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Edible mushrooms – perspectives and considerations

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Abstract

The cultivation of edible mushrooms has been an activity of great ecological, social and economic importance for many years. There is a great diversity of different species of these mushrooms, truffles, chanterelles, pine mushrooms, *Termitomyces*, with more than 1100 registered species, many of which are of great economic importance not only for export but also for developing countries. The collection and consumption of these mushrooms vary by country, being, for example, extensive and intensive in China and more restricted in South American countries. The ecological value they have should also be highlighted, since some species live in symbiosis with trees, helping the growth of forests and commercial plantations. These fungi contribute to human nutrition supplying micronutrients, polysaccharides, amino acids, fibers and proteins; also, they synthesize active secondary metabolites such as saponins, glycosides, alkaloids, flavonoids, tannins, polyphenols and some other reducing compounds. This review about edible mushrooms addresses the generalities and production, description of several species, some toxic species in Mexico and finally several aspects of these mushrooms' biotechnology.

Keywords: biotechnology; production; species recognition; wild

Introduction

Mushrooms are fungi with hard fungal tissue and they are dispersed all over the world (Zhang *et al*., 2021). Approximately 14,000 mushroom species have been recognised and 10% of them are edible mushrooms that have been extensively used with medical or food purpose (Qing *et al*., 2021), being a total of 700 species that can be consumed in a safe way and also are useful to human health (Li *et al*., 2021a). Edible mushrooms have become a profitable and sustainable form of feeding due to their great content of dietary fiber, vitamins (thiamine and riboflavin), polysaccharides and proteo-glucans (Slusarczyk *et al*., 2021).

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The total production of edible mushrooms (including truffles), according to FAO (2022) was 42.79 million tons in 2022, of which China was the producer of more than 19 million tons (43%), followed by Japan (441 thousand tons), the United States (384 thousand tons) and the Netherlands (190 thousand tons). In Latin America, according to data from Sánchez *et al*. (2018) production continues to grow and Mexico is the first producer with 63.7 thousand tons, followed by Brazil (15.6 thousand tons), Chile (12 thousand tons) and Colombia (8 thousand tons).

Edible mushrooms, in addition to the possibility of being used as food and for medicinal purposes, have the advantage of being able to be produced in short periods with low economic investment, low technological level, and their production does not depend on environmental conditions (Rosmiza *et al.,* 2016), so, they represent a sustainable alternative with a high nutritional value for developing countries.

The present review was done by searching in Scopus databases, Web of Science, Research Gate, PubMed/MEDILINE and Google Scholar, so the aim of this article review is to analyse edible mushrooms generalities and production, description of several species, some toxic species in Mexico and finally several aspects of these mushrooms biotechnology.

Generalities and production

One of the countries that has a great variety of wild edible mushrooms is Mexico and by 2014 there was already a consumption of approximately 371 species (Garibay-Orijel and Ruan-Soto, 2014). Due to the great variety of species found in the country, it is relevant to carry out studies on their characteristics, conservation and alternatives or strategies for their use.

In Mexico, the cultivation of edible mushrooms began in the 1930s with the mushrooms, followed by other species such as shiitake (*Lentinula edodes* (Berk.) Pegler) and white ears or mushrooms (*Pleurotus ostreatus* Jacq. ex Fr.) P. Kumm. (1871) (Guzmán *et al*., 2013a).

The characterization of wild edible mushrooms, in addition to generating great social, scientific, economic and technological benefits, represent an alternative for food security since their strains can be domesticated, thus promoting rural production by small growers (Mayett and Martínez-Carrera, 2010).

In general, wild mushrooms offer various metabolites with important biological activities, highlighting hypocholesterolemic, antiviral, immunomodulatory, anticancer, antibacterial, and antitumor activities, among others. Also, edible mushrooms are nutraceuticals with therapeutic potential, and different compounds such as enzymes, flavonoids, β-glucans, fatty acids, polyketides, polyphenols, and terpenoids can be obtained from them (Suárez-Arango and Nieto, 2013) (Table 1).

Table 1. Bioactive compounds, phenolic compounds and organic acids of edible mushrooms

Edible mushrooms	Bioactive and phenolic compounds	Organic acids	References
Agaricus bisporus (J.E.Lange) Imbach, 1946	Pyrogallol, hydroxybenzoic acid derivatives, flavonoids, lectins, 4-hydroxybenzoic acid, 2,4-dihydroxybenzoic acid, 4-hydroxyphenylacetic acid, protocatechuic acid, catechin, gallocatechin, *o*-coumaric acid, cinnamic acid, 5-feruloylquinic acid, 3,5 dicaffeoylquinic acid	Formic acid, fumaric acid, lactic acid, malic acid, malonic acid, oxalic acid, succinic acid	Moro *et al.* (2012); Ndungutse *et al*. (2015); Fogarasi *et al.* (2018); Gąsecka *et al.* (2018a).
Agaricus bitorquis (Quélet) Sacc.	Gallic acid, caffeic acid and ferulic acid	Formic acid, citric acid, fumaric acid, lactic acid, malonic acid, oxalic acid, succinic acid	Gąsecka *et al.* (2018a).

