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Substrates for mushroom, enzyme and metabolites production: A review

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Abstract

The agri-food industry produces a large quantity and variety of foods that are the basis of diet for humans in the world, generating waste with a high content of compounds such as lignin, cellulose and hemicellulose that are difficult to degrade. There are chemical methodologies for the partial degradation of agro-industrial waste, but it carries a possibly greater risk of environmental contamination by the chemicals used for such purposes, so natural alternatives are sought for its degradation and obtain an economic and sustainable benefit for its use through mushroom cultivation. Mushroom production can be carried out using macrofungi that are edible, have medicine value also enzyme or metabolite-producing.

Waste such as sunflower seed husk, peanut husk, corn husks, potato husk, coffee husk, cocoa husk, bean shell, pea shell, sawdust from different woods, cob and stubble of corn, oat stubble, tomato stubble, sorghum stubble, straw from various cereals, wheat bran, rice bran, cotton stalks, sugarcane bagasse, tequila agave waste, quinoa waste, coconut and banana wastes, dehydrated jicama, almond leaves, among others, are used as a substrate for the cultivation of mushrooms, which have been used alone or in mixtures, seeking to increase the production of carpophores or their metabolites and enzymes.

Key words: Agro-industrial waste, Culture, Enzymes, Mushrooms, Substrates

Introduction

Across the globe, approximately 200 billion tons of plant biomass are produced per year through photosynthetic process (Zhang, 2008). However, much of this organic matter is not edible by humans and animals, which represents a source of environmental contamination. It is worth mentioning that it is estimated that the production of crop residues is around 4 billion tons per year and 75% comes from cereals (Lal, 2008). The residues generated as a result of agriculture, horticulture, agroforestry and agro-industrial activities are rich in organic compounds such as lignin, cellulose and hemicellulose, which can be used as livestock feed, however, a large amount of these residues remain unused is used and become a cause for environmental issues.

Agro-industrial wastes such as sunflower seed husk, peanut husk, sawdust from different woods, corn cob, corn stubble, corn husk, rice straw, wheat or rice bran, wheat straw mixed with eucalyptus sawdust, straw from different cereals, potato husk, cotton stalks, various grasses, sugarcane bagasse, tequila agave residues, quinoa residues, coconut and banana residues, palm kernel husk, dehydrated jicama, coffee pulp and coffee husk, almond leaves, cocoa husk, bean shell, pea shell, passion fruit, wood shavings, oat stubble, tomato stubble, broccoli residue, cauliflower and romanesco residue, lupine residue, residue hibiscus, cocoa leaves, coconut leaves, coconut fiber, sorghum stubble, etc., can be used and transformed into products of greater value and utility through biotechnological processes, including mushroom cultivation (Figlas *et al.,* 2007; Philippoussis, 2009; Sharma *et al.,* 2013; Ha-

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Thi *et al.,* 2015; Figlas *et al.,* 2016; Infante *et al.,* 2016; Lun-Nam *et al.,* 2017).

Currently, society has a great demand for nutritious food, but it is also concerned with combating environmental pollution; consequently, considerable emphasis is placed on the recovery and recycling of waste generated by the agricultural and agri-food sector (Philippoussis, 2009). The physico-chemical properties of these wastes offer a great opportunity to be exploited showing enormous biotechnological value since they can be used as a substrate-support in solid-state fermentation process for the cultivation of edible or medicinal mushrooms and later, as nutrient-enriched animal feed, as well as for microbial production of secondary metabolites and enzymes and more recently for energy production in biorefineries (ZawiŠlak *et al.,* 2020). Mushroom production is a viable alternative to use lignocellulosic waste as they have the ability to produce enzymes that degrade these materials (Carrera *et al.,* 2000). In the present review article, efforts have been made to compile all types of residues or by-products used for cultivation of varieties of edible and medicinal mushrooms grown worldwide.

Conditioning substrate for mushroom cultivation: The cultivation of mushrooms as a biotechnological process is very efficient to recover, use and transform lignocellulosic waste, giving it added value and at the same time help in reducing environmental contamination. The cultivation of mushrooms represents an economically important and expanded biotechnological industry worldwide, in addition these mushrooms have also been used for the production of food proteins, enzymes or metabolites of biotechnological interest from lignocellulosic materials. *Agaricus bisporus*, *Pleurotus* spp., *Ganoderma lucidum* and *Lentinula edodes* are some of the commercially produced mushrooms in the world (Philippoussis, 2009).

