CHAPTER 2
LITERATURE REVIEW

Edible Mushrooms

Mushrooms are the fleshy and edible fruit bodies of several species of macro fungi (fungi which bear fruiting structures that are large enough to be seen with the naked eye). They can appear either below ground (hypogeous) or above ground (epigeous) where they may be picked by hand. Mushrooms have been used as food and medicine in many parts of the world. Although mushrooms are often grouped with vegetables and fruits, they are actually belongs to the fungal kingdom. They are macro-fungi which belong either to Basidiomycetes or Ascomycetes and they are very distinct from plants, animals and bacteria as described by Mushigeni and Chang (2001). Chang and Miles (1991) stated that mushroom with their great variety of species, constitutive a cost effective means of both supplementing the nutrition to human. 4-5 different mushrooms are now industrially cultivated throughout the world and in India three mushrooms are now being cultivated such as *Agaricus bisporus, Pleurotus* sp. and *Volvoriella volvocea*. *Pleurotus ostreatus,* the oyster mushroom, is a common edible mushroom. More than 2000 species of edible mushrooms are known, out of which only few species have been cultivated commercially by preparing beds. Among the various edible mushroom types, *Pleurotus* species have become more popular and widely cultivated throughout the world particularly in Asia and Europe as they have simple and low cost production technology shows higher bio-efficiency. Mushrooms are the source of extra ordinary power and virility and are used in the preparation of many continental dishes and have medicinal properties like anticancerous, anticholesteral, antitumorous. Cultivation of edible mushroom obtains nutritive food materials by decomposing various agricultural waste materials due to its saprophytic nature. Cultivation of edible mushroom is a biotechnological process, which reduces and equally protects the environment from excess solid waste pollution (Mshandete and Cuff, 2008; Sánchez, 2010). Miles and Chang (1997) reported that out of about 70,000 described species of fungi, it has been suggested that around 14,000-15,000 species produces fruiting bodies of sufficient size and suitable structures to be considered as macro fungi. Of these, about 5,000 species are considered to possess varying degrees of edibility and more than 2,000 species from 31 genera are regarded as prime edible mushrooms. But only

100 of them are experimentally grown, 50 economically cultivated and 30 commercially cultivated and only about 6 to have reached an industrial scale of production in many countries (Table 1). Furthermore, about 1,800 are known to possess medicinal properties. They also reported that the number of poisonous mushrooms are relatively very small (approximately 10%), of these about 30 species are considered to be lethal.

Table 1: Present status of world production of mushroom

Countries	Total Productions (Metric Ton)		
	1997	2007	2012
China	5,62,194	15,68,523	51,58,773
United States of America	3,66,810	3,59,630	3,88,450
Netherlands	2,40,000	2,40,000	3,07,000
Poland	1,00,000	1,60,000	2,20,000
Spain	81,304	1,40,000	1,46,000
France	1,73,000	1,25,000	1,16,574
Italy	57,646	85,900	7,85,000
Ireland	57,800	75,000	67,063
Canada	68,020	73,257	82,000
United Kingdom	1,07,359	72,000	73,100
Japan	74,782	67,000	61,500
Germany	60,000	55,000	52,907
Indonesia	19,000	48,247	40,659
India	**9,000**	**48,000**	**52,350**
Belgium	NA	43,000	42,000
Australia	35,485	42,739	46,493
Korea	13,181	28,764	26,000
Iran	10,000	28,000	87,675
Hungary	13,599	21,200	19,330
Viet Nam	10,000	18,000	23,000
Denmark	8,766	11,000	10,700
Thailand	9,000	10,000	6,820
Israel	1,260	9,500	10,000
South Africa	7,406	9,395	14,284
New Zealand	7,500	8,500	9,884
Switzerland	7,239	7,440	7,977
Other Countries	85,911	59,279	61,346
Total Production	**21,86,222**	**34,14,392**	**79,16,885**