Auricularia auricula	Glucan, acidic polysaccharides		Lakhanpal and Rana (2005); Zhang *et al*. (2007).
Boletus edulis Bull. Fr.	*p*-coumaric acid, β-glucan, α-glucans, chitins, protocatechuic acid, *p*-hydroxybenzoic acid.	Oxalic acid and fumaric acid	Santoyo *et al*. (2012); Heleno *et al*. (2015a); Özcan and Ertan (2018).
Bovista aestivalis (Bonord.) Demoulin (1979)		Oxalic acid, traces of malic acid, fumaric acid	Barros *et al*., (2013).
Calvatia spp.	Flavonoid, ascorbic acid, and ergosterol		Gąsecka *et al*. (2018b).
Hericium erinaceus (Bull.) Persoon, 1825	Hericenones, erinacines, gallic acid, *p*-hydroxybenzoic acid, *p*-coumaric acid	Malic acid, fumaric acid	Lakhanpal and Rana (2005); Heleno *et al*. (2015b).
Infundibulicybe spp.	Catechin, chlorogenic acid, coumaric acid		Sevindik *et al*. (2020)
Ganoderma lucidum (Curtis) P. Karst.	Ganoderic acids, ganodermanontriol, ganoderiol, polysaccharides, germanium, triterpenoids, nucleotides and nucleosides, β-glucan	Malonic acid, hexopyranosiduronic acid and pentaric acid	Xu *et al*. (2010); Walton (2014); Zou *et al*. (2022).
Gymnopus dryophilus (Bull.) Murrill 1916	Polysaccharide CDP, β-glucan		Pacheco-Sánchez (2006); Díaz-Talamantes *et* al. (2022).
Lactarius indigo (Schwein.) Fr. 1838	Organic extracts, terpenoids and polyphenols	Cinnamic acid	López-Vázquez *et al*. (2017).
Lentinula edodes (Berk.) Pegler	Eritadenin, lentinan, emitanina, quitina, ergosterol	Succinic acid, tartaric acid, malic acid, acetic acid, citric acid and fumaric acid	Li *et al*. (2017); Rivera *et al*. (2017).
Lycoperdon perlatum PERS.	β-glucans, flavonoids, ascorbic acid, β-carotene, lycopene, α-tocopherol	Oxalic acid, malic acid, succinic acid and fumaric acid	Bouçada de Barros (2008); Rugolo *et al*. (2022).
Pleurotus ostreatus (Jacq. ex Fr.) P. Kumm.	Functional proteins (ubiquinone-9, ubiquitin-like peptide, nebrodeolysin, and glycoprotein), proteoglycans pleuran (β -1, 3-glucan with galactose, and mannose), glucans, proteoglycan, laccase, pleurostrin (peptide), 4-hydroxybenzoic acid, 2,4-dihydroxybenzoic acid, 4-hydroxyphenylacetic acid, protocatechuic acid, catechin, gallocatechin, *o*-coumaric acid, cinnamic acid, 5-feruloylquinic acid, 3,5 dicaffeoylquinic acid	Oxalic acid, malic acid, shikimic acid, succinic acid and fumaric acid	El Enshasy *et al*. (2012); Oloke and Adebayo (2015); Fogarasi *et al*. (2018); Rugolo *et al*. (2022).
Pleurotus pulmonarius (Fr.) Quél. (1872)	Polysaccharides (1,3), (1,6)-linked β –glucan and		Smiderle *et al*. (2008); Lavi *et al*. (2012).

	polysaccharides such as β (1,3)-glucopyranosyl.		
Russula spp.	P-hydroxybenzoic acid and cinnamic acid	Oxalic acid, malic acid, fumaric acid	Barros *et al*. (2013); Kostić *et al*. (2020).
Schizophyllum commune Fr. (1815)	Phenolic compounds, carboxylic esters and β-glucan namely schizophyllan	Ascorbic and tartaric acid	Boonthatui *et al*. (2021); Kirtzel *et al*., (2020).
Tremella fuciformis Berk. (1856)	Polysaccharide, phenolic acids (4-hydroxybenzoic acid, gentisic acid and 4-coumaric acid)		Huang *et al*. (2022);
Tricholoma matsutake (S.Ito & Imai) Singer (1943)	Ergosterols, polysaccharides, polyphenols	Gluconic acid	Iwase (1992); Li *et al*. (2021a);
Volvariella volvacea (Bulliard ex Fries) Singer, 1951	Fip-vvo, β-glucan		Hsu *et al*. (1997); Li *et al*. (2014); Sangthong *et al*. (2022).

The production of edible mushrooms is part of a global strategy to reduce poverty and diversify agricultural production (Zharare *et al*., 2010). For making the process efficient, it is important to select fungal strains with high growth speed, high yield, prominent sensory features and high biological efficiency (Ahmed et al., 2013).

The cultivation of edible mushrooms is successful by having a quality seed, an appropriate substrate and environmental factors such as humidity and temperature (Uddin *et al*., 2011). Numerous substrates can be used for the production of these fungi, according to Masevhe *et al*. (2016), being the most appropriate those locally available that have an adequate content of lignin, hemicellulose, cellulose, high carbon content, essential nutrients (nitrogen, potassium, iron and phosphorus) and that are sterile. Some other sources of substrates could be horticultural waste, wood, wheat straw, papers, sugarcane residues, leaves, cottonseed hulls, among others (Siwulski *et al*., 2019). Other studies showed that many of the agricultural wastes can be used successfully for the cultivation of mushrooms, like sugarcane bagasse, sawdust and corn cobs. The mixture of different substrates could be advantageous to increase the nutrition of the mycelia (Siwulski *et al*., 2019) and lime and cornmeal can be used to balance the pH (Carrasco *et al*., 2018).

The production of mushrooms, in general, uses different by-products of low economic value which are generated in forestry and agriculture, thus avoiding those residues to be incinerated, consequently, it is a cost-effective business, specifically for developing countries and represents a model of circular agriculture contributing to the sustainability of forests and their surrounds (Okuda, 2022).

Description of several species of edible mushrooms

Agaricus bisporus (J.E.Lange) Imbach, 1946, and *Agaricus bitorquis* (Quélet) Sacc. In the early stages of development, the young sporophore (fruiting body) of Agaricus species is enclosed in a protective covering called the general veil. This veil surrounds the entire mushroom and is usually ephemeral, breaking down rapidly as the fruiting body grows. Another veil, known as the partial veil, connects the edge of the cap (pileus) to the stem (stipe). As the cap expands and opens, the partial veil breaks, often leaving remnants on the stem or as a ring on the upper part of the stem. The mature sporophore consists of a stipe (stem) and a cap (pileus). The cap is usually rounded or convex and may vary in color and texture depending on the species. In the case of *A. bisporus* the cap is frequently colored brown and white and for A. *bitorquis* the cap is dry, smooth, and white (but stains yellowish in age), and measures 4 to 15 cm in diameter, convex to flat, often with dirt on the cap.

Underneath the cap of an Agaricus mushroom, there are thin, blade-like structures called gills. These gills are arranged radially, extending from the edge of the cap towards the center. The gills bear the reproductive structures of the mushroom, including basidia and cystidia (Callac, 2007).

A. bisporus can be found in several state of Mexico such as, Jalisco (Sánchez-Jácome and Guzmán-Dávalos, 2011); Morelos (López *et al*., 1985); Michoacán (CONABIO, 2005); Baja California (Ayala and Guzmán, 1984), Veracruz (López-Ramírez, 2011). In the case of *A. bitorquis* is distributed in Baja California (Ayala-Sánchez *et al*., 2015), Mexico City (Guzmán, 1977), Hidalgo (Frutis and Guzmán, 1983), Jalisco (Guzmán-Dávalos and Fragoza, 1995), Morelos and Puebla (Palestina-Villa *et al*., 2019).

Amanita caesarea (Scop.) Pers., 1801, is a common species in the forests of the state of Durango (Figure 1).

