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A mini review on the potential pharmacological properties, cultivation, and market value of edible *Lentinus* mushrooms (*Polyporaceae*)

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Abstract

Lentinus is a saprobic genus consisting of many edible species. Some species are widely consumed and important for the commercial market. *Lentinus* species are mostly distributed in tropical and subtropical regions, and few species like growing in temperate regions. According to our literature reviews, some *Lentinus* species have high nutrient value, medicinal properties, biotechnological, and environmental applications due to their reported bioactivities. *Lentinus* can also be considered as an important part for the economy as they are edible. In this short review, potential pharmacological properties, cultivation methods and economical value of *Lentinus* species are provided.

Keywords – economic – edible mushrooms – fungus – lentoid – medicinal mushrooms.

Introduction

Lentinus Fr. is a genus of *Polyporaceae*, which was established with *L. crinitus* (L.) Fr. as the type species. (Corner 1981, Grand et al. 2011, He et al. 2019). There are 635 taxon names listed under *Lentinus* in the Index Fungorum (http://www.indexfungorum.org/). For a total of 55 species including asexual morphs (He et al. 2019). This genus is widely distributed, and many phylogenetic studies have been done to resolve the relationships among *Lentinus* species (Corner 1981, Grand 2004, Grand et al. 2011, Seelan 2015, Seelan et al. 2015, Senthilarasu 2015). Corner (1981) defined the genus *Lentinus* different from other related genera by having skeleton-binding hyphae, and the genus mostly relates to *Polyporus*. Later Pegler (1983) published an extensive monograph of *Lentinus* as a polyphyletic and there are two subgenera of *Lentinus* sensu are *Lentinus* subg. *Lentinus* and *Lentinus* subg. *Panus*, which they separate is based on different hyphal systems and hymenophoral trama (Pegler 1983). However, *Lentinus* has widely document taxonomically controversial (Hibbett & Vilgalys 1991, Pegler 1983, Binder et al. (2005, 2013), Seelan et al. 2015).

Lentinus was confused in previous taxonomic classification in groups of lentinoid and pleurotoid, which were *Heliocybe* Redhead & Ginns, *Lentinus* Fr., *Lentinula* Earle, *Lentinellus* P. Karst., *Neolentinus* Redhead & Ginns, *Panellus* P. Karst., *Panus* Fr., *Pleurotus* (Fr.) P. Kumm. (Donk 1964,

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Corner 1981, Pegler 1983, Singer 1986). The lentinoid characteristics distinctively have an eccentric to the central stipe attachment, decurrent gills, a tough and consistency basidome when compared to pleurotoid. Pleurotoid characteristics have fleshy and soft consistency basidome, and lateral to central attachment (Seelan et al. 2015), and their macro-morphology are provided in Fig. 1. *Lentinus* belongs to the lentinoid group because their main macro-characters are often fibrillose to squamulose on pileus and not split longitudinally when mature, decurrent lamellulae and usually serrulate to serrate lamellae edge, pores are present in some species e.g. *L. arcularius* (Batsch) Zmitr. and *L. brumalis* (Pers.) Zmitr., variable in stipe, absent annulus or present in *L. sajor-caju* (Fr.) Fr., absent volva. For micro-characters, they have hyphae pegs in most species and white oblong to cylindrical spores (Corner 1981, Largent 1986). It is widely distributed in both tropical and temperate regions, but the abundant species are present in tropical countries (Kirk et al. 2008, Seelan 2015). All species of *Lentinus* are known as wood decomposers playing an important role in the natural biological community of interacting organisms and their physical environment. They typically grow on fallen tree trunks, decaying wood, and old stumps. *Lentinus* basidiomes are soft when young and become leathery when matured. They are usually suitable for consumption when 3–5 days young. In Thailand, they can be found in the wet season from June to September, and some dry materials can stick on substrate throughout the year (Jonathan & Fasidi 2001, Gbolagade et al. 2006, Sysouphanthong et al. 2010).