*Source: Table 50, World Mushroom and Truffles: Production. 1961-2007; United Nations, FAO, FAOSTAT (8/28/2009) and FAOSTAT | © FAO Statistics Division 2015 | 14 July 2015

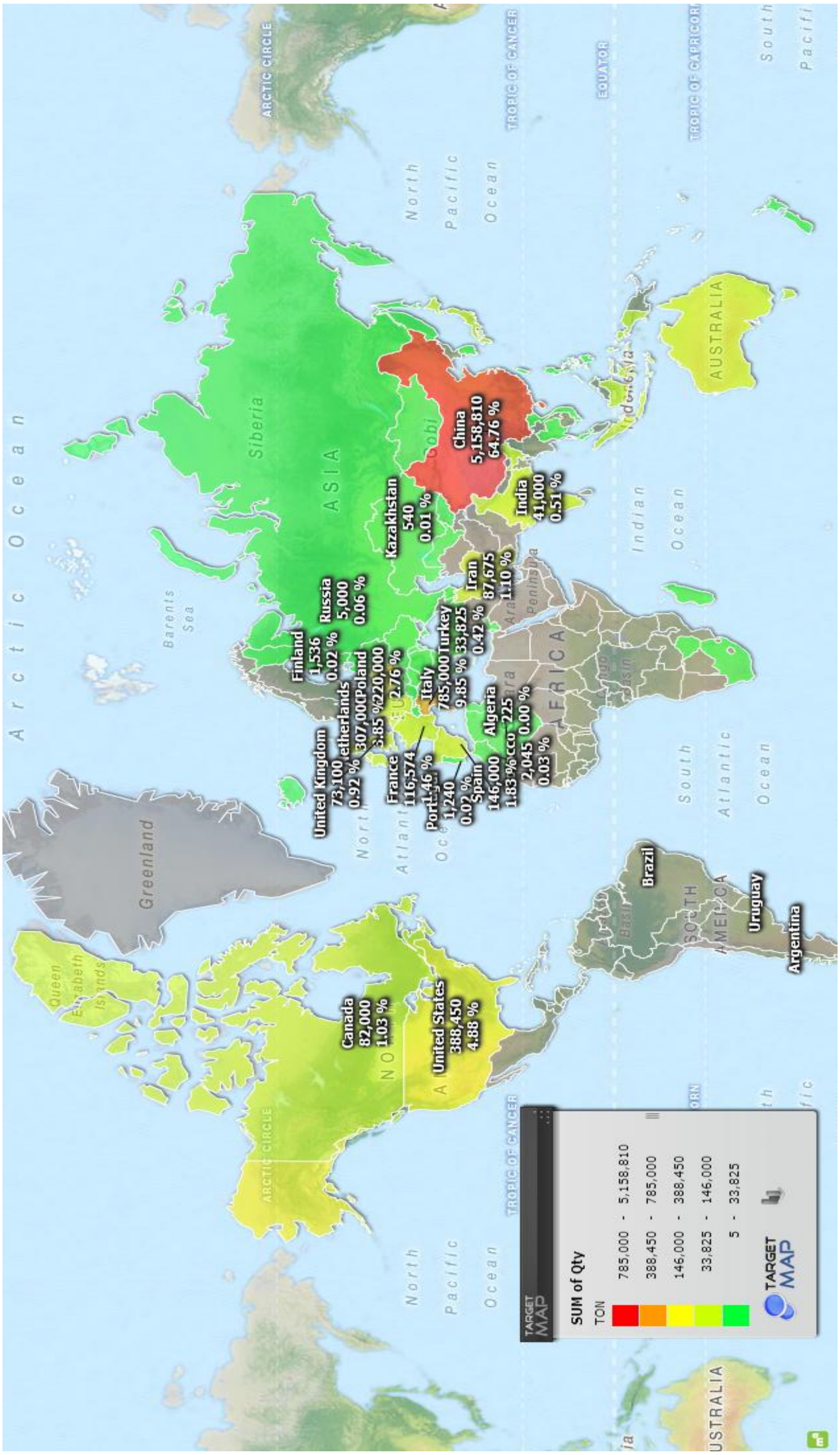

Figure 1: Global scenario of mushroom production

Oyster Mushroom

Oyster mushroom (i.e. *Pleurotus* spp.) is one of the major cultivated mushroom of India is commonly called as Dhengri because of its oyster like shape. The genus *Pleurotus* belongs to family Tricholomataceae. About 40 different species are now cultivated popularly throughout the world out of which 12 species are cultivated in different parts of India. Chang *et*. *al*. (1991) and Erkal (1992) stated that in terms of its yield and production *Pleurotus* is the second large cultivated mushroom right next to *Agaricus bisporus* throughout the world (Figure 1 and Table 1). Cultivation of oyster mushroom increased greatly throughout the worlds during the last few decades and it's accounted about 14.2% of the total world edible mushroom as described by Chang (1999). Cultivation of oyster mushroom is gaining popularity because of its simplicity in technique and less investment. In India, mushroom production rate was also quite higher and almost all the states are producing different edible mushroom out of which, *Agaricus bisporus* and *Pleurotus* species widely distributed (Table 2).