Figure 1. *Amanita caesarea* (Scop.) Pers., 1801 (Source: Authors)

According to Díaz-Moreno (2004) this fungus has a cap of 8-20 cm, first hemispherical and finally flattened, with a straight and slightly ribbed margin. The cuticle is separable, smooth and shiny, slightly lubricated in humid weather, of a bright reddish-orange color, which later yellows. The spores are white. The stem is separable, cylindrical, 6-15 x 2-3 cm, full bright yellow, with a yellow striated ring. The flesh is tender, white, except under the cuticle and on the outside of the stem, where it is yellow. It lives in thermal flat-leaf forests, basically associated with cork oaks, oaks and chestnut trees, in open and illuminated places facing east, with a clear preference for silicic soils. It fruits from spring to early fall.

There is a certain danger of confusion with the toxic Amanita (*Amanita phalloides* (Vaill. ex Fr.) Link, 1821) (Díaz-Moreno, 2004), a poisonous species that will be described under this heading.

The nutritional properties of this mushroom include 34.77 g per 100 g dry weight of protein, 55.63 g per 100 g dry weight of carbohydrates and 3.50 g per 100 g dry weight of fat (Ouzouni *et al*., 2009).

In the genus *Auricularia*, 10 to 15 species are recognized, distributed intercontinental to cosmopolitan throughout the world (Looney *et al*., 2013) and they are important because the medicinal and edible properties (Wu *et al*., 2021). According to their morphology, it can be characterized through a basidiomata described as substipitate, resupinate to gelatinous, with hairs on the superior surface. Also, the species have basidia with three transverse septa with cylindrical to clavate shapes and hyaline basidiospores, with oily guttules (Parmasto and Parmasto, 1987; Montoya-Alvarez *et al*., 2011).

One example of this genus is the specie *Auricularia americana* Parmasto & I. Parmasto ex Audet, Boulet & Sirard that is characterized by a basidiomata that fresh is gelatinous, orange-brown to reddish brown colour, occasionally substipitate, sessile or caespitose, upper surface pilose. This species is distributed in North America and North Asia (Wu *et al*., 2021).

Boletus edulis Bull. Fr. is characterized by having a cap 7 to 30 cm, wide when mature. These mushrooms are slightly sticky to the touch, convex in shape when young, flattening with age. They are reddish-brown in colour, but may be white in areas near the margin and may turn darken as they mature (Kozikowski, 1996). The lower surface of the cap has thin tubes and is where the spores are produced, measuring 1 to 2 cm deep and whitish at first, turning yellow-green when ripe (Grund and Harrison, 1976) (Figure 2).

Figure 2. *Boletus edulis* Bull. Fr. (Source: Authors)

B. edulis stands out for its characteristic aroma and a sweet hazelnut flavour, which makes it highly appreciated in haute cuisine (Liu *et al*., 2016). It is distributed in Canada, the United States, Europe and Asia. In Mexico in the Altiplano, the west, the central states and Oaxaca (CONABIO, 2016).

Bovista aestivalis (Bonord.) Demoulin (1979) presents basidiospores globose to subglobose, smooth to woody, hyaline to yellow in water; capillitium mainly of the intermediate type; eucapillitial threads 3.2 to 8.0 μm in diameter, thick-walled (up to 0.8 μm), yellow to brownish-yellow in water, absence of paracapillitial threads; exoperidium white to whitish in juvenile, turning yellowish-white to pale yellow in adult; endoperidium yellowish gray to opaque yellow, persistent, composed of intertwined hyphae, with the presence of septa and thick walls; gleba (internal mass containing spores) greyish-yellow to yellowish-brown, cottony; brownish-orange subgleba, composed of compact, often reduced cells (Bates *et al*., 2009). The specie can be found in Mexico in Baja California (Ochoa and Moreno 2006), Chihuahua (Moreno *et al*., 2010), Estado de México, Oaxaca and Veracruz (Calonge *et al*., 2004), Hidalgo and Jalisco (Bautista-Hernández *et al*., 2011).

Calvatia cyathiformis (Bosc) Morgan. is spherical and smooth on the top with fruiting body about 5 to 20 cm in diameter and 4 to 6 cm long and a brownish colour when is young. As the mushroom grows, it becomes pear-shaped and turn darker, purplish colour may be because the existence of the gleba at the top of it, at this point the spores (purple to grey) are ready to be released (Davis *et al*., 2012; Coetzee and van Wyk, 2009) (Figure 3).

Figure 3. *Calvatia cyathiformis* (Bosc) Morgan. J. Cincinnati Soc. Nat. Hist. 12: 168 (1890) (Source: Authors)

All species of the genus *Calvatia* are edible (Morris, 1987), but only when they are still immature because the gleba is still firm and white (Læssoe and Spooner, 1994). *C. cyathiformis* has been recorded in open areas of Abies (fir) and Pinus (pine) forests in Mexico. Reports of its presence have been made in several states, including Sonora, Guadalajara (Jalisco), Querétaro, Puebla, Chiapas, the State of Mexico (Estado de Mexico), and Veracruz (Guzmán *et al*, 2013b).

Hericium erinaceus (Bull.) Persoon, 1825, has obvious basidiomes containing several single, classically long, flaccid, fleshy spines, which are white at first and later become yellowish-brownish with age. Species in this genus *Hericium* are identified macroscopically by the existence of branched vs. unbranched hymenophore structures with spines single or in multiple clumps, and microscopically by the presence of amyloid basidiospores. This mushroom has white, soft meat and sweet taste, properties that make it edible (Quiñonez-Martinez *et al*., 2022). This species can be found in the states of Durango and Chihuahua (Páez-Olivan *et al*., 2022; Quiñonez-Martinez *et al*., 2014).

Infundibulicybe gibba (Pers.) Harmaja (2003) has a cap dull buff to tan with an occasional pinkish tinge and grows to about 3 cm to 9 cm with funnel-shaped, a small bulge in the center. It has no ring and has a white stem between 2 and 8 cm long and 1 cm in diameter. It has a slight 'cyanic' odor and the taste is mild. The spores are white, teardrop-shaped and about 5.5-8 µm by 4-5 µm (Davis *et al*., 2012). It is edible when young and it can be fried or used in risottos or soups (Eyssartier and Roux, 2013). This specie can be found in Chiapas, Mexico (Ruan-Soto *et al*., 2021).

Infundibulicybe squamulosa (Persoon 1801: Fries 1821) Harmaja (2003) has a cap from 3 to 10 cm across that is planoconvex with a depression in the center, dry, bald or with very small fibrillose scales, orange-brown to pale orangish tan; gills running down the stem, close, white or pale cream, sometimes becoming faintly brownish in old age; stem from 2.5 to 5 cm long, 6 to 13 mm thick, dry; bald or finely scurfy, colored like the cap, base covered with white mycelium; odor and taste not distinctive (Sturgeon, 2018). The specie can be found in Tlaxcala, Central Mexico (Reyes-López et al., 2020).