Pleurotus is one of the most studied and cultivated genus known for its nutritional value and ability to biodegrade recalcitrant compounds. For this reason a lot of work has been done to take advantage of different lignocellulosic residues for its cultivation (Sharma *et al.,* 2013; Ha-Thi0 *et al.,* 2015; Infante *et al.,* 2016; Lun-Nam *et al.,* 2017). Mushroom cultivation in general involves two phases of their life cycle, *i.e.,* the vegetative phase and the reproductive phase. After inoculation, the mycelium grows on the substrate, biodegrades its components and thereafter, the fruiting bodies develop. The growth and fruiting of fungus are regulated by temperature, the gaseous environment, nutrients, status, water activity and in certain cases light (Zadrazil *et al.,* 2004). Under controlled environment cultivation system, the temperature is manipulated by means of heating or cooling systems to maintain the optimum ones for vegetative growth or fruiting (Martínez-Carrera *et al.,* 2000). The level of carbon dioxide and humidity are also controlled and the production of fruiting bodies on the surface of the substrate occurs as a series of cycles depending on the type of fungus grown (Philippoussis, 2009). Most lignocellulosic residues require a pre-treatment to be used as a substrate for the cultivation of mushrooms, which can either be sterilized or pasteurized, where the elimination or reduction of contaminating microorganisms is sought and increase the water activity of the substrate so that itis optimal for the growth of mushrooms.

The preparation of substrate varies according to the type of mushroom used for cultivation and production, e.g., the large-scale production of *Agaricus bisporus* requires specialized machinery to process tons of wheat straw, where it is very difficult to control different variables of cultivation (concentration of carbon and nitrogen, pH of the medium, among others), which allow a successful composting process, good colonization and fruiting of fungi (Wood and Smith, 1987). Not all mushrooms require a fermented substrate such as those of genus *Agaricus*, fungi of some genera such as *Pleurotus* and *Lentinula* are considered white-rot fungi that are grown on pasteurized lignocellulosic substrates instead of compost (Zadrazil *et al.,* 2004). It is worth mentioning that it is necessary to find the final disposal of waste spent by cultivated mushrooms. It has been suggested that these waste can be used as animal feed for the production of fertilizers and energy production, however, more research is required in this regard (Mohd-Hanafi *et al.,* 2018).

Substrates used for mushroom production: Various lignocellulosic residues that can be used for the production of mushrooms are listed in Table 1, while the mixture of substrates has also been reported Table 2. Sunflower (*Helianthus annuus*) seed husk is an agro-industrial waste resulting from oil extraction process, has little utility and causes environmental problem because it degrades slowly. It has been marketed as a support material in poultry, as a chimney material, but these markets are limited. It is also used as a forage for ruminants such as cows and sheep, but high lignin content makes it useless as animal feed (Figlas *et al.,* 2016). In some cases, they are incinerated, but this contributes in another way in contaminating the environment, it has been buried in the ground, but it is not safe for the field because it con contain *Sclerotinia sclerotiorum*, a phytopathogenic fungus (Curvetto *et al.,* 2005). An alternative is to use as substrate for mushroom cultivation (González-Matute *et al.,* 2010; González-Matute *et al.,* 2011). Sunflower seed husk has been used as a substrate for the production of *Ganoderma lucidum*, *Pleurotus* spp., *Lentinula edodes* and *Hericium erinaceus* (Figlas *et al.,* 2007).

Sunflower seed husk has been used as the main ingredient in a compost mixture to produce edible mushrooms such as *Agaricus bisporus* white variety, *Agaricus bisporus* brown variety and *Agaricus blazei*. This mixture contains 51.4% sunflower seed husk, 40% wheat straw, 3.8% wheat bran, 1.2% urea, 1.2% ammonium sulfate and 2.4% gypsum, obtaining a high biological efficiency (Pokhrel and Ohga, 2007). It is also mixed with wheat bran, barley bran and/or oils to produce *Schizophyllum commune* (Figlas *et al.,* 2014).The husk of sunflower seeds are also used for the production of medicinal mushrooms such as *Grifola gargal* and *Grifola sordulenta*, where a high protein content and high laccase activity were observed

