bohara, R.A.; Rehan, I.F.; Marraiki, N.; Batiha, G.E.-S.; Hetta, H.F.; Singh, M.P. Pleurotus Sajor-Caju-Mediated Synthesis of Silver and Gold Nanoparticles Active against Colon Cancer Cell Lines: A New Era of Herbonanoceutics. *Molecules* **2020**, *25*, 3091. [CrossRef] [PubMed]
113. Chaturvedi, V.K.; Yadav, N.; Rai, N.K.; Bohara, R.A.; Rai, S.N.; Aleya, L.; Singh, M.P. Two Birds with One Stone: Oyster Mushroom Mediated Bimetallic Au-Pt Nanoparticles for Agro-Waste Management and Anticancer Activity. *Environ. Sci. Pollut. Res.* **2021**, *28*, 13761–13775. [CrossRef]
114. Zárate-Salazar, J.R.; Santos, M.N.; Caballero, E.N.M.; Martins, O.G.; Herrera, Á.A.P. Use of Lignocellulosic Corn and Rice Wastes as Substrates for Oyster Mushroom (*Pleurotus ostreatus Jacq.*) Cultivation. *SN Appl. Sci.* **2020**, *2*, 1904. [CrossRef]
115. Tesfay, T.; Godifey, T.; Mesfin, R.; Kalayu, G. Evaluation of Waste Paper for Cultivation of Oyster Mushroom (*Pleurotus ostreatus*) with Some Added Supplementary Materials. *AMB Expr.* **2020**, *10*, 15. [CrossRef]
116. Carrasco-Cabrera, C.P.; Bell, T.L.; Kertesz, M.A. Caffeine Metabolism during Cultivation of Oyster Mushroom (*Pleurotus ostreatus*) with Spent Coffee Grounds. *Appl. Microbiol. Biotechnol.* **2019**, *103*, 5831–5841. [CrossRef]
117. Seekram, P.; Thammasittirong, A.; Thammasittirong, S.N.-R. Evaluation of Spent Mushroom Substrate after Cultivation of *Pleurotus ostreatus* as a New Raw Material for Xylooligosaccharides Production Using Crude Xylanases from Aspergillus Flavus KUB2. *3 Biotech* **2021**, *11*, 176. [CrossRef]
118. Anele, U.Y.; Anike, F.N.; Davis-Mitchell, A.; Isikhuemhen, O.S. Solid-State Fermentation with *Pleurotus ostreatus* Improves the Nutritive Value of Corn Stover-Kudzu Biomass. *Folia Microbiol.* **2021**, *66*, 41–48. [CrossRef]
119. Eliopoulos, C.; Arapoglou, D.; Chorianopoulos, N.; Markou, G.; Haroutounian, S.A. Conversion of Brewers' Spent Grain into Proteinaceous Animal Feed Using Solid State Fermentation. *Environ. Sci. Pollut. Res.* **2021**. [CrossRef]
120. Teixeira, W.F.A.; Batista, R.D.; do Amaral Santos, C.C.A.; Júnior, A.C.F.; Terrasan, C.R.F.; de Santana, M.W.P.R.; de Siqueira, F.G.; de Paula-Elias, F.C.; de Almeida, A.F. Minimal Enzymes Cocktail Development by Filamentous Fungi Consortia in Solid-State Cultivation and Valorization of Pineapple Crown Waste by Enzymatic Saccharification. *Waste Biomass Valor.* **2021**, *12*, 2521–2539. [CrossRef]
121. Zheng, M.; Zuo, S.; Niu, D.; Jiang, D.; Tao, Y.; Xu, C. Effect of Four Species of White Rot Fungi on the Chemical Composition and In Vitro Rumen Degradability of Naked Oat Straw. *Waste Biomass Valor.* **2021**, *12*, 435–443. [CrossRef]
122. Majumder, K.; Paul, B.; Sundas, R. An Analysis of Exo-Polygalacturonase Bioprocess in Submerged and Solid-State Fermentation by *Pleurotus ostreatus* Using Pomelo Peel Powder as Carbon Source. *J. Genet. Eng. Biotechnol.* **2020**, *18*, 47. [CrossRef]