Ganoderma lucidum (Curtis) P. Karst belongs to the genus *Ganoderma* in which the species are characterized by having basidiocarps with a shiny surface associated with thick-walled pilocystidia located in an extracellular melanin matrix (Moncalvo, 2000). This specie has a hat of are kidney-shaped with reddish or yellowish colors, with a varnished and very shiny surface; if the lower part is yellow, it indicates high triterpenoid content (Chen, 2005). It is said that this mushroom is unique due to its great pharmaceutical value, with a wide variety of products on the market in various forms, such as powders, dietary supplements and tea (Wachtel-Galor *et al*., 2011) and it can be found in the state of Sonora (López-Peña *et al*., 2016).

Gymnopus dryophilus (Bull.) Murrill (1916), is a saprophytic mushroom, although it can attack living wood. It belongs to the section of the genus *Levipedes*, which is characterized by having a smooth stem without hairs at the base (Phillips, 1983). It is a wild high mountain mushroom with cultural and economic value, because it is frequently used for sale and self-consumption (Burrola-Aguilar *et al*., 2012).

The species has a pileipellis (uppermost layer of hyphae in the pileus of a fungal fruit body) formed by lobulated, inflated or coralloid cells, well-developed cheilocystidia (it is a relatively large cell found in the hymenium of basidiomycetes), smooth stipe and hyphae they rarely turn green in alkali (Antonín and Noordeloos, 2010). It can be found in the state of Jalisco (Rodríguez Alcántar *et al*., 2019) and Oxaca (Garibay-Orijel *et al*., 2009).

Lactarius indigo (Schwein.) Fr. 1838, has a cap from 5 to 15 cm; convex with vase-shaped; the colour can be from deep to medium blue when fresh to greyish or silvery blue when faded, occasionally developing brownish areas when old. It is found in several different ecosystems from oak-hickory forests to Ponderosa pine zones in the south-western United States to cloud forests in Mexico (Lamus *et al*., 2012) (Figure 4).

Figure 4. *Lactarius indigo* (Schwein.) Fr. 1838 (Source: Authors)

Its flavour is slightly bitter (Hall, 2003) or peppery taste (McKnight and McKnight, 1987), and has a grainy, coarse texture (Roody, 2003).

Cano-Estrada and Romero-Bautista (2016) explain that extracts from the fungus *L. indigo* can be used to prevent tumour cell growth. Also, this mushroom represents an important source of bioactive compounds and nutritional characteristics beneficial to health, standing out from the nutritional properties its high protein content (20 to 24 %) and low lipid content (1 to 3.2%) (Espejel-Sánchez *et al*., 2021).

Lentinula edodes (Berk.) Pegler is an edible mushroom of brown colour and intense aroma native to East Asia. It is usually consumed more often dried than fresh and is added to soups, scrambles and other dishes to make them more flavourful (Chung, 2005). It is a white-rot fungus that belongs to the Basidiomycetes and grows in dead wood of broad-leaved trees in nature (Takabatake, 2015).

Its most distinctive morphological characteristics are an umbrella-shaped cap with a tan to brown colour and edges that roll downward and inward, the gills are whitish to cream-colored, located at the bottom of the cap. The stem of the mushroom is also white or cream, but may turn brown as the mushroom grows (Forestry and Natural Resources Extension Program, 2017). It has been cultivated in Latin America since the early 1980s in several countries including Mexico (Martínez-Carrera, 2002).

Lycoperdon perlatum Pers., is the common puffball belongs to the family Agaricaceae. It has a wide distribution and can be found in various parts of the world including Mexico, specifically in Oaxaca state (Zamora-Martínez *et al*., 2013). The fruit body of *L. perlatum* is medium-sized, typically measuring between 1.5 to 6 cm in width and 3 to 7 cm in height. It has a round shape that tapers into a wide stalk (Roberts and Evans, 2011). This is a saprobic species, meaning it obtains nutrients by decomposing organic matter. It typically grows solitarily, but it can also be found scattered, in groups, or in clusters on the ground (Læssøe *et al*., 1995). The common puffball is considered edible when young, particularly when the internal flesh is completely white. However, caution is needed to avoid confusion with immature fruit bodies of poisonous *Amanita* species, which can be deadly if consumed (Akpi *et al*., 2017).

Pleurotus ostreatus (Jacq. ex Fr.) P. Kumm. (1871), commonly known as the oyster mushroom, is a species belonging to the *Basidiomycota* phylum. It has a global distribution, being found in all continents except for Antarctica. Since World War I, it has been cultivated commercially on a large scale (Piska *et al*., 2017). The fruiting bodies of *P. ostreatus* can have varying colors, ranging from pink, grey to dark-brown. They typically range in size from 4 to 15 cm (Wojewoda, 2003). This mushroom is highly valued for its dietary importance. It contains various primary and secondary metabolites, as well as essential chemical elements. In terms of nutritional value, 100 g of fresh fruiting bodies provide approximately 15% of the recommended daily intake of vitamin C, and 40% of niacin, riboflavin, and thiamine. It also contains 0.5 mg of vitamin B12. Additionally, this species is known for its high content of oleic acid (40%) and linolenic acid (55%). It also contains substances that are responsible for reducing serum cholesterol levels. Apart from its nutritional value, this mushroom is considered medicinal due to its wide spectrum of biological activities. It synthesizes various bioactive compounds that have been studied for their potential health benefits. Some of the reported medicinal properties of this mushroom include antioxidant, antimicrobial, antiviral, anti-inflammatory, and immunomodulatory effects (Piska *et al*., 2017). The cultivation of this mushroom began in Mexico in 1974 (Martínez-Carrera, 1997). By 1997, the annual production of *P. ostreatus* in Mexico was estimated to be around 1825 tons (Leal-Lara, 1998) and in this same year Mexico was recognized as the main producer of *Pleurotus* spp. in the entire American continent (Sánchez and Royse, 2001). Some examples of states where this mushroom is cultivated are México, Tlaxcala, Veracruz, Puebla, and Morelos (Aguilar *et al*., 2002; Portugal-Portugal *et al.,* 2002; Dickel *et al*., 2000; González-Fuentes, 1977).