Biological activities

Mushroom species have been consumed by humans for thousands of years because of their good taste and unique flavors (Valverde et al. 2015, Roncero-Ramos & Delgado-Andrade 2017). Mushroom species have high nutritional value as well as medicinal properties, and they can reduce the risks and treat certain diseases (Oyetayo 2011, Qin et al. 2015, Valverde et al. 2015, Lau & Abdullah 2017, Fernandes et al. 2021). *Lentinus* species are edible mushrooms that could offer several important medicinal compounds, and studies on the genus are becoming widespread, which gives a practical exhibition and explanation. Therefore, bioactive compounds and biological activities of *Lentinus* species have received much attention in recent years because of the increasing interest in human health, and they have been studied in vitro and in vivo by many researchers, and interesting studies are provided in Table 1. Several studies have been showing *Lentinus* species exhibiting antioxidant (Dulay et al. 2015, Sevindik 2018); antibacterial and antitumor (López-Legarda et al. 2020); and antiviral, immune-modulating and cholesterol-regulating effects (Dulay et al. 2015). *Lentinus polychrous* Lév. is an edible species consumed by Thai local communities. It was analyzed phytochemical contents and bioactivities, its hot water-extracted polysaccharide fractions that can be protective activity on the viral and stronger than *Ganoderma lucidum* (Curtis) P. Karst (Fangkrathok et al. 2013, 2021). In addition, protein-based pharmaceutical products were considered to be one of the major new categories of medicine, and the soluble protein fraction of *L. tigrinus* was considered to be a potent anti-cancer compound. However, these compounds are not yet completely isolated and identified for the active single proteins or peptides (Mohammadnejad et al. 2019). Furthermore, *Lentinus crinitus* (L.) Fr. was found to have high ligninolytic and antioxidant activities, and the development of its lithium-enriched mycelial biomass could be used as an alternative functional food (Adenipekun & Isikhuemhen 2008). Phenolic function as reducing agents of cancer and other human diseases (Anantharaju et al. 2016), which it was observed that *L. squarrosulus* Mont. contained 18.7 g/100g of phenolic acids (Ghasemzadeh & Ghasemzadeh 2011, Ao & Deb 2019).

Nutritional value

Mushrooms have high nutrient value included protein, carbohydrate minerals and vitamins. Their nutritional contents can be compared with the foods such as egg, milk (Akyüz & Kirbağ 2010, Enas et al. 2016, Ho et al. 2020, Niego et al. 2021); and the details are shown in Fig. 2. The nutritional value index of mushrooms is 6 to 31 (Ferdousi et al. 2019), and it varies depending on species, their environment, condition and substrates supplied for mushroom cultivation (Carrasco et al. 2018, Chang & Wasser 2017). A commercial strain of *Lentinus* has been used for nutritional and medicinal purposes. For instance; five commercial species of *Lentinus* species such as *L. conatus*, *L. cladopus*, *L. sajor-caju*, *L. squarrosulus* and *L. torulosus*, and were analyzed for sugars, fatty acids, ascorbic acid, carotenoids, lycopene, phenolic compounds and amino acids (Atri 2014). There are many studies that have been analyzing the nutritional composition of *Lentinus* species as showed in Table 2. *Lentinus* has good medicinal properties, and also nutritional values such as high content of proteins, carbohydrates, low amounts of fat, vitamins, carotenoids and minerals (P, K, Mn, Ni, and Fe) (Singdevsachan et al. 2013, Lau & Abdullah 2017). Consequently, *Lentinus* could potentially be a wealthy source of nutritional and medicinal compounds.

Fig. 1 – Comparison of morphlogical characteristics of lentinoid and pleurotoid mushrooms. **1, 2** Lentinoid mushrooms. **3, 4** Pleurotoid mushrooms. Scale bars = 5 cm.

According to available data (Table 2), *Lentinus sajor-caju* have a highest protein content (62.27 ± 0.02 g/100 g), carbohydrate content (68.24 ± 0.22 g/100 g) and high energy content (408.22 ± 2.64 kcal/100 g). The protein content is close to milk (6%), eggs (26%) and rice (5%) (Source – U.S. Department of Agriculture, Agricultural Research Service. Food Data Central, 2019. fdc.nal.usda.gov). Hence, it could be considered as an alternative of protein source of *Lentinus* species have high carbohydrate content and low-fat content making them ideal ingredients to be included in the modernday healthy diet. The most consumed species have not been reported yet as different countries have different preferences. For example, *L. squarrosulus* is popularly consumed as a food by local people in Africa (Lau & Abdullah 2017) while *L. sajor-caju* is the most consumed and widely sold in the local Thai market (Karunarathna et al. 2011). For other species, it might be popular in local communities but there have been no such records yet. *Lentinus squarrosulus* has highest monosodium glutamate-like and sweet amino acids when compared with *Hymenopellis superbiens* (Berk.) R.H. Petersen and *Naematelia aurantialba* (Bandoni & M. Zang) Millanes & Wedin (Zhou et al. 2015). Species from this genus could be integrated in the daily diet as functional foods providing health-giving additives and medicinal benefits.