Cultivation Technology of oyster mushroom

Mushroom cultivation represents the only current economically viable biotechnology process for the conversion of waste plant residues from forests and agriculture (Wood and Smith, 1987). Cultivation viable processes for the bioconversion of lignocellulosic wastes (Bano *et al*., 1993; Cohen *et al*., 2002). Singh *et al*., (1990) reported that the cultivation of oyster mushroom is gaining importance in tropical and subtropical regions due to its simple way of cultivation and high biological efficiency. Das and Mukherjee (2007) stated that different species of *Pleurotus* are usually found to be most efficient in the degradation of lignocellulose substrates among all types of white rot fungi. Weinheim, (2006) suggested that cultivation of mushroom also decrease the air pollution with turning agricultural wastes also help in the management in pastes and other fungal inoculum through the edible mushroom cultivation. He also stated that the cultivation of edible mushroom also help in solving many problems like improving the economic condition of rural people as well as in improvement in the health of people as mushroom considered as a valuable health food which contains considerable amount of protein, calories and minerals. Sawdust and sugarcane bagasse were the best substrates for growing of oyster mushroom than other agro-based substrates (Ahmed, 1998). Wide spread malnutrition with ever increasing protein gap in our country has necessitated the search for alternative source of protein because the production of pulses has not kept pace with our requirement due to high population growth. Sanchez *et al.,* (2002) stated that the cultivation of *Pleurotus* sp. is one of the major techniques for the bioconversion of agricultural wastes into a protein rich food which will sustain the food security for the people of developing countries. Several technologies has been developed for the cultivation of oyster mushroom to increase the productivity of mushroom as described by Holker *et al.* (2004).There are different methods of oyster mushroom cultivation like bag, shelf, log, bottle, tray, jar and grid-frame as described by Stamets (2000) but the most adopted cultivation technique is bag and shelf cultivation (Choi, 2003). Thomas *et al*., (1998) stated that various agricultural wastes rich in cellulose can be used as substrates for cultivation of dhingri mushrooms and about 200kinds of wastes in which this mushroom can be grown as reported by Poppe (2000). *Pleurotus* species requires about 20 to 30°C temperature both for its vegetative growth and reproductive phase in natural habitat (Chang and Miles, 2004).Oyster mushrooms have ability to grow at wide range of temperatures and utilizing various lignocellulose substrates (Khan and Garcha, 1984). Hassan *et al*., (2011) suggested that oyster mushroom can be grown on various substrates including paddy straw, maize stalks, vegetable plant residues, sugarcane bagasse etc. and this substrates influences its growth, yield and composition (Iqbal *et al*., 2005; Kimenju *et al*., 2009; Khare *et al*., 2010). However, an ideal substrate should contain nitrogen as supplement and carbohydrates for rapid mushroom growth. Oyster mushroom can be cultivated in different waste materials and a very wide range of waste materials have been used. Several report on the suitability of various substrates for mushroom production suggested rice straw (*Oryza sativa*), wheat straw (*Triticum aestivum*), ragi straw (*Elucine coracana*), bajra straw (*Pennisetum typhoides*), sorghum straw (*Sorghum vulgare*), maize stalk (*Zea mays*) reported by Bano *et al*.,1987; Goswami *et al*.,1987 and Gupta and Langar,1988. Woods of poplar (*Populus robusta*), oak (*Quercus leucotrichopora*), horse chest nut (*Aesculus indica*), *Acasia* sp., chopped banana pseudo stem, cotton stalk, pea shells and poplar saw dust has also been used for cultivation (Philippoussis *et al*., 2001; Zervakis *et al*., 2001). Pavlik (2005) also stated that the production of *Pleurotus* mushroom varies with the species of trees used for cultivation and investigation revealed that the production ranges from 21% biological efficiency for beech wood to 3% BE for alder woods. The growth of oyster mushroom also requires high humidity (80-90%) and temperature (25-30°C) for the vegetative growth called spawn running and a lower temperature (18-25°C) for fruit body formation as described by Onyango *et al*., (2011) and like other mushrooms, oyster mushroom can be grown on various agricultural waste with the use of different technologies. According to Zhang *et al* (2002), different types of straw can be used for *Pleurotus* cultivation and straw can be used as composted or pasteurized form. Higher yield was observed of *Pleurotus sajor-caju* when it was grown in ground straw than the chopped straw. It was also observed that 10% more yield obtained in case on paddy straw and using more quantity of spawn also improves the biological efficiency. Obodai *et al.* (2003) also reported that paddy straw is the best substrate for the cultivation of *Pleurotus ostreatus* supplemented with banana leaves, corn husks, rice husks and elephant grass. On the contrary, wheat straw supplemented with *Lolium perenne* grass chaff stimulate the fruit body formation and yield of *P. pulmonarius* (Domondon *et al;* 2004) Studies of Ahemad *et al* (2009) revealed that cultivation of *Pleurotus florida* on different agro wastes showed significant better result and it was found that using soybean straw give higher yield, crude protein content and phosphorus content in compare to paddy straw and wheat straw. While maximum water content and crude fibre was found in case of paddy straw cultivated oyster mushroom. Sawdust is one of the main substrate and studies revealed that biological yield was highest found in case of mango plant saw dust followed by mahogany and sirish as described by Islam *et al* (2009). Cost benefit analysis revealed that the Mango sawdust and Shiris sawdust were promising substrates for the growing of oyster mushroom (*Pleurotus flabellatus*).