123. Zamora Zamora, H.D.; Silva, T.A.L.; Varão, L.H.R.; Baffi, M.A.; Pasquini, D. Simultaneous Production of Cellulases, Hemicellulases, and Reducing Sugars by *Pleurotus ostreatus* Growth in One-Pot Solid State Fermentation Using *Alstroemeria* sp. Waste. *Biomass Conv. Bioref.* **2021**. [CrossRef]
124. Atlı, B.; Yamaç, M.; Yıldız, Z.; Şőlener, M. Solid State Fermentation Optimization of *Pleurotus ostreatus* for Lovastatin Production. *Pharm. Chem. J.* **2019**, *53*, 858–864. [CrossRef]
125. Giacobbe, S.; Piscitelli, A.; Raganati, F.; Lettera, V.; Sannia, G.; Marzocchella, A.; Pezzella, C. Butanol Production from Laccase-Pretreated Brewer's Spent Grain. *Biotechnol. Biofuels* **2019**, *12*, 47. [CrossRef]
126. Falade, A.O. Valorization of Agricultural Wastes for Production of Biocatalysts of Environmental Significance: Towards a Sustainable Environment. *Environ. Sustain.* **2021**, *4*, 317–328. [CrossRef]
127. Fasiku, S.; Monilola Wakil, S. Pretreatment of Maize Straw with Pleurotus ostreatus and Lentinus Squarrosulus for Bioethanol Production Using *Saccharomyces cerevisiae*. *Nov. Res. Microbiol. J.* **2021**, *5*, 1480–1493. [CrossRef]
128. Andrade, M.C.; Gorgulho Silva, C.D.O.; de Souza Moreira, L.R.; Ferreira Filho, E.X. Crop Residues: Applications of Lignocellulosic Biomass in the Context of a Biorefinery. *Front. Energy* **2021**. [CrossRef]
129. Tramontina, R.; Brenelli, L.B.; Sodré, V.; Franco Cairo, J.P.; Travália, B.M.; Egawa, V.Y.; Goldbeck, R.; Squina, F.M. Enzymatic Removal of Inhibitory Compounds from Lignocellulosic Hydrolysates for Biomass to Bioproducts Applications. *World J. Microbiol. Biotechnol.* **2020**, *36*, 166. [CrossRef]
130. Moreira, B.R.D.A.; Viana, R.D.S.; Magalhães, A.C.; Caraschi, J.C.; Zied, D.C.; Dias, E.S.; Rinker, D.L. Production of *Pleurotus ostreatus Var. Florida* on Briquettes and Recycling Its Spent Substrate as Briquettes for Fuel Grade Biosolids. *J. Clean. Prod.* **2020**, *274*, 123919. [CrossRef]
131. Medina, J.; Monreal, C.M.; Orellana, L.; Calabi-Floody, M.; González, M.E.; Meier, S.; Borie, F.; Cornejo, P. Influence of Saprophytic Fungi and Inorganic Additives on Enzyme Activities and Chemical Properties of the Biodegradation Process of Wheat Straw for the Production of Organo-Mineral Amendments. *J. Environ. Manag.* **2020**, *255*, 109922. [CrossRef] [PubMed]
132. Singh, R.; Das, R.; Sangwan, S.; Rohatgi, B.; Khanam, R.; Peera, S.K.P.G.; Das, S.; Lyngdoh, Y.A.; Langyan, S.; Shukla, A.; et al. Utilisation of Agro-Industrial Waste for Sustainable Green Production: A Review. *Environ. Sustain.* **2021**, *4*, 619–636. [CrossRef]
133. Leong, Y.K.; Ma, T.-W.; Chang, J.-S.; Yang, F.-C. Recent Advances and Future Directions on the Valorization of Spent Mushroom Substrate (SMS): A Review. *Bioresour. Technol.* **2022**, *344*, 126157. [CrossRef]