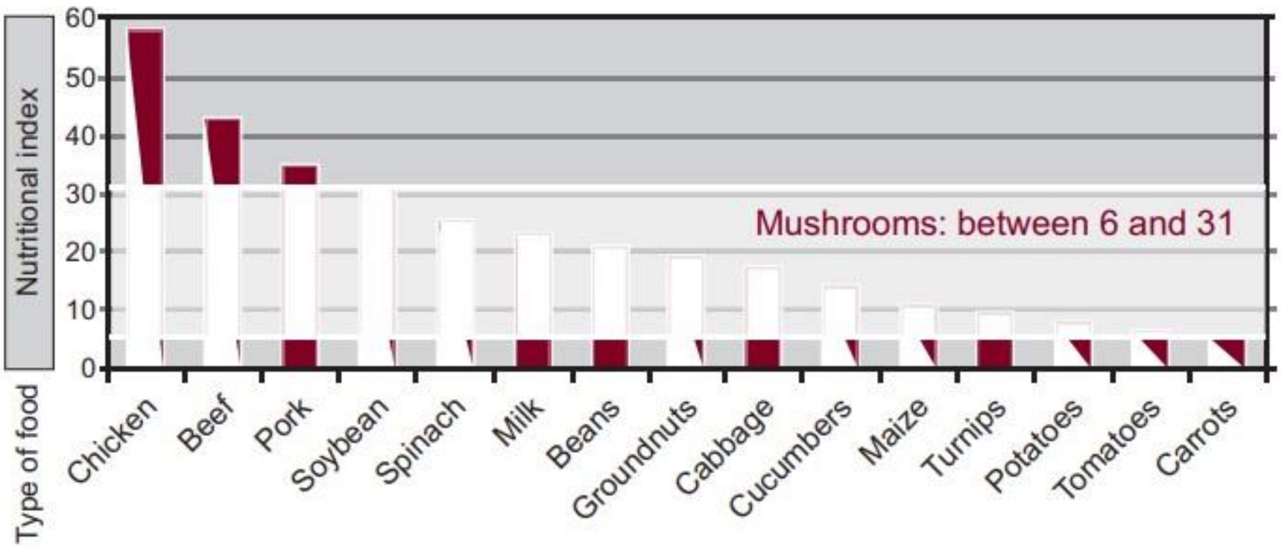

Fig. 2 – Comparison of the nutritional index of some important food as compared to mushrooms. Source – FAO. 2004 – Wild edible fungi, a global overview of their use and importance to people by Ferdousi et al. (2019).

Cultivation of *Lentinus* species

Mushroom production in the world has greatly increased, and there are many mushroom species have been widely cultivated which include *Agaricus bisporus* (J.E. Lange) Imbach (button mushrooms), *Auricularia* spp. (wood ear mushrooms), *Flammulina velutipes* (Curtis) (Enoki macrofungi), *Lentinula edodes* (Berk.) Pegler (shiitake), *Pleurotus* spp. (oyster mushrooms), and *Volvariella volvacea* (Bull.) Singer (straw mushrooms) (Reis et al. 2012, Ghosh 2020). Some mushrooms species are cultivated for their medicinal value which are *Taiwanofungus camphoratus* (M. Zang & C.H. Su) Sheng H. Wu, Z.H. Yu, Y.C. Dai & C.H. Su, *Ganoderma* spp. (Lingzhi mushroom), *Tropicoporus linteus* (Berk. & M.A. Curtis) L.W. Zhou & Y.C. Dai (black hoof mushroom) (Govorushko et al. 2019, Hyde et al. 2019). The factors affecting these mushrooms growth and cultivation include intrinsic factors and extrinsic factors. Both factors are affected by growing mushrooms. An extrinsic will impact the growth of the primarily basidiomes; and an intrinsic factor will impact the growth of the mycelium, the primordia formation and as well as the fruiting body development. To get a high mushrooms product, mushrooms cultivation needs the appropriate conditions and parameters based on the strain of the species (Mahari et al. 2020). *Lentinus* species are edible, but most of them are tough and leathery species (Karunarathna et al. 2011, Sharma 2014). The genus *Lentinus* comprises 55 species, but only some species have been cultivated such as *L. crinitus*, *L. levis*, *L. polychrous*, *L. sajor-caju*, *L. squarrosulus*, *L. swartzii* Berk and *L. tigrinus.* Previous studies have been done for e.g., suitable media, pH, optimization temperature and evaluation of mushrooms yield, for the optimizing *Lentinus* cultivation. (Fasidi & Kadiri 1993, Sobal et al. 1997, Okhuoya et al. 2005, Lechner & Papinutti 2006, Lechner & Albertó 2007, Salmones & Gutierrez-Lecuona 2008, Ratanapongleka & Phetsom 2014, Hussein et al. 2016, Conceição et al. 2017). In this review, we summarize methods of cultivation of *Lentinus* species consisting of different steps and methods from several studies; and the critical process, conditions, materials, and methods are provided in following steps:

1. Mycelia culture condition

The suitable growth conditions of mycelium of *Lentinus* have been optimized and evaluated on different solid and liquid media (Fasidi & Kadiri 1993, Mensah & Obodai 2014), and photos of good mycelial growths are showed in Fig. 3 (1). According to Dulay et al. (2012) and Dulay et al. (2017), it was reported that the mycelium of *Lentinus* grew well at pH 6.5–7.0, and incubated at 30±2°C (room temperature) under dark condition. The formulation of chemically-defined culture media is determined by the nutritional requirements of *Lentinus* species. It was found that the mycelia favorably grew well on starch, fructose, sucrose, ammonium chloride, yeast extract and malt extract at C/N ratio of 10:1, 10:1, and 40:1 (Dulay et al. 2020).

2. Spawn type and preparation

Spawn is an important factor in mushrooms production modern method of spawn preparation with cereal grains such as sorghum grain, wheat, millet, straw, coffee pulp, cotton waste and as well as sawdust. These materials can either be used alone or combined in different mixtures (Nwanze et al. 2005). No studies on the spawn optimization of *Lentinus* have been reported yet. The general spawn condition at which *Lentinus* species grow well is 25–32 °C (Kim et al 1994, Marim et al. 2018) in darkness condition for 2–3 weeks for complete colonization. The good condition of spawn containing mycelium is provided in Fig. 3(2).

3. Substrate types

Lentinus species can grow in various substrates, specifically in lignocellulose waste. *Lentinus* species were successfully cultivated on sawdust (Okhuoya et al. 2005, Ayodele et al. 2007, Oghenekaro et al. 2009). There are five economic tropical tree species of sawdust namely, *Brachystegia nigerica* (okwen tree), *Chlorophora excelsa* (Sierra Leone, Liberia), *Celtis* sp. (hackberries or nettle trees), *Guera cedrata* (Bossy, Kwabohoro, Obobo) and *Nesogordenia papaverifera* (Kotibe, Kissinhungo, Danta) that have been reported suitable for cultivating *Lentinus* species. Furthermore, it can be cultivated with other materials such as cotton waste (Chang et al. 1981), barley straw (Sobal et al. 1997), paddy straw (Das et al. 2015), wood logs (Kadiri & Halliru Arzai 2004), wheat straw (Lechner & Papinutti 2006), bark and leaves of fruit trees (Adesina et al. 2011), and oil palm fruit fiber (Chiejina & Osibe 2015). The additive is used for the cultivation of *Lentinus* include rice bran, wheat bran, sugar, calcium carbonate ($CaCO_3$), and calcium sulfate (CaSO4). Moreover, composted and non-composted agricultural wastes have also been tested and used for the cultivation of *Lentinus* species. The yield of these mushrooms will be depended on the availability of nutrients in their environment. Therefore, if we want to improve biological efficiency, we should add nutrients supplements to substrate types. The unique nutritional requirements of each *Lentinus* species were suggested using the main material along with the required appropriate supplements and balance of carbon/nitrogen ratio in order to obtain extra yield (Okhuoya et al. 2005, Dulay et al. 2020). Furthermore, cultivations of *Lentinus* on logs of dead wood of the trees above are also considered by some local people, but scientific study of the yield value has not been reported. The photos of *Lentinus* products from sawdust substrate are in Fig. 3 (5,8) and from logs are in Fig 3 (4,6).