Table 2: Mushroom production in India

Sl. No.	State	Amount of Mushroom Production (tons)				
		Button Mushroom	Oyster Mushroom	Milky Mushroom	Other Mushroom	Total Production
1.	Andhra Pradesh	2,992	15	15	0	3,022
2.	Arunachal Pradesh	20	5	0	1	26
3.	Assam	20	100	5	0	125
4.	Bihar	400	80	0	0	480
5.	Chhattisgarh	0	50	0	0	50
6.	Goa	500	20	0	0	520
7.	Gujrat	0	5	0	0	5
8.	Haryana	7,175	0	3	0	7,178
9.	Himachal Pradesh	5,864	110	17	2	5,993
10.	Jammu & Kashmir	565	15	0	0	580
11.	Jharkhand	200	20	0	0	220
12.	Karnataka	0	15	10	0	25
13.	Kerala	0	500	300	0	800
14.	Maharashtra	2,725	200	50	0	2,975
15.	Madhya Pradesh	10	5	0	0	15
16.	Manipur	0	10	0	50	60
17.	Meghalaya	25	2	0	0	27
18.	Mizoram	0	50	0	0	50
19.	Nagaland	0	75	0	250	325
20.	Orissa	36	810	0	5,000	5,846
21.	Punjab	58,000	2,000	0	0	60,000
22.	Rajasthan	100	10	0	10	120
23.	Sikkim	1	2	0	0	3
24.	Tamil Nadu	4,000	2,000	500	0	6,500
25.	Tripura	0	100	0	0	100
26.	Uttarakhand	8,000	0	0	0	8,000
27.	Uttar Pradesh	7,000	0	0	0	7,000
28.	**West Bengal**	**50**	**50**	**0**	**0**	**100**
Union Territories						
1.	A & N Island	0	100	0	0	100
2.	Chandigarh	0	0	0	0	0
3.	Dadar & Nagar Haveli	0	0	0	0	0
4.	Daman & Diu	0	0	0	0	0
5.	Delhi	3,000	50	20	0	3,070
6.	Lakshadweep	0	0	0	0	0
7	Puducherry	0	0	0	0	0
	Total Production	**1,00,683**	**6,399**	**920**	**5,313**	**1,13,315**

Source: RMCU, Directorate of Mushroom Research, ICAR, Solan.

Nutritional value of oyster mushroom

Mushrooms are rich in proteins, minerals and vitamins and it is popularly known as the vegetarian's meat. Kurtzman (1976) stated that mushroom protein is considered to be intermediate between that of animal and vegetables. It also contains essential amino acids required for human health (Hayes and Haddad, 1976). Shah *et al.,* (2004) stated that mushrooms has high nutritive and medicinal value and contributes to a healthy diet because of its rich source of vitamins, minerals and proteins. As reported by Sharma and Madan (1993), the oyster mushroom (*Pleurotus ostreatus*) is an edible mushroom having excellent flavour and taste and it is characterized by its high protein content (30–40% on dry weight basis). Mushrooms contains about 85-95% water, 3% protein, 4% carbohydrates, 0.1% fats, 1% minerals and vitamins as reported by Tewari, (1986). According to Eswaran and Ramabadran, (2000) mushrooms