Russula virescens (Schaeff.) Fr. (1836), usually identified as the Green-cracking is a species of found in various parts of the world including the state of Hidalgo, Mexico (Jiménez-Gonzales *et al*., 2013). The cap is typically measuring 4-15 cm in diameter. Initially, it appears almost globose (spherical), but as it matures, it becomes flattened-convex and may develop a slight depression in the centre. The cap surface has fine radial wrinkles or grooves. The colour of the cap is typically purplish, greenish lilac, or purple-pink when young. However, as the mushroom ages, these vibrant colours fade, and the cap takes on a generalized greenish hue due to the loss of violet pigments. The fading of colours is a distinctive characteristic of this species. The flesh or meat of *R. virescens* is known to be very tough. When cut or broken, the flesh is firm and does not easily break apart. This toughness is a notable feature of this species (Moreno *et al*., 1986).

Schizophyllum commune Fr. (1815), generally recognized as the split gill mushroom, is indeed a fascinating species with potential for food production in tropical regions (Kamalebo *et al*., 2018). Its cultivation may be done on agricultural by-products as substrates, which can help reduce waste and utilize available resources efficiently. According to Vázquez-Mendoza (2013), *S. commune* has been found growing on a wide range of lignocellulosic substrates such as wood or plant debris, which is advantageous for its cultivation as it can utilize abundant organic waste. Cappello-García *et al*. (2018) mentioned that this mushroom is capable of fruiting at high temperatures; this characteristic is particularly beneficial for cultivation in tropical regions where temperatures can be consistently warm or hot like Asia, Africa, and the Americas, including Mexico and Guatemala. This suggests that it has cultural acceptance and potential as a food source (Kamalebo *et al*., 2018). In Mexico, this specie has been recorded in all states (Díaz-Moreno 2004, Olivo-Aranda and Herrera, 1994).

Tremella fuciformis Berk. (1856), commonly known as snow ear or white fungus, is a basidiomycete fungus that produces a gelatinous fruiting body. This fungus has been used in traditional Chinese medicine for thousands of years due to its various therapeutic effects. *Tremella* polysaccharide is an important active substance found in the fruiting body, mycelium, and fermentation broth of *T. fuciformis*. One of the significant therapeutic effects attributed to *Tremella* polysaccharide is its potential for skin care. It is believed to have moisturizing and anti-aging properties, helping to improve the elasticity and appearance of the skin (Ma *et al*., 2021). In Mexico this specie can be found in Jalisco (Rodríguez-Alcántar *et al*., 2019); Durango (Raymundo *et* al., 2012); Chiapas (Chanona-Gómez *et al*., 2007) and some others.

Tricholoma matsutake (S. Ito & Imai) Singer (1943) is a highly valued mushroom and considered gourmet delicacy in Japan and various other Asian countries. It has a distinct aroma and flavour, which contribute to its culinary appeal. Matsutake mushrooms are primarily found in East Asia, including Japan, China, Korea, and Taiwan and they also occur in the northern and central regions of Europe, particularly in countries such as Sweden, Finland, and Norway. They are known for their symbiotic relationship with certain tree species, particularly conifers like pine trees (Aoki *et al*., 2022). The growth of *T. matsutake* basidiomata, also known as fruiting bodies, is closely associated with the development of a mixture called 'shiro'. Shiro is a combination of soil, mycelium, and ectomycorrhizas (Wang *et al*., 2017). In Mexico *T. matsutake* can be found in Hidalgo, Veracruz, México, Oaxaca, Durango, Michoacán and Puebla (Zamora y Nieto de Pascual, 2004).

Volvariella volvacea (Bulliard ex Fries) Singer, 1951, also known as "rice mushroom", "straw fungus" or "Chinese mushroom", is a species found in tropical and subtropical climates (Liu *et al*., 2020). Its cultivation is believed to have originated in China, possibly before the 18th century (Chang, 1977), and has been used due to its high concentrations of nutrients and bioactive compounds with medicinal properties (Thuc *et al*., 2020). This fungus received its common name because it was originally found growing on the residue from cleaning rice grains. However, due to its ability to break down lignin, a substance present in plants, it has been successfully cultivated in a variety of substrates, including stubble, waste from grain industrialization processes, reeds, and pulp. This gives it great value as an alternative to take advantage of this waste and turn it into a useful resource (Thuc *et al*., 2020). Besides, *V. volvacea* is a popular edible mushroom known for its delicious taste and nutritional value (Li *et al*., 2021b) and it is also rich in vitamin B1, vitamin B3, vitamin C1 and amino acids (Hou *et al*., 2017). This specie together with *V. bombycina* var. *bombycina*, var. *flaviceps* have been found in the states of Morelos, Baja California, Jalisco, Puebla, Oaxaca, Yucatán, Sonora, Veracruz and Quintana Roo (Sobal-Cruz *et al*., 2016; Ayala-Sánchez *et al*., 2015; Pérez-Silva *et al*., 2006, Vázquez *et al*., 1989; Salmones *et al*., 1988).

Some toxic species in Mexico

Numerous taxa of poisonous species of mushrooms have been reported; some of the most common genera are *Amanita, Chlorophyllum, Cantharocybe, Inocybe, Entoloma, Leccinellum, Russula,* and *Xerocomus* (Tawatsin *et al*., 2018; Parnmen *et al*., 2020; Parnmen *et al*., 2021). These species have toxic substances that generally produce myotoxicity, neurotoxicity, endocrine toxicity, gastrointestinal disturbances and cytotoxicity. The description and principal symptoms are described in Table 2.

Table 2. Toxic species of mushrooms in Mexico

Toxic species	Symptoms or damage	Reference
Agaricus bisporus (J.E.Lange) Imbach, 1946	This is one of the most consumed mushrooms in the world, but it is potentially carcinogenic since contains aromatic hydrazines, which is a direct-acting chemical carcinogen.	Walton *et al*. (1997, 2001).
Agaricus xanthodermus Genev. (1876)	The symptoms are severe gastrointestinal irritation and in exceptional occasions, comma.	Gill and Strauch (1984); Hender *et al*. (2000).
Amanita bisporigera G.F.Atk. (1906)	The first symptoms of poisoning appear 6 to 24 hours after consumption, followed by a period of apparent improvement, resulting in liver and kidney failure, and death of the consumer on the fourth day.	Nici and Kim (2011).
Amanita muscaria (L.) Lam. (1783)	This is a well-known toxic mushroom that frequently is mistaken for the edible mushroom *A. rubescens*. The most common symptoms of intoxication are ataxia, motor depression, muscle twitches, changes in mood, gastrointestinal disturbances, perception and feelings, euphoria, dizziness and drowsiness.	Tsujikawa *et al*. (2007); Stormer *et al.* (2004).
Amanita phalloides (Vaill. ex Fr.) Link, 1821)	The toxicity is induced by phallotoxin, amatoxin and virotoxin. The mushroom destroys the cells of the central nervous system, kidneys, liver, muscles, which in most cases is fatal. The first symptoms are stomach aches, vomiting, nausea, diarrhea that appear ten or twelve hours after eating, and death in two or three days.	Díaz-Moreno (2004); Wong and Ng (2006).