(Postemsky and Curvetto, 2015). The residual biomass of coffee (*Coffea arabica*), which includes pulp and mucilage, represents the most abundant by-product of the process of obtaining the coffee bean since it is around 60% of the weight of fresh fruit. This residue contains fiber, fat, cellulose, lignin, etc. (González *et al.,* 2020). Such residues are used as natural fertilizers, which has advantages and disadvantages, since this organic matter on decomposing can generate leachates that can be rich in metals and in turn can be harmful to the surrounding crops. On the other hand, the coffee residue has been mixed with wheat straw (*Triticum durum*), barley straw (*Hordeum vulgare*), bean straw (*Phaseolus vulgaris*), corn stubble (*Zea mays*), cedar shavings (*Cedrela odorata*) has been used for the production of edible mushrooms such as *Pleurotus* spp. and medicinal mushrooms such as *Ganoderma lucidum* and *Lentinula edodes* (Bermudez-Savón *et al.,* 2007; Romero-Arenas *et al.,* 2013).

Pleurotus ostreatus is widely consumed for its excellent nutritional quality. Since it is a white-rot fungus, their enzymes degrade lignocellulosic compounds present in coffee residues, either alone or mixed with other agro-industrial residues (González *et al.,* 2020). Multiple studies have been carried out to evaluate the biological efficiency of *Pleurotus ostreatus* grown on the aforementioned substrates, observing a biological efficiency on the coffee pulp similar to that of wheat straw and higher than that obtained in corn stubble (Romero-Arenas *et al.,* 2013; González *et al.,* 2020). In a study, the growth of *Pleurotus ostreatus* on coffee pulp and/or cedar shavings, as well as the mixture of both substrates in 1:1 ratio, it was observed that the mushroom can grow in three conditions, however, higher production was observed on the coffee pulp (García-Oduardo *et al.,* 2006; Bermúdez-Savón *et al.,* 2007). *Lentinula edodes* commonly known as shiitake or Japanese mushroom is capable of degrading cellulose, hemicellulose and lignin, and for its cultivation wheat straw, corn cob or sugarcane bagasse are used, which showed better yield as compared when this fungus was cultivated on its natural substrate. It requires approximately 25 °C temperature and relative humidity close to 100%, with respect to light/dark periods, it will depend on the growth stage of mushroom (Rodríguez-Valencia and Jaramillo-López, 2005).

Ganoderma lucidum is one of the polypore representatives best known for its medicinal properties. It has a kidney shape with a woody texture with a diameter of 5 to 20 cm and has a shiny surface when wet. It is a saprophytic fungus found on logs of oak trees (*Quercus acutissima, Quercus aliena* and *Quercus serrata*) and requires a temperature of 30°C, and a relative humidity of approximately 95% and depending on the growth stage the light emission is manipulated (Rodríguez-Valencia and Jaramillo-López, 2005). For the cultivation of medicinal mushrooms *Ganoderma lucidum* and *Lentinula edodes,* which are ligninolytic fungi, a heat treatment of the substrates is also required to break up structures and eliminate contaminating microorganisms (Rodríguez-Valencia and Jaramillo-López, 2005). Specifically, the coffee residues, alone or mixed, are sterilized in autoclave or in a traditional way by using steam at atmospheric pressure, then inoculation is carried out and the optimal conditions are provided for the development of fungi. In a study, it was been observed that coffee residues are an excellent substrate for the production of *Ganoderma lucidum* and *Lentinula edodes* (Rodríguez-Valencia and Jaramillo-López, 2005). Wheat straw is the most abundant lignocellulosic residues in the world. It is rich in lignin, cellulose and hemicellulose, which is generally consumed by farm animals, while a limited percent is used in the production of pulp for paper, however, there is a possibility of using it as a substrate for the growth of mushrooms like *Agrocybe aegerita, Volvariella volvacea* and *Pleurotus* spp. (Bian *et al.,* 2019). It is worth mentioning that the combination of tomato stubble with wheat straw in 1:1 ratio increased the biological efficiency grow of fruiting bodies of *Pleurotus ostreatus* and *Pleurotus pulmonarius* (Sánchez *et al.,* 2008).