have been identified as a good source of food for alleviate malnutrition in developing countries for its flavour, texture, food value and its production capacity per unit area. A high nutritional value of oyster mushrooms has been reported by Stanley (2011) which states that oyster mushroom contains about 25-50% protein, 2-5% fat, 17-47% sugars, 7-38% myco-cellulose and minerals (potassium, phosphorus, calcium, sodium) of about 8-12%. Edible mushrooms are also rich in vitamins such as niacin, riboflavin, vitamin D, C, B1, B5 and B6 as recorded by Syed *et.al*. (2009).

According to Manzi *et.al.* (2001), cultivated mushrooms have higher protein contents and minerals, low in fat and rich in vitamins B, vitamin D, vitamin K and sometimes vitamins A and C. In 1991, Peter reported that mushroom a food of high quality, flavour and nutrition value have high content of protein, low content of fat (4%), vitamins (B1, B2, C, niacin, biotin etc), minerals (P, Na, K, Ca) and high content of fiber and carbohydrates. Pandey and Ghosh, (1996) also recorded the chemical composition of the fresh fruiting bodies of oyster mushroom which clearly states that a large quantity of moisture (90.8%), whereas fresh as well as dry oyster mushrooms are rich in proteins (30.4%), fat (2.2%), carbohydrates (57.6%), fiber (8.7%) and ash (9.8%) with 345 K (cal) energy value on 100 g dry weight basis; while vitamins such as thiamine (4.8 mg), riboflavin (4.7 mg) and niacin (108.7 mg), minerals like; calcium (98 mg), phosphorus (476 mg), ferrous (8.5 mg) and sodium (61 mg) on 100 g dry weight basis was also found to be present. Biochemical studies revealed that many bioactive compounds such as hemicellulose, polysacchirides, glycoproteins, lipopolysacchirides, peptides triterpinoides has een isolated from variour species of oyster mushroom (Asfors and Ley., 1993; Tzianabos, 2000; Daba and Ezeronye, 2003 and Lindequist *et al*, 2005) According to Bauh *et al.*(2010), oyster mushroom also contains appreciable amounts of potassium, phosphorus, copper and iron but have low levels of calcium. Mushroom protein is intermediate between that of animals and vegetables. Oyster mushroom has no starch, low sugar content and high amount of fibre, hence it serves as the least fattening food (Osei, 1996).