134. Mohd Hanafi, F.H.; Rezania, S.; Mat Taib, S.; Md Din, M.F.; Yamauchi, M.; Sakamoto, M.; Hara, H.; Park, J.; Ebrahimi, S.S. Environmentally Sustainable Applications of Agro-Based Spent Mushroom Substrate (SMS): An Overview. *J. Mater. Cycles Waste Manag.* **2018**, *20*, 1383–1396. [CrossRef]
135. Umor, N.A.; Ismail, S.; Abdullah, S.; Huzaifah, M.H.R.; Huzir, N.M.; Mahmood, N.A.N.; Zahrim, A.Y. Zero Waste Management of Spent Mushroom Compost. *J. Mater. Cycles Waste Manag.* **2021**, *23*, 1726–1736. [CrossRef]
136. Vodovnik, M.; Vrabec, K.; Hellwig, P.; Benndorf, D.; Sežun, M.; Gregori, A.; Gottumukkala, L.D.; Anderson, R.C.; Reichl, U. Valorisation of Deinking Sludge as a Substrate for Lignocellulolytic Enzymes Production by *Pleurotus ostreatus*. *J. Clean. Prod.* **2018**, *197*, 253–263. [CrossRef]
137. Chmelová, D.; Legerská, B.; Kunstová, J.; Ondrejovič, M.; Miertuš, S. The Production of Laccases by White-Rot Fungi under Solid-State Fermentation Conditions. *World J. Microbiol. Biotechnol.* **2022**, *38*, 21. [CrossRef]
138. Bilal, M.; Iqbal, H.M.N. Ligninolytic Enzymes Mediated Ligninolysis: An Untapped Biocatalytic Potential to Deconstruct Lignocellulosic Molecules in a Sustainable Manner. *Catal. Lett.* **2020**, *150*, 524–543. [CrossRef]
139. Brugnari, T.; Braga, D.M.; dos Santos, C.S.A.; Torres, B.H.C.; Modkovski, T.A.; Haminiuk, C.W.I.; Maciel, G.M. Laccases as Green and Versatile Biocatalysts: From Lab to Enzyme Market—An Overview. *Bioresour. Bioprocess.* **2021**, *8*, 131. [CrossRef]
140. Kumar, A.; Singh, A.K.; Bilal, M.; Chandra, R. Extremophilic Ligninolytic Enzymes: Versatile Biocatalytic Tools with Impressive Biotechnological Potential. *Catal. Lett.* **2021**. [CrossRef]
141. Kunjadia, P.D.; Sanghvi, G.V.; Kunjadia, A.P.; Mukhopadhyay, P.N.; Dave, G.S. Role of Ligninolytic Enzymes of White Rot Fungi (*Pleurotus* spp.) Grown with Azo Dyes. *SpringerPlus* **2016**, *5*, 1487. [CrossRef]
142. Irshad, A.; Sarwar, N.; Sadia, H.; Riaz, M.; Sharif, S.; Shahid, M.; Khan, J.A. Silver Nano-Particles: Synthesis and Characterization by Using Glucans Extracted from *Pleurotus ostreatus*. *Appl. Nanosci.* **2020**, *10*, 3205–3214. [CrossRef]
143. Owaid, M.N. Green Synthesis of Silver Nanoparticles by *Pleurotus* (Oyster Mushroom) and Their Bioactivity: Review. *Environ. Nanotechnol. Monit. Manag.* **2019**, *12*, 100256. [CrossRef]
144. Martínez-Flores, H.E.; Contreras-Chávez, R.; Garnica-Romo, M.G. Effect of Extraction Processes on Bioactive Compounds from Pleurotus ostreatus and Pleurotus Djamor: Their Applications in the Synthesis of Silver Nanoparticles. *J. Inorg. Organomet. Polym.* **2021**, *31*, 1406–1418. [CrossRef]
145. Manimaran, K.; Murugesan, S.; Ragavendran, C.; Balasubramani, G.; Natarajan, D.; Ganesan, A.; Seedevi, P. Biosynthesis of TiO_2 Nanoparticles Using Edible Mushroom (*Pleurotus Djamor*) Extract: Mosquito Larvicidal, Histopathological, Antibacterial and Anticancer Effect. *J. Clust. Sci.* **2021**, *32*, 1229–1240. [CrossRef]