Amanita virosa (Fr.) Bertill., (1838)	It is very poisonous and its ingestion can cause death. This mushroom contains measurable amounts of amatoxins that causes the toxicity.	Faulstich and Cochet-Meilhac (1976).
Clitocybe rivulosa (Pers.) P. Kumm., *Clitocybe phyllophila* (Pers.) P. Kumm.	It is described in literature as poisonous mushrooms due to gastrointestinal problems, and in severe cases collapses and bradycardia; usually the symptoms appear after 15 min to 2 hours of ingestion.	Dehay *et al*. (2009).
Cortinarius orellanus Fries, 1838	The species contain a cyclopeptide compound named orellanine, whose metabolites are very active, so when this compound is oxidized, for example in kidney tissue, quinone accumulates and binds with biological structures leading to cell damage.	Karlson-Stiber and Persson (2003).
Galerina marginata (Batsch) Kühner	It is a highly poisonous mushroom that contains amatoxins, which are potent toxins that can cause severe liver and kidney damage. The symptoms of poisoning typically appear within 6 to 24 hours after consumption. Initially, there may be gastrointestinal symptoms such as nausea, vomiting, and diarrhea. However, these symptoms may subside temporarily, leading to a period of apparent recovery. If left untreated, poisoning from *G. marginata* can be fatal. The death of the individual typically occurs around the fourth day after consuming the mushroom.	Bresinsky and Besl (1989).
Psilocybe cubensis (Earle) Singer, 1948 and *Psilocybe. mexicana* R. Heim 1957	They have some hallucinogenic properties. The toxin that these mushrooms contain is psylocibin. The symptoms of intoxication start 30 minutes after ingestion of fresh or dried mushroom and begins with nausea, anxiety, asthenia and vertigo, neurosensorial symptoms consisting of disorientation, visual problems, motor incoordination. Some others symptoms are hypertension, tachycardia and mydriasis.	Berger and Guss (2005).
Ramaria formosa (Pers.) Quél. (1888)	It is mildly poisonous if consumed and the principal symptoms are mid to acute nausea, diarrhea, vomiting and colicky pain.	de Oliveira (2009).
Russula emetica (Schaeff.) Pers.	If this mushroom is eaten undercooked or raw, it can make people seriously ill. The first symptoms are vomiting and nausea, together with intense stomach pains and, finally, diarrhea. Poisoning by this mushroom is almost never fatal, except in frail or immunocompromised persons or very young children.	Kibby (2012).
Scleroderma areolatum Ehrenb.	The ingestion can lead to vomiting, diarrhea, and in larger quantities, fainting.	Phillips (2010).
Suillellus luridus (Schaeff.) Murrill (1909)	If eaten raw or not sufficiently cooked, symptoms of gastrointestinal poisoning can	Tomalak *et al*. (2011).

	occur within 30 minutes to two hours, including abdominal cramps, vomiting, nausea and diarrhea.	

Toxic mushrooms are common in countries where edible mushrooms are consumed, and poisoning is recorded every year, mainly due to a misidentification of the species; the toxins of these mushrooms cause syndromes that can be fatal in some cases (Lima *et al*., 2012).

Palapala *et al*. (2002) established some characteristics of poisonous mushrooms that could be used to the identification of them and ovoid intoxication or death. Some of these characteristics are: appearance of a green or purple coloration when cutting or splitting the fungus; when you the mushroom is eaten, the tongue itches or feels like it burns; bad aroma, bitter taste, no worms and presence of scales on the cap.

Edible mushrooms biotechnology

Most species of edible fungi can be mass-cultivated under natural or semi-controlled conditions (González *et al*., 2020), and in fact this practice is the most widespread in production for consumption. However, with a good part of them, *in vitro* studies have been carried out with diverse objectives, among which outstand the obtaining of genetic material of guaranteed purity for industrial purposes, the conservation of germplasm, the massive propagation in bioreactors (either for consumption or to obtain metabolites) and even as a model to achieve approximations to the culture conditions of other fungi.

The largest production of edible mushrooms is concentrated in the species *Agaricus bisporus* and *Lentinula edodes* (Roncero-Ramos and Delgado-Andrade, 2017). Both grow in natural conditions or can be cultivated in common substrates for mass production. Possibly for this reason, *in vitro* culture for these species has been developed only for very specific purposes.

With the aim of reducing the production cost of *Agaricus bisporus*, Rashid *et al*. (2018) used aqueous extracts of the plant *Sesbania sesban* as a nitrogen source in culture media containing various compost extracts, $CaSO_4$, and phosphate rock. The best results in mycelial growth were obtained by combining 30% wheat straw, 45% horse manure, 15% *Sesbania sesban* straw, 5% $CaSO_4$ and 5% phosphate rock. Salmones *et al.* (2018) evaluated the growth of eight *A. bisporus* strains on solid or liquid medium with malt extract supplemented with yeast or compost extract, within a range of 22-28 °C. Four strains grew favorably in the medium supplemented with compost extract, showing their potential to be incorporated into the market. Krakowska *et al.* (2021) developed a method for monitoring the accumulation of bioelements during the *in vitro* culture of *A. bisporus*, given the importance of minerals in the nutritional and therapeutic value of this fungus. *Agaricus bitorquis*, another edible fungus of the same genus, grows well on agar supplemented with malt extract (MEA) (Brinda *et al*., 2021).

Although *Lentinula edodes* can be grown on oak logs, the reduction of forest areas has led to the appearance of alternatives such as cultivation on artificial logs, made from wood residues. A problem to be solved continues to be the duration of the period between the beginning of the growth of the fungus and the first harvest (around a year). To reduce this time, Kumar *et al.* (2019) tested different media, pH and temperatures, and found the best results for the Le-17-04 strand in potato dextrose agar (PDA) medium at 24^0 C, and at pH 5 and 6. However, in another study with the lines DMR-356, DMR-35 and DMR-410 the use of poplar sawdust extract broth led to a much higher mycelial growth than the obtained in potato dextrose broth (PDB) (Paswal *et al*., 2021). The explanation of this phenomenon seems to be related to a closer approximation to the metabolites that are synthesized in the natural conditions of growth of the fungus, which agrees with previous results obtained in Brazil by Andrade *et al.* (2008) with eucalyptus extracts.