Mushrooms of genus *Volvariella* on lignocellulosic substrates that include rice straw, wheat bran, sawdust from different woods, banana leaves and sugarcane bagasse. The biological efficiency of fruiting bodies was achieved and their speed of mycelial invasion was measured. *Volvariella volvacea* and *Volvariella diplasia* were grown on the mixture of wheat straw with rice bran, observing a significantly faster mycelial growth compared to other substrates evaluated, the second-best substrate was wheat straw for *Volvariella volvacea* and the mixture of straw and wheat bran for *Volvariella diplasia*. Regarding fruiting, the culture on wheat straw mixed with rice bran presented the highest production in both species of *Volvariella*, the lowest biological and economic yields were found when the culture was grown on the mixture of wheat straw with banana leaves for *Volvariella volvacea* and wheat straw with sugarcane bagasse for *Volvariella diplasia* (Tripathy, 2010).

Various agro-industrial residues have little use, such as residues from the stem of cotton plant (*Gossypium hirsutum*), coconut fiber (*Cocos nucifera*) or stubble of sorghum plant (*Sorghum bicolor*). Few studies have also been done on the use of these materials for mushroom production. In a study, the production of fruiting bodies of *Pleurotus sajor-caju, Pleurotus platypus* and *Pleurotus citrinopileatus*, grown in the aforementioned residues, were reported. In all cases, at least 30 days was required to obtain fruiting bodies. The primordia of *Pleurotus sajor-caju* and *Pleurotus platypus* appeared approximately 21 and 23 days in the coconut fiber and up to 25 days in cotton waste (Ragunathan and Swaminathan, 2003). *Pleurotus ostreatus* and *Pleurotus pulmonarius* have also been cultivated on cotton residues, observing adequate growth (Garcés-Molina *et al.,* 2005). In some studies, more than two substrates were mixed, to increase biological efficiency and reduce the production time. For the cultivation of *Pleurotus ostreatus*, some of the proposed mixtures are wood shavings, sugar beet and other ligninolytic residues mixture of palm fiber (*Aracaceae* genus), wheat bran, rice bran and soy residues (*Glycine max*), and mixture of soy residues, rice bran and carrot pulp (*Daucus carota*) as a complement. The results revealed that the mixture containing wood shavings and sugar beet was more

Table 1: Substrates used for the cultivation of edible and medicinal mushrooms

Substrates	Mushrooms	References
Sunflower seed husk Coconut fiber Cocoa fruit shells Banana plant leaves Cedar shavings	*Agaricus bisporus, Agaricus blazei* *Auricularia fuscosuccinea,* *Oudemansiella canarii*, *Schizophyllum commune*	González-Matute *et al.*, 2011 Carreño-Ruíz *et al.*, 2014
Coffee pulp	*Pleurotus ostreatus*	García-Oduardo *et al.*, 2006
Coffee cherry	*Pleurotus ostreatus*	González *et al.*, 2020
Coffee bagasse	*Pleurotus ostreatus*	Romero-Arenas *et al.*, 2013
Wheatstraw Cotton waste Peanutshells White poplarsawdust Oaksawdust Corncob Olive press-cake	*Pleurotus ostreatus, Pleurotus eryngii, Pleurotus pulmonarius, Agrocybe aegerita, Lentinula edodes, Volvariella volvacea, Auricularia auricula-judae*	Zervakis *et al.*, 2001
Cottonseed hull Sawdust Corn cob	*Oudemansiella canarii*	Xu *et al.*, 2015
Sunflower seed hulls	*Hericium erinaceus*	Figlas *et al.*, 2007
Banana plant leaves Sawdust of *Cariniana pyriformis*	*Pleurotus djamor*	Motato *et al.*, 2006
Corn residues Quinoa waste (*Chenopodium quinoa*)	*Pleurotus ostreatus*	Toledo-Álvarez, 2008
Sawdust Corn cob Sugar cane bagasse	*Pleurotus ostreatus, Pleurotus cystidiosus*	Thi-Hoa *et al.*, 2015
Waste of *Agave tequilana*	*Pleurotus djamor, Pleurotus ostreatus*	Cruz-Moreno, 2019
Rice straw Corn stubble	*Pleurotus pulmonarius, Pleurotus djamor*	Vega and Franco, 2012
Wheat straw Cotton waste Peanut shells	*Pleurotus ostreatus, Pleurotus eryngii*, *Pleurotus pulmonarius, Agrocybe aegerita*, *Volvariella volvacea*	Philippoussis *et al.*, 2001
Palm kernel shell	*Pleurotus ostreatus*	Lun-Nam *et al.*, 2018
Corn cob Corn husk	*Pleurotus pulmonarius*	Infante *et al.*, 2016
Rice husk Wheat straw Sawdust	*Pleurotus eryngii*	Andrino *et al.*, 2011
Agave salmiana Agave weberi	*Pleurotus ostreatus*	Heredia-Solís *et al.*, 2014
Sugar cane bagasse Maize stem Sawdust Coffee waste	*Pleurotus ostreatus*	Garzón-Gómez and Cuervo-Andrade, 2008
Potato peel banana peel Sugarcane pulp	*Pleurotus ostreatus*	Rivera-Omen *et al.*, 2013
Chips of poplars Chips of eucalyptus	*Pleurotus ostreatus*	Varnero *et al.*, 2010
Rice	*Pleurotus sajor-caju*	Zhang *et al.*, 2002
Rice hulls	*Pleurotus ostreatus*	Castro-Bolaño *et al.*, 2018
Corn husk Almond leaves Wood sawdust	*Pleurotus ostreatus*	Hernández-Martínez, 2020
Cocoa Shell	*Pleurotus ostreatus*	Lindao-Pérez, 2016