146. Manimaran, K.; Natarajan, D.; Balasubramani, G.; Murugesan, S. *Pleurotus Sajor Caju* Mediated TiO_2 Nanoparticles: A Novel Source for Control of Mosquito Larvae, Human Pathogenic Bacteria and Bone Cancer Cells. *J. Clust. Sci.* **2021**. [CrossRef]
147. Manimaran, K.; Balasubramani, G.; Ragavendran, C.; Natarajan, D.; Murugesan, S. Biological Applications of Synthesized ZnO Nanoparticles Using *Pleurotus Djamor* Against Mosquito Larvicidal, Histopathology, Antibacterial, Antioxidant and Anticancer Effect. *J. Clust. Sci.* **2021**, *32*, 1635–1647. [CrossRef]

148. Sargin, I.; Karakurt, S.; Alkan, S.; Arslan, G. Live Cell Imaging With Biocompatible Fluorescent Carbon Quantum Dots Derived From Edible Mushrooms *Agaricus Bisporus*, *Pleurotus ostreatus*, and *Suillus Luteus*. *J. Fluoresc.* **2021**, *31*, 1461–1473. [CrossRef] [PubMed]
149. Kaur, P.; Thakur, M.; Tondan, D.; Bamrah, G.K.; Misra, S.; Kumar, P.; Pandohee, J.; Kulshrestha, S. Nanomaterial Conjugated Lignocellulosic Waste: Cost-Effective Production of Sustainable Bioenergy Using Enzymes. *3 Biotech* **2021**, *11*, 480. [CrossRef] [PubMed]
150. Koul, B.; Yakoob, M.; Shah, M.P. Agricultural Waste Management Strategies for Environmental Sustainability. *Environ. Res.* **2022**, *206*, 112285. [CrossRef] [PubMed]
151. Ahmed, P.M.; de Figueroa, L.I.C.; Pajot, H.F. Dual Purpose of Ligninolytic- Basidiomycetes: Mycoremediation of Bioethanol Distillation Vinasse Coupled to Sustainable Bio-Based Compounds Production. *Fungal Biol. Rev.* **2020**, *34*, 25–40. [CrossRef]
152. Karimi, F.; Mazaheri, D.; Saei Moghaddam, M.; Mataei Moghaddam, A.; Sanati, A.L.; Orooji, Y. Solid-State Fermentation as an Alternative Technology for Cost-Effective Production of Bioethanol as Useful Renewable Energy: A Review. *Biomass Conv. Bioref.* **2021**. [CrossRef]
153. Naresh Kumar, M.; Ravikumar, R.; Thenmozhi, S.; Ranjith Kumar, M.; Kirupa Shankar, M. Choice of Pretreatment Technology for Sustainable Production of Bioethanol from Lignocellulosic Biomass: Bottle Necks and Recommendations. *Waste Biomass Valor.* **2019**, *10*, 1693–1709. [CrossRef]
154. Antunes, F.; Marçal, S.; Taofiq, O.; Morais, A.M.M.B.; Freitas, A.C.; CFRFerreira, I.; Pintado, M. Valorization of Mushroom By-Products as a Source of Value-Added Compounds and Potential Applications. *Molecules* **2020**, *25*, 2672. [CrossRef]
155. Ryden, P.; Efthymiou, M.-N.; Tindyebwa, T.A.M.; Elliston, A.; Wilson, D.R.; Waldron, K.W.; Malakar, P.K. Bioethanol Production from Spent Mushroom Compost Derived from Chaff of Millet and Sorghum. *Biotechnol. Biofuels* **2017**, *10*, 195. [CrossRef]
156. Huang, W.; Yuan, H.; Li, X. Multi-Perspective Analyses of Rice Straw Modification by *Pleurotus ostreatus* and Effects on Biomethane Production. *Bioresour. Technol.* **2020**, *296*, 122365. [CrossRef]
157. Richard, E.N.; Hilonga, A.; Machunda, R.L.; Njau, K.N. Two-Stage Banana Leaves Wastes Utilization towards Mushroom Growth and Biogas Production. *3 Biotech* **2020**, *10*, 542. [CrossRef]