Table 1 Potential bioactive compound and biological activities of some *Lentinus* species.

Species name	Bioactive compound	Biological activities	References
Lentinus crinitus (L.) Fr.	β-tocopherol Didehydro-1-desoxy-hypnophilinol A Didehydro-1-desoxy-hypnophilinol B Hypnophilol Hypnophilin alcohol Organic acids Phenolic acids P-hydroxybenzoic acid Polysaccharides 1-Desoxyhypnophilin 1-Desoxyhypnophilol 2,2-Dimethyl-6-methoxy-4-chromanone 2,2-Dimethyl-6-methoxy-4-chromanol 6,7-Epoxy-4(15)-hirsutene-5-ol 6,7-Epoxy-4(15)-hirsutene-1,5-diol 6,7-Epoxy-4(15),8,8a-hirsutadien-5-ol (S)-2,2-Dimethyl-3-hydroxy-6-methoxy-4-chromanone	Antitumor effects Antimicrobial effects	Abate & Abraham (1994), Abrahanr & Abate (1995), López-Legarda et al. (2020), Bertéli et al. (2021)
L. cladopus Lév.	N/ A	Antimicrobial effects	Sudirman (2010)
L. connatus Berk.	Connatusin A Connatusin B	N/ A	Rukachaisirikul et al. (2005)
L. polychrous Lév.	6-methylheptane-1,2,3,4,5-pentaol, (22E,24R)-ergosta-7,22-dien-3β,5α,6β-triol 3β,5α-dihydroxy-(22E,24R)-ergosta-7,22-dien-6-one ergosta-4,6,8(14),22-tetraen-3-one (3β,5α,8α,22E)-5,8-diepoxy-ergosta-6,22-dien-3-ol 5,8-epidioxy-(3β,5α,8α,22E)-ergosta-6,9(11),22-trien-3-ol (6)	Antioxidant, Anticancer Cancer cell line cytotoxicity Antiviral Anti-inflammatory Immunomodulatory effects	Thetsrimuang et al. (2011), Fangkrathok et al. (2013), Fangkrathok et al. (2021)

Table 1 Continued.

Species name	Bioactive compound	Biological activities	References
L. squarrosulus Mont.	1-tetradecene 3-trifluoroacetoxypentadecane 6-ethyloct-3-yl ester 9-eicosene Fumaric acid Heteroglycan Glucan Monochloride Octahydropyrrolo [1,2 a] pyrazine Phenolic acids Protein fraction Water-soluble glucan Water-soluble heteroglycan	Antioxidant effects Antimicrobial effects Antinociceptives Anticancer effects Antihypertensive Antiulcer ability Immunomodulatory	Bhunia et al. (2011), Mhd Omar et al. (2011), Sen et al. (2013a, b), Ahmad et al. (2014), Mensah &Obodai (2014), Poompouang & Suksomtip (2016), Ghate & Sridhar (2017), Lau & Abdullah (2017), Prateep et al. (2017), Ugbogu et al. (2019), Agunloye (2021), Ayimbila & Keawsompong (2021)
L. tigrinus (Bull.) Fr.	Lentinamycin-A Lentinamycin-B Lentomycin-A Lentomycin-B Octa-2,3-diene-5,7-diyne-1-ol (-)-3,4-Nonadiene-6,8-diyn-1-ol (-)-Marasin Phenolics	Antioxidant Antimicrobial effects hypoglycemic activities	Bew et al. (1996), Dulay et al. (2015, 2017)

N/A, not available.

Table 2 Comparing the proximate nutritional values of some *Lentinus* species.

Species name	Ash (%)	Carbohydrate (g/100 g DW)	Fat (g/100 g DW)	Fiber (%)	Moisture (g/100 g FW or DW)	Protein (g/100 g DW)	Reducing sugar (g/100 g DW)	Energy (kcal/100 g)	References
L. sajor-caju (Fr.) Fr.	8.41 ± .2	68.24±0.22	2.42±0.02	7.02 ± .05	85.1 ± .02 FW; 14.9 ± .02 DW	62.27 ± 0.02	2.1±0.09	408.22±2.64	Singdevsachan et al. (2013), Ao & Deb (2019)

Table 2 Continued.