Table continued

Substrates	Mushrooms	References
Rachis of Palm		
Coconut shell		
Vicia faba peel	*Pleurotus ostreatus*	Martínez-Padrón, 2017
Peanuts shell (*Arachis hypogaea*)	*Pleurotus sapidus*	Rojas-Ledezma, 2016
Lazy bean shell (*Cajanus cajan*)		
Rind of passion fruit	*Pleurotus sapidus, Pleurotus ostreatus*	Coello-Loor, 2012
Kikuyo lawn	*Pleurotus ostreatus, Pleurotus pulmonarius*	Garcés-Molina *et al.,* 2005
Forage peanut		
Bean pod		
Cotton rind		
Extract of coffee pulp	*Pleurotus* spp.	Bermúdez-Savón *et al.,* 2007
Coconuts shells	*Pleurotus ostreatus* f. sp. florida	Bermúdez *et al.,* 2001
Oat straw	*Pleurotus ostreatus*	Maccapa-Pocco, 2021
Cattail hay		
Quinoa brush		
Tomato stubble	*Pleurotus pulmonarius, Pleurotus ostreatus*	Sánchez *et al.,* 2008
Residues of *Lupinos mutabilis*	*Pleurotus ostreatus*	Aguilar-Yaguana, 2020
Dry stems of jamaica (*Hibiscus sabdariffa*)	*Pleurotus ostreatus, Pleurotus pulmonarius*	Cayetano-Catarino and Bernabé-González, 2008
Wheat bran	*Pleurotus sajor-caju*	Shahadat *et al.,* 2010
Rice bran		
Cotton stalk	*Pleurotus sajor-caju, Pleurotus citrinopileatus,*	Ragunathan and
Coconut fiber	*Pleurotus platypus*	Swaminathan, 2003
Sorghum stover		
Coffee residues	*Lentinula edodes, Ganoderma lucidum*	Rodríguez-Valencia and
Corn bran		Jaramillo-López, 2005
Paddy straw	*Volvariella volvacea, Volvariella diplasia*	Tripathy, 2010
Sunflower seed hull	*Pleurotus ostreatus*	Figlas *et al.,* 2016
Sorghum	*Neolentinus ponderosus*	Zuluaga-Jiménez *et al.,* 2017

efficient in decreasing the growth time, increase in biomass produced and high biological efficiency with respect to the use of materials that were used individually for the growth of mushroom. Likewise, it was observed that the mixture of coconut fiber, wheat, rice and soybean bran resulted in higher yield, higher biological efficiency and increase in the weight of biomass produced with respect to the use of materials separately (Jafarpour *et al.,* 2010). Two other mixtures used for the growth of mushrooms of genus *Pleurotus* were peanut husk (*Arachis hypogaea*) added with cotton husk and grass (*Pennisetum clandestinum*) with starch husk, showed the appearance of primordia at 20 days after inoculation with first mixture and 30 days after second. It was also observed that the appearance of primordia was 60% higher in *Pleurotus ostreatus* compared to *Pleurotus pulmonarius* in the first treatment (Garcés-Molina *et al.,* 2005).