158. Devi, R.; Kapoor, S.; Thakur, R.; Sharma, E.; Tiwari, R.K.; Joshi, S.J. Lignocellulolytic Enzymes and Bioethanol Production from Spent Biomass of Edible Mushrooms Using Saccharomyces Cerevisiae and *Pachysolen Tannophilus*. *Biomass Conv. Bioref.* **2022**. [CrossRef]
159. Sotthisawad, K.; Mahakhan, P.; Vichitphan, K.; Vichitphan, S.; Sawaengkaew, J. Bioconversion of Mushroom Cultivation Waste Materials into Cellulolytic Enzymes and Bioethanol. *Arab. J. Sci. Eng.* **2017**, *42*, 2261–2271. [CrossRef]
160. Sonwani, R.; Gupta, S.B.; Soni, R. Production of Bioethanol from Biodegraded Alkali Pretreated Rice Straw. *Vegetos* **2020**, *33*, 128–134. [CrossRef]
161. Suri, P.; Dwivedi, D.; Rathour, R.K.; Rana, N.; Sharma, V.; Bhatia, R.K.; Bhatt, A.K. Enhanced C-5 Sugar Production from Pine Needle Waste Biomass Using *Bacillus* sp. XPB-11 Mutant and Its Biotransformation to Bioethanol. *Biomass Conv. Bioref.* **2021**. [CrossRef]
162. Bilal, M.; Asgher, M.; Iqbal, H.M.N.; Ramzan, M. Enhanced Bio-Ethanol Production from Old Newspapers Waste Through Alkali and Enzymatic Delignification. *Waste Biomass Valor.* **2017**, *8*, 2271–2281. [CrossRef]
163. Izmirlioglu, G.; Demirci, A. Simultaneous Saccharification and Fermentation of Ethanol from Potato Waste by Co-Cultures of *Aspergillus Niger* and *Saccharomyces Cerevisiae* in Biofilm Reactors. *Fuel* **2017**, *202*, 260–270. [CrossRef]
164. Shankar, K.; Kulkarni, N.S.; Jayalakshmi, S.K.; Sreeramulu, K. Saccharification of the Pretreated Husks of Corn, Peanut and Coffee Cherry by the Lignocellulolytic Enzymes Secreted by Sphingobacterium sp. Ksn for the Production of Bioethanol. *Biomass Bioenergy* **2019**, *127*, 105298. [CrossRef]
165. Sudhakar, M.P.; Ravel, M.; Perumal, K. Pretreatment and Process Optimization of Bioethanol Production from Spent Biomass of Ganoderma Lucidum Using *Saccharomyces Cerevisiae*. *Fuel* **2021**, *306*, 121680. [CrossRef]
166. Holmatov, B.; Schyns, J.F.; Krol, M.S.; Gerbens-Leenes, P.W.; Hoekstra, A.Y. Can Crop Residues Provide Fuel for Future Transport? Limited Global Residue Bioethanol Potentials and Large Associated Land, Water and Carbon Footprints. *Renew. Sustain. Energy Rev.* **2021**, *149*, 111417. [CrossRef]
167. Periyasamy, S.; Karthik, V.; Senthil Kumar, P.; Isabel, J.B.; Temesgen, T.; Hunegnaw, B.M.; Melese, B.B.; Mohamed, B.A.; Vo, D.-V.N. Chemical, Physical and Biological Methods to Convert Lignocellulosic Waste into Value-Added Products. A Review. *Environ. Chem. Lett.* **2022**. [CrossRef]
168. Rajesh Banu, J.; Preethi; Kavitha, S.; Tyagi, V.K.; Gunasekaran, M.; Karthikeyan, O.P.; Kumar, G. Lignocellulosic Biomass Based Biorefinery: A Successful Platform towards Circular Bioeconomy. *Fuel* **2021**, *302*, 121086. [CrossRef]
169. Hassan, S.S.; Williams, G.A.; Jaiswal, A.K. Emerging Technologies for the Pretreatment of Lignocellulosic Biomass. *Bioresour. Technol.* **2018**, *262*, 310–318. [CrossRef] [PubMed]