Medicinal and Therapeutic value of mushrooms

Mushrooms are not only the sources of nutrients but also a good source of therapeutic food useful in preventing diseases such as hypertension, diabetes, hypercholesterolemia and cancer as reported by Bobek *et. al.* (1995, 1999). Among the large resources of fungi, higher basidiomycetes especially the mushrooms are unlimited source of therapeutically useful biologically active agents (Table 3). There are approximately 700 species of higher basidiomycetes that have been found to possess significant pharmacological activities as reported by Mizuno (1995) and Wassar (2002). Zaidman (2005) reported that the modern study on medicinal mushroom have expanded exponentially during last two decades and it not only restricted in China, Japan and Korea only but also spread over the USA and it was scientifically explained that compounds derived from the mushrooms have important function in human system. Medicinal mushrooms have an established history of use in traditional oriental medicine and many of them are *Auricularia, Flammulina, Ganoderma, Grifola, Lentinus, Pleurotus, Agaricus* which possess a wide range of medicinal properties. According to Manzi *et. al*. (2001) these functional characteristics are mainly due to the presence of dietary fibre and in particular chitin and glucans. The significant pharmacological effect and physiological properties of mushrooms are bio-regulations, maintenance of homeostasis and regulation of biorhythm, cure of various diseases and prevention and improvement from life threatening diseases such as cancer, cerebral stroke and heart disease. Manzi *et al* (2001) also explained that mushroom have been reported to be of therapeutic value, useful in preventing disease such as hypertension, hypercholesterolemia, cancer and also having antibacterial and antiviral properties and these functional characteristics are mainly of their chemical compositions.

Table 3: Major medicinal compounds extracted from different medicinal mushrooms

Name of the mushrooms	Name of the Compounds	References
Ganoderma lucidum	Polysaccharide (GI-PS)	Zhang and Lin, (2004)
Ganoderma applanatum	Exopolymer (GAE)	Yang *et al* (2007)
Agaricus subrufescens	Beta glucans and oligosaccharides (AO)	Kim *et al*. (2005)
Cordyceps sinensis	Polysaccharide CSP-1	Li *et. al*. (2006)
Grofola frondosa	Alpha-glucan (MT-alpha glucan)	Kubo *et al*., (1994) Konno *et al*., (2001)
Pleurotus ostreatus	Ostreolysin	Berne *et al* (2002)
Pleurotus eryngii	Eyringin and Eryngiolisin	Wang and Ng (2004); Ngai and Ng (2006)