For the production of *Pleurotus djamour*, banana peel (*Musa paradisiaca*) and sawdust (*Cariniana pyriformis*) enriched with leaves, stem and fruit of banana plant were used in the following proportions: sawdust with banana leaves (50/50), sawdust with banana stem (50/50), sawdust with banana fruit (50/50), and a final mixture of sawdust with the leaves, stem and fruit of banana (25/25/25/25). The best results were observed in the growth production and fruiting bodies, enzyme production and the biological efficiency was high in the mixture of sawdust and banana plant leaves. Similar results were observed when mushroom was grown only in banana leaves (Motato *et al.,* 2006). Hoa *et al.* (2015) evaluated seven substrate formulas that included sawdust, corn cob, sugarcane bagasse individually and in combination, sawdust with corn cob (80/20) and sawdust with sugarcane bagasse (50/50), finding a significant difference in the total colonization period, characteristics of the fruiting bodies, yield, biological efficiency, nutritional composition and mineral content of *Pleurotus ostreatus* and *Pleurotus cystidiosus*.

It was also observed that individually, the corncob and sugarcane bagasse efficiently allowed the growth of both fungi, with high values of pileus diameter, stipe thickness, mushroom weight, yield, biological efficiency, protein, fiber, ash, mineral content of the fruiting bodies of both mushrooms. However, the mushrooms had the longest time to obtain the first harvest when only corncob was used as substrate, 46 days for *Pleurotus ostreatus* and 64 days for *Pleurotus cystidiosus*. Although they observed that the C/N ratio of the substrates in all the conditions was correlated total colonization period, weight of the mushroom, yield, biological efficiency and protein content of both species of *Pleurotus*. In Mexico, the tequila industry is one of the most important economic sector and as a producer of lignocellulosic residues of agave (*Agave tequilana* W. var. Azul). It is used as a substrate to cultivate mushrooms of the genus *Pleurotus*. Agave

Table 2: Mixture of substrates used for the cultivation of edible and medicinal mushrooms

Substrates	Mushrooms	References
Potato dextrose agar Wheat and potato-dextrose Agar	*Lentinula boryana, Pleurotus djamor var. roseus, Pycnoporus sp.*	Díaz-Godínez *et al.,* 2016
Sugar cane bagasse, pigüe sawdust (*Piptocoma discolor*) and wheat bran (40-40-20 %) Sugar cane bagasse, sawdust of other woods and wheat bran (40–40-20%)	*Pleurotus ostreatus*	Santillán-Tandapilco and Morocho-Novoa, 2018
Sugar cane bagasse and wheat bran (4:1) Eucalyptus sawdust and wheat bran (4:1)	*Oudemansiella canarii* (Jungh.) Höhn	Silveira-Ruegger *et al.,* 2001
Mezcalero maguey bagasse (*Agave cupreata*) and rice straw	*Pleurotus pulmonarius*	Bernabé-González *et al.,* 2004
Rice straw and wheat straw Rice straw, paper, sugar cane bagasse and sawdust	*Pleurotus ostreatus*	Sharma *et al.,* 2013
Green plantain peel; mature plantain peel; green plantain peel-cane bagasse (50/50) Mature plantain peel and cane bagasse (50/50)	*Pleurotus ostreatus*	Manjarrés *et al.,* 2010
Peanut shell, rice bran and soya flour	*Pleurotus ostreatus*	Flores-Ramírez, 2019
Wood chips, sugar beet pellet pulp, palm fiber, wheat bran, rice bran and soya cake powder Soya cake powder, rice bran and carrot pulp	*Pleurotus ostreatus*	Jafarpour *et al.,* 2010
Coffee pulp, wood chips, cocoa and coconut shells	*Pleurotus* spp.	García-Oduardo *et al.,* 2006
Oak sawdust supplemented	*Grifola frondosa*	Acosta-Urdapilleta *et al.,* 2018
Agar and whole wheat flour Potato dextrose agar and wheat straw extract Potato dextrose agar and rice straw extract	*Pleurotus ostreatus, Pleurotus eryngii, Pleurotus pulmonarius, Pleurotus citrinopileatus, Pleurotus djamor var.roseus*	Acosta-Urdapilleta *et al.,* 2016