Among the best-known genera of edible fungi is *Pleurotus* sp., which stands out not only for its culinary value but also because it synthesizes pharmaceutically useful substances such as antitumor polysaccharides, polyphenols and other metabolites related to oxidative stress (Ferrer *et al*., 2019). Mushrooms in this genus are wild-harvested and can be grown in solid or liquid media. In solid media, convenient results have been obtained in PDA and Saboureaud dextrose agar (SDA) for *P. ostreatus* (Angulo *et al*., 2022), in order to obtain pure cultures for subsequent planting in natural substrates. In liquid medium, Sabouraud dextrose broth (SDB) is considered very favorable for the cultivation of *P. cystidiosus* (Dulay *et al*., 2015).

Beltrán *et al*. (2020) pointed out that submerged culture is very useful for production of this genus, particularly the *P. ostreatus* species. Hoa and Wang (2015) worked on optimizing the conditions for submerged culture of *Pleurotus ostreatus* and *Pleurotus cystidiosus*. Gomes-Corrêa *et al*. (2016) referred various sources of carbon and nitrogen for this purpose, such as reducing sugars (mainly glucose and xylose), corn liquor, amino acids, PDB, soybean cake, casein hydrolyzate, yeast extract and peptone.

Schizophyllum commune is a fungus that grows in almost all regions of the planet, and stands out for its proteins, vitamins, and mineral content (Dasanayaka and Wijeyaratne, 2017). In the wild, it lives on rotten wood, but its high humidity requirements determine its seasonal growth; therefore, its domestication is essential to guarantee a stable supply to the market. In Malaysia, Aminah *et al.* (2020) were able to determine that *S. commune* grows satisfactorily in solid malt extract agar at pH 6 and a temperature of 30 °C, thereby establishing the initial conditions for its domestication.

Volvariella volvacea is cultivated on rice straw throughout East and Southeast Asia, although in other countries with favorable climatic conditions other substrates are used, such as the remains of pasture crops and sugarcane, as in Mexico (Salmones, 2018). As in other species, the efficiency of production depends on the quality of the inoculum used, and to guarantee the latter, *in vitro* culture procedures are used. Sharma *et al.* (2019) investigated the effect of various liquid nutrient media on the growth of four strains of *V. volvacea* and found that the highest values of mycelial growth were obtained in malt extract broth, potato dextrose broth and sweet potato dextrose broth. Previously, Tudses (2016) had reported the possibility of using sweet potato as a substitute for PDA in the cultivation of this fungus. On the other hand, Brinda *et al.* (2021) found that *V. volvacea* also grows satisfactorily on solid medium (PDA) supplemented with peptone.

Tricholoma matsutake is a mycorrhizal fungus that grows in Europe, North America, and Asia; in this last continent and mainly in Japan, it is highly appreciated in the kitchen. It grows associated with *Pinaceae* and *Fagaceae* trees, in an area around the trunk that has been called "fairy ring" (Yun *et al*., 1997). Although there are studies on the artificial cultivation of *T. matsutake*, this fungus only forms fruiting bodies in the fairy ring area. Several authors have suggested that this phenomenon is affected by bacteria that contribute to the formation of fruiting bodies.

Based on those studies, Oh and Lim (2018) isolated and identified 28 species of fairy ring bacteria, mainly from the genera *Paraburkholderia, Burkholderia, Staphylococcus*, and *Caballeronia*. The co-culture in solid medium of these bacteria with *T. matsutake* showed that most of them inhibited the growth of the fungus, but three of them stimulated it, particularly *Paenibacillus taichungensis* and *Staphylococcus* sp., with biomass increases between 346 and 404%. (Oh and Lim, 2018). Although the medium in which this stimulation occurred contains an amount of glucose that is not found under natural conditions, this result could be useful in obtaining biostimulants for fungus culture. However, more research is needed to fine-tune the *in vitro* growth of the fungus, since a significant amount of mycelium is required for fruiting bodies to form (Yamanaka *et al.,* 2020). On the other hand, biological processes that occur *in vitro* appear to have a certain level of complexity; Horimai *et al.* (2020) showed that inocula of *T. matsutake* from sibling spores do not have the same ability to colonize host trees, and that instead inoculation with mixtures of two or three isolates significantly increased the level of colonization of the fungus. Elucidation of the mechanisms of symbiosis between *T. matsutake* and host trees will be an important contribution.

A closely related species to *T. matsutake* is *Tricholoma bakamatsutake*, which does not grow associated with *Pinaceae* trees, but only around beeches and oaks. Yamanaka *et al*. (2019) tested the effect of 16 organic and inorganic nitrogen sources on the growth of *T. bakamatsutake*. Most of the sources used reduced the mycelial growth of the fungus, but the amino acids valine and glutamine increased the formation of chlamydospores. The use of these chlamydospores to infect host trees could favor the production of the fungus under natural conditions.

Under the common name "truffles" two types of mushrooms are known: truffles, belonging to the genus *Tuber*, and desert truffles, which include the genera *Terfezia, Tirmania* and *Mattirolomyces*; all have been studied through *in vitro* culture to some extent. Arenas *et al.* (2018) cultivated *Terfezia claveryi* in Modified Melin Norkans (MMN) medium and successfully inoculated *Helianthemum almeriense* plants with the obtained mycelium.

In vitro studies have also been carried out with other edible fungi of lesser economic importance. Díaz-Talamantes *et al*. (2017) investigated the culture conditions of several genera (*Bovista aestivalis, Infundibulicybe squamulosa, I. gibba, Lycoperdon perlatum* and *Gymnopus dryophilus*), obtaining the best results for the latter. Several lines of *Lyophyllum* sp. grew well on PDA and abundant biomass was obtained in liquid medium with malt extract, peptone, and yeast extract (ME-PY) (Arana-Gabriel *et al*., 2018). Chung (2021) found differences between the culture media and the most favorable conditions for the growth of six strains of *Suillus luteus, Suillus granulatus* and *Suillus bellinii* obtained from *Pinus radiata* plantations.

In general, as Guerin-Laguette (2021) points out, problems persist in the transfer of biological material obtained *in vitro* to *ex vitro* conditions, linked above all to the differences between the two environments and to the interactions with other microorganisms that occur *ex vitro*.

A summary of the results discussed here on the *in vitro* culture of these fungi is presented in Table 3.