Oyster mushroom as a source of medicinal value

Oyster mushrooms are considered to be as functional food because of their positive effect on human being in various ways (Sadler and Saltmarsh; 1998), which comprises many microbial, plant and animal origin containing several biologically active compounds beneficial for human health and reducing the risk of chronic diseases. It also contains dietary supplements, medicinal foods, phyto-chemicals as described by Hasler (1996).There is a common saying that “medicines and foods have a common origin” (Kaul, 2001). Chang (2007) reported that mushrooms possess a wide range of metabolites consists of pharmaceutical values e.g. antitumour, immunomodulatory, antioxidant, anti-inflammatory, hypocholesterolaemic, antihypertensive, anti-hyperglycaemic, antimicrobial and antiviral activities. Major medicinal properties attributed to mushrooms include anticancer, antibiotic, antiviral activities, immunity and blood lipid lowering effects. *Pleurotus* spp. are also rich in medicinal values. Various studies have been performed to evaluate the medicinal properties and it was found that *Pleurotus florida* has antioxidant and antitumor activities (Nayana and Janardhanan, 2000; Manpreet *et al*., 2004), *Pleurotus sajor-caju* has hypertensive effects through its active ingredients which affect the renin- angiotensin system (Chang, 1996), *P. ostreatus* possesses antitumor activity (Yoshioka *et al*., 1985) and hypoglycaemic effects in experimentally diabetic induced rats (Chorvathova *et al*., 1993). Oyster mushrooms are very effective in reducing the total plasma cholesterol and triglyceride level (Alam *et al*., 2007) and thus reduce the chance of atherosclerosis and other cardiovascular and artery related disorders. Fruiting body as well as actively growing mycelia of different species of *Pleurotus* also contains a number of therapeutic values such as anti-inflammatory, immunomodulatory, immunostimulatory (Asfors and Ley; 1993), anticancer activity (Wasser; 2002) and ribonuclease activity (Wang and Ng; 2000). *Pleurotus* mushroom produces a wide range of bioactive compounds which actively helps in improving human health and the medicinal properties are as follows:

Antimicrobial properties

Oyster mushroom has been explored to active against several microbes and thus helps in defense mechanisms. Gerasimenya *et al* (2002) reported that the water extract of *Pleurotus ostreatus* can inhibit the growth of *Aspergillus niger* while some other extracts of *P. ostreatus* can inhibit the growth of *Bacillus sp*, *E. coli, Vibrio cholera* and *Salmonella typhi* (Periasamy, 2005). It also helps to reduce the pathogenic effect of *Eschrichia coli, Staphylococcus epidermidis*, *S. aureus* (Akyuz *et al.*, 2010) and species of *Candida* (Wolff *et al.,* 2008)*, Streptococcus, Enterococcus* (Kotra and Mobashery, 1998; Sandven, 2000; Thomson and Moland, 2000). Antimicrobial and antifungal activity of *Pleurotus* sp depends upon the nature of the solvent, ether extract were more active against *Bacillus subtilis, E. coli* and *Saccharomyces cerevisiae* as compared to acetone extract as described by Iwalokun (2007). Another study by Nithya and Raghunathan (2009) revealed that *P. sajor-caju* showed higher antimicrobial activity against *Pseudomonas aeruginosa* and *E. coli* when compared with *S. aureus* (Table 4). On the contrary, it was reported that bioactive compound 'Eryngin' and 'Eryngiolysin' isolated from *P. eryngii* actively inhibit the growth of *Fusarium oxysporum* and *Mycosphaerella archidicola* (Wang and Ng, 2004) *Bacillus* spp. (Ngai and Ng, 2006) respectively.

Table 4: Antimicrobial activity of *Pleurotus* sp.

Species	Compound extracted	Effective against	References
P ostreatus	Crude extract from fermentation broth	Gram positive, Gram Negative and *Aspergillus niger*	Gerasimenya *et al* (2002)
	Various extracts; two main unidentified extracts	*Bacillus sp., E. Coli, Vibrio cholerare, Salmonella typhi*	Periasamy (2005)
	Hexane dichloromethane extract containing p-anesaldehyde	*Bacillus subtilis, Pseudomonas aeruginosa, Aspergillus niger* and *Fusarium oxysporum*	Okamoto *et al.* (2002)
P. sajor-caju	12kDa ribonuclease	*Fusarium oxysporum, Pseudomonas aeruginosa* and *staphylococcus aureus*	Ngai and Ng (2004)
P. eryngii	Eyringin- an antifungal peptide	*Fusarium oxysporum* and *Mycospaerella arachidicola*	Wang and Ng (2004)
	Eyringiolysin- a haemolysin	*Bacillus sp*	Ngai and Ng (2006)