residues mixed with wheat straw were used as subsrate for cultivating *Pleurotus* spp. The colonization time, biological efficiency, the weight of biomass produced, the yield of mushrooms with respect to the support, production period and percentage of bioconversion of the system were estimated and it was noted that when *Pleurotus ostreatus* was grown on wheat straw without another component, the colonization period was better than in different mixtures.

The biological efficiency was 99%, a higher yield and fresh biomass were obtained but the production period was higher. In the case of *Pleurotus djamor*, the treatment with agave and wheat straw residues (3:1) showed the best results, with a higher protein content, a biological efficiency close to 60% and a production period of 53% short with only wheat straw. The highest percentage of bioconversion was observed when a support medium only of agave residues was used for *Pleurotus djamor* with approximately 50%. On the other hand, Philippoussis *et al.* (2001) evaluated the capacity of some edible mushrooms grew on mixtures of wheat straw mixed with cotton waste and wheat straw with peanut shells. It was observed that the mixture of wheat straw and cotton waste favored the fruiting of *Pleurotus ostreatus*, *Pleurotus pulmonarius* and *Volvariella volvacea*, while *Pleurotus eryngii* and *Agrocybe aegerita* were favored when they were grown only in wheat straw, while the lowest growth of all mushrooms was found on the peanut shell. Wheat straw combined with rice straw, or with paper residues, or with sugarcane bagasse, or with wood sawdust has been used as substrate. The effect of the substrate on mycelial growth, colonization time, time of appearance of primordia, yield of biomass produced, biological efficiency and chemical composition of *Pleurotus ostreatus* was, observed and among all the treatments rice straw showed the best yields and high biological efficiency, followed by the combination of rice straw with wheat straw, and rice straw mixed with paper waste. The chemical composition of the mushrooms was better when it was grown on rice straw (Sharma *et al.,* 2013). Andrino *et al.* (2011) evaluated the growth and BE of *Pleurotus eryngii* on mixtures of rice husk with wheat straw and residues from the brewing industry, showed biological efficiency of 87.35%.

Other lignocellulosic residues mixed with wheat straw were used as substrate to evaluate the growth of *Pleurotus ostreatus*, such is the case of white poplar shavings (*Populus alba*), eucalyptus shavings (*Eucalyptus globulus*) and mixture of wheat straw with eucalyptus shavings and wheat straw alone. The results obtained indicated that all the substrates, mainly the substrates of wheat straw and wheat straw with eucalyptus shavings were suitable for the cultivation of this mushroom, also the protein content of the fruiting bodies was high when they were grown in all substrates and their C/N ratio decreased after harvest (Varnero *et al.,* 2010). Edible mushrooms *Auricularia fuscosuccinea, Oudemansiella canarii* and *Schizophyllum commune* have also been developed on agricultural residues with a high content of cellulose and lignin such as coconut fiber, cocoa fruit shells (*Theobroma cacao*), banana leaves and cedar sawdust, either individually or in 1:1 combination of each of these materials. It was observed that *Auricularia fuscosuccinea* showed the highest growth in banana leaves, *Oudemansiella canarii* did so on coconut fiber and cocoa fruit shells; *Schizophyllum commune* developed favorably in the combination of coconut fiber with cocoa fruit shells, in addition, for each growth test of these fungi the support of cedar sawdust was unfavorable, it should be mentioned that the use of said substrates to evaluate the development potential of these mushrooms represent an area of opportunity to take advantage of them in tropical areas (Carreño-Ruíz *et al.,* 2014). Some mixtures of biodegradable supports include enrichment with typical materials in the growth of edible mushrooms such as wheat bran, mixed with agricultural residues such as sugarcane bagasse or eucalyptus sawdust; the lignocellulosic residues were subjected to thermal sterilization and after reducing the temperature they were inoculated with *Oudemansiella canarii*, the culture was incubated at 25ºC until the appearance of primordia, obtaining fresh fruiting bodies of size between 9-10 cm with a smooth flavor and consistency. It was also observed that the sugarcane bagasse produced the highest productivity values (4.47%), biological efficiency (55.66%) and 38.78% degradation (Silveira-Ruegger *et al.,* 2001). On the other hand, for this same edible mushroom, lignocellulosic wastes such as cottonseed hull, sawdust from various woods, corn cob were used and their combinations were supplemented with 18% wheat bran and 2% calcium hydroxide. The effects of different combinations of substrates were observed on the productivity, chemical and amino acid content, biological efficiency and essential amino acids of the treatment containing 80% cottonseed hull was the highest among all the treatments tested. The mixtures that included sawdust were treatments T2 (80% sawdust), T4 (40% sawdust + 40% cotton seed husk) and T6 (40% sawdust + 40% corn cob), presented lower yields and biological efficiency, the corn cob was good for the production of this mushroom, particularly in terms of yield and biological efficiency, while the mycelial growth rate and colonization time were lower compared to those of other substrates, likewise, comparing biological efficiency and essential amino acids, treatment with 80% cotton seed hull was the best substrate for the cultivation of *Oudemansiella canarii* (Xu *et al.,* 2015).