Species name	Ash (%)	Carbohydrate (g/100 g DW)	Fat (g/100 g DW)	Fiber (%)	Moisture (g/100 g FW or DW)	Protein (g/100 g DW)	Reducing sugar (g/100 g DW)	Energy (kcal/100 g)	References
L. squarrosulus Mont.	10.66 ± .4	41.27 ± 0.19	6.76±0.22	9.48±0.04	87.3 ± .02 FW; 12.7 ± .02 DW	42.77±0.57	6.05 ± .02	342.35±3.0	Ao & Deb (2019), Borokini et al. (2021)
L. squarrosulus var. squarrosulus Mont.	3.12 ± .2	19.14 ± .01	N/ A	6.1 ± .1	86.2 ± .01 FW; 13.8 ± .01 DW	18.77 ± .02	5.39 ± .08	N/ A	Ao & Deb (2019)
L. tigrinus (Bull.) Fr.	3.41 ± .2	52.4 ± 0.5	2.1 ± 0.4	17.4 ± 0.5	73.7 ± .04 FW; 26.3 ± .04 DW	31.85 ± .03	30.1 ± 0.3	N/ A	Dulay et al. (2014), Ao & Deb (2019)

FW, fresh weight; DW, dry weight; N/A, no data available.

Economical important

Mushroom production has been increasing globally. In the world markets for the mushrooms, the industry has divided mushrooms into three types included edible mushrooms, medicinal mushrooms and wild mushrooms (Chang 2006). Mushrooms species have been integrated in many developing sectors in the food and nutraceutical industry further developing the market (Berch et al. 2007, Chang 2007, Zhang et al. 2014, Niego et al. 2021). More than 2,000 edible mushrooms species are widely accepted for human consumption, and have been documented to be used as food (Li et al. 2021). Mushroom is essential to the national economy in terms of mushroom production and generating income for local farmers. Cultivated mushrooms can be sold in both locally or exported to other countries to improve the country economy. With the increasing of quality of local product; the acceptance and demand for edible mushrooms have also significantly increased, and *Lentinus* species are consumed by many countries in Southeast Asia such as Laos (Tapingkae 2005, López-Legarda et al. 2020), Malaysia (Lee et al. 2009), Philippines (De Leon et al. 2013), Thailand (Pukahuta et al. 2008), Vietnam (Joly & Perreau 1977), and in central part of Africa (Lau & Abdullah 2017).

Fig. 3 – The cultivation process of *Lentinus* species. **1** Mycelium growth on solid media. **2** Spawn preparation on sorghum. **3** Mycelium growing on bag substrate. **4,6,7** *Lentinus squarrosulus* grows on logs. **5, 8** *Lentinus squarrosulus* grows on bag substrates.

Among of all commercially cultivated mushrooms, *Lentinus* species can be economically important mushrooms. *Lentinus squarrosulus* is the most cultivated species commonly found in both outdoor markets and supermarkets; and it is commercially cultivated using agricultural wastes to help the producers to reduce the cost of cultivation and increase profits. The price is around 120-130 baht (TH.) per kilogram. Processed mushrooms are recommended to enhance the shelf life and modified to obtain a high price. The processing can be canned, dried, extract as medicinal or healthy drinks, and packed in frozen forms (Oddson & Jelen 1981, Raman et al. 2018). *Lentinus* can be found as dried mushroom (Fig. 4), dried powder forms, fermented mushrooms in the local market. Therefore, cultivating *Lentinus* is suitable for farmers who start to cultivate mushrooms for commercial purposes. However, climate variability problems might cause negative effects for both the large-scale producers and small farmers, causing no mushrooms to enter the markets. Some mushrooms are considered to be effective in killing insect larva. Adeoye-Isijola et al. (2021), reported that activities of ethanol extract from the *L. squarrosulus* had insecticidal effects against the *Aedes aegypti* larva and pupa, having great potential as an alternative source of environmentally friendly insecticides. More importantly, *Lentinus* species are widely used in biotechnology and biochemical applications such as “bioremediation and delignification” (Bayramoglu et al. 2002, Arica & Bayramoğlu 2007). The mycelia of *L. sajur-caju* could be considered as suitable biosorbents for the removal of cadmium in wastewater treatment systems (Bayramoglu et al. 2002), thus, reducing the cost of industrial wastewater treatment. From their potential benefits, *Lentinus* species could be important economical commodities.

Fig. 4 – Processing of mushrooms, *Lentinus squarrosulus* as a dried form.

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