Antitumor activity

The most significant medicinal effect of mushrooms and their metabolites that have attracted the attention is their antitumor properties. Lucas has first demonstrated the antitumor activity of higher basidiomycetes in 1957 (Lucas *et. al.* 1957). Wasser, (2002) stated that there are approximately 650 species of higher Basidiomycetes that have been found to possess antitumor activity. Various crude extracts of *Pleurotus* sp have been shown to possess strong antitumor activity. Jose and Janardhanan (2000, 2002) reported that the methanolic extract of the fruit body of *P. florida* and *P. pulmonaris* significantly reduces the tumors in mice. Li *et al* (2008) revealed that Lectin isolated from *P. citrinopileatus* showing a potent antitumor activity in mice bearing sarcoma S-180. *In vitro* studies revealed that extracts of *P. ostreatus* active against cancer cell. This type of cytotoxic effect was due to the presence of higher content of flavonoids in the fruiting bodies. Several components have been isolated from the extracts of different *Pleurotus* sp and among the isolated polysaccharides some are known to be a potent antitumor and immunomodulating substances (Wassar, 2002; Zhang *et al.*, 2007). Maiti *et al* (2011) reported that Cibacron blue affinity of purified protein, protein fraction extracted from *P. ostreatus* having a higher antitumor activity against different tumour inducing agents. Zhang *et al* (2004) reported that the polysaccharides extracted from the fruiting body and mycelia of *P. tuber-regium* effectively inhibit the solid tumour proliferation in mice. Wang *et al.* (2000) has reported that a lectin isolated from the *P. ostreatus* successfully inhibit the growth of sarcoma and hepatoma in mice. Antiproliferative effect was also observed in case of another lectin isolated from *P. eous* without causing any cytotoxicity as described by Mahajan *et al* (2002). Thekkuttuparambil *et al.,* (2007) was found that *Pleurotus florida, Pleurotus pulmonaris* and *Ganoderma lucidum* possessed profound antioxidant and antitumor activities.

Antioxidant activity

In the year 2001, Kaul quoted a very important statement that “medicines and food have a common origin”. Chang (1996) also stated that mushroom is an important food item and a very good source of nutrition as well as therapeutic properties concerning human health. Mushrooms can be a producer of such bioactive compounds with free radicle scavenging activity as mushroom fruiting body can be produced very early as well as the mycelia can be grown in very short time and also the medium can be designed to produce optimal level of bioactive compounds (Chang R., 1996; Chang S., 1999; Lindequist *et. al*., 2005; Wassar, 1999). There are several species of *Ganoderma, Grifola* and *Pleurotus* having antioxidant activities and it was scientifically proved that *P. ostreatus* having great antioxidant value (Kaul, 2001; Zhang *et. al.* 2002; Khan *et al.* 2010). Bhatnagar *et. al.* (2008) reported that hypercholesterolemia has an important role in inducing the oxidative stress and it is related to diabetes. More over the oxidative stress causes a wide range of disease such as Alzheimer’s disease, neurodegeneration, ageing etc. and most importantly cancer as suggested by Nunomura *et al.* (2006), Wood-Kaczmar *et al.* (2006) and Khan *et al* (2010). Klein and Perry (1982) explained that the wild mushrooms exerts vitamin C which is very effective against heart disease, neurological disorders, cataractogenesis, cancer and the compounds were found through HPLC reaction against 2,6-dichlorophenolindophenol. Thekkuttuparambil *et. al.* (2007) and Wassar SP (2002) reported that the medicinal mushrooms namely *Ganoderma lucidam, Pleurotus pulmonaris, Pleurotus florida* possess to profound the medicinal activities. Methanolic extract of the mushrooms effectively reduces the ferric ions in FRAP assay as well as scavenged DPPH radicles. Kasuga *et al.* (1995) suggested that mushrooms are considered to be a good source of proteins and phenolic compounds, such as variegatic acid and diboviquinone for