Table 3. Main results on *in vitro* culture of edible fungi

Species	Culture conditions	Purpose	Reference
A. bisporus	Culture in liquid or solid medium supplemented with plant extracts	Reduction in production costs	Rashid *et al*. (2018)
	Culture in liquid or solid medium supplemented with compost extracts	Evaluation of the influence of temperature on growth	Salmones *et al*. (2018)
	Culture in liquid medium enriched with mineral nutrients	Quantification of nutrient accumulation and its effect on fungal biomass	Krakowska *et al*. (2021)
A. bitorquis	Culture in solid medium	Obtaining mycelium	Brinda *et al*. (2021)
Lentinula edodes	Liquid medium + eucalyptus extract	Use of plant extracts compatible with the environment of natural growth	Andrade *et al*. (2008)
	Liquid and solid media	Reduction in time to first harvest	Kumar *et al*. (2019)
	Liquid medium + poplar sawdust extract	Use of plant extracts compatible with the environment of natural growth	Paswal *et al*. (2021)
P. ostreatus	Submerged cullture	Obtaining mycelium	Hoa and Wang (2015) Beltrán *et al*. (2020)
	Solid media (PDA, SDA)	Obtaining mycelium	Angulo *et al*. (2022)

P. cystidiosus	Submerged culture	Obtaining mycelium	Hoa and Wang (2015) Dulay *et al*. (2015)
V. volvacea	Liquid medium (SPDB)	Optimization of culture conditions	Tudses (2016)
	Liquid media (MEB, PDB, SPDB)	Optimization of culture conditions	Sharma *et al*. (2019)
	Solid medium + peptone	Optimization of culture conditions	Brinda *et al*. (2021)
Schizophyllum commune	Solid medium (MAE)	Domestication	Aminah *et al*. (2020)
Tricholoma matsutake	Co-culture with bacteria in solid medium	Improving culture conditions	Oh and Lim (2018)
Terfezia claveryi	Modified Melin Norkans medium	Pure cultures for inoculation of plants	Arenas *et al*. (2018)
Other	Diverse	Obtaining biomass	Díaz-Talamantes *et al*. (2017) Arana-Gabriel *et al*. (2018) Chung (2021)

In addition to their nutritional value, all these edible mushrooms synthesize substances that have pharmaceutical properties or industrial application; for these reasons, studies have been carried out to obtain useful metabolites under *in vitro* culture. Although some research has been carried out in solid media, the use of liquid medium (submerged culture) is preferred due to its advantages in terms of growth and ease of handling, although Dudekula *et al.* (2020) point out that this system has its own drawbacks that must be overcome in each case. Le *et al*. (2007) worked on optimizing the growth of *Pleurotus nebrodensis* to obtain exopolysaccharides, using maltose as carbon source and yeast extract as nitrogen source, and obtained 4.13 g L^{-1} of biomass. Elisashvili (2012), with glucose as carbon source, obtained biomass yields (g L^{-1}) of 5.6 (*Lentinus edodes*), 7.7 (*Agaricus nevoi*) and 5.3 – 11.3 (three species of *Pleurotus*) in submerged culture. *Pleurotus ostreatus* mycelium, cultivated in liquid medium with potato and yeast extract, synthesizes polysaccharides with antitumor activity (Cao *et al.,* 2015).

Lentinula edodes extracts obtained by culture in solid medium (PDA) or liquid medium (malt extract broth) showed inhibitory activity against foodborne pathogens or contaminant bacteria (*Bacillus, Listeria, Staphylococcus, Klebsiella, Proteus*) (Ishikawa *et al*., 2001). The substances synthesized by this fungus also have an effect on plant pathogenic microorganisms. *Penicillium expansum* causes postharvest rot in apples and can be controlled with the application of filtrates from *L. edodes* culture (Wang *et al.,* 2013). Kaur *et al.* (2016) cultivated *L. edodes* in solid medium, then fermented the mycelium in liquid medium (malt extract + yeast extract) and used the filtrate of this culture to control *in vitro* and *in vivo Xanthomonas campestris* pv. *vesicatoria*, a bacterium that causes various diseases in plants. García-Cruz *et al*. (2020) determined that the pH of 4.5 is the most favorable for the production of polysaccharides by *L. edodes* in submerged culture. Other effects of *Lentinula edodes* extracts and metabolites on tumors and other pathologies in mammals, including humans, have been documented by Ponnusamy *et al.* (2022).

Numerous fungi play an important role in the bioremediation of heavy metals, hydrocarbons, and pesticides, some of which are edible. The production of laccases and the degradation of the herbicide Scepter® (imazaquin) by *Pleurotus ostreatus* cultivated in solid medium (PDA) or liquid with yeast extract has been demonstrated (Rezende *et al*., 2005). Laccases from four species of *Pleurotus* degrade the DB14 dye in solid MEA medium with this compound (Singh *et al*., 2013). Similar results have been reported by Moreira-Neto *et* *al*. (2013) for the degradation of Cibacron Brilliant Blue and Cibacron Red dyes in solid (PDA) and liquid media by several genera of fungi, including *Pleurotus*.

In vitro cultures of edible fungi have also been used as material for proteomics studies on *Pleurotus sapidus* (Zorn *et al.,* 2005) and *Pleurotus ostreatus* (Petráčková *et al*., 2016), among others (Al-Obaidi, 2016).

Conclusions

The consumption and cultivation of edible mushrooms is a tradition in many countries, mainly in Asia. This production has been expanding to Europe and America, where it has been gaining importance and growing gradually because its cultivation cycle is short, relatively cheap and it is sold at a good price in the market. Additionally, most of these fungi can grow on waste from agricultural and industrial productions, which allows the recycling of these wastes into profitable work. The properties of edible mushrooms are not limited to their culinary and nutritional value, which makes them highly appreciated in haute cuisine, but to the fact that a good part of them are recognized for their medicinal properties, due to the synthesis of substances with biological activity on several human diseases. Even though precautions should be taken in their consumption, because they are easy to confuse with other toxic mushrooms that can cause harmful symptoms and even death, interest in edible mushrooms continues to grow, and has led to the application of biotechnology for various purposes, among which the obtaining of high purity genetic material and the production of metabolites in bioreactors stand out. Although they grow well in solid culture medium, the use of submerged culture has allowed the establishment of conditions to obtain useful substances in bioreactors. More recently, the *in vitro* culture of edible mushrooms begins to find other applications, such as the control of plant diseases and the bioremediation of herbicides and heavy metals. For all these reasons, it can be predicted that the production of edible mushrooms, both *in vivo* and *in vitro*, will continue to grow in the coming years.

Authors' Contributions

SPA and JRS conceptualization; SPA, EFHA, JRS and MITG writing original draft; SPA, EFHA, VHVR and SAGG writing, review and editing. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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