Production of enzymes and bioactive compounds: It is important to indicate that although this review contemplates the cultivation of mushrooms, it should be mentioned that the cultivation of fungi also has the purpose of producing enzymes and bioactive compounds. Lignocellulosic substrates have been used for this purpose, but inert supports impregnated with culture media have also been used. Among the inert supports used is polyurethane foam to produce pectinases from *Aspergillus niger* (Díaz-Godínez *et al.,* 2001), laccases from *Pleurotus ostreatus* (Téllez-Téllez *et al.,* 2008; Velazquez *et al.,* 2014), xylanases from *Sporisorium reilianum* (Álvarez-Cervantes *et al.,* 2013), xylanases, cellulases and acid proteases from *Stenocarpella maydis* (Domínguez *et al.,* 2014), laccases, cellulases and xylanases from *Pleurotus ostreatus* (Álvarez -Cervantes *et al.,* 2016). It is worth mentioning that the production of different fungal enzymes through solid or submerged fermentation in vegetative or reproductive stages will depend on the medium and culture conditions, on the presence of inducers or xenobiotics (Díaz *et al.,* 2013). On the other hand, the increase in biomass production in inducing media such as wheat straw and wheat grains have been evaluated, observing that there is a correlation between the cellular increase in the vegetative phase of *Pleurotus ostreatus* and a higher enzymatic production of laccases and proteases (Sainos *et al.,* 2006). Díaz-Godínez *et al.* (2017) suggested that the production and activity of laccases of *Pleurotus ostreatus* increased in submerged cultures with respect to solid growth system. It has also been suggested that the multiple molecules with biological activity such as inhibition of angiotensin-converting enzyme, antioxidants, antifungal, ribosome-inactivating proteins, antibacterial, that are produced by edible mushrooms depend on the substrate and growth system (Díaz-Godínez and Díaz, 2021). On the other hand, Acosta-Urdapilleta *et al.* (2020) observed differences in the proximal chemical composition and antioxidant activity of fruiting bodies of five species of *Pleurotus* developed on wheat straw. In different edible mushrooms such as *Pleurotus eryngii, Lentinula edodes, Pleurotus ostreatus, Flammulina velutipes, Pleurotus citrinopileatus* and *Ganoderma lucidum*, their mycelial growth was evaluated using different organic wastes, among them; culture media with agar and vermicompost, vermiwash, calcined pork bones or fish waste, observing that the C/N ratio, ash and pH were decisive in their growth (Grandes-Blanco *et al.,* 2019).

The exorbitant amount of agricultural waste generated constitutes environmental problem, has led to search for alternatives for their use, giving it added value; the alternative of using them as a substrate for cultivating mushrooms is of great socio-economic interest. These lignocellulosic residues allow us to grow mushrooms that can contribute to human nutrition due to their highly digestible protein content, high fiber content and very low-fat content. In addition, some of these mushrooms produce metabolites that have a biological function as immunoregulatory, anti-cholesterol, antihypertensive, with antioxidant activity, and/or produce enzymes that are used in various industries with biotechnological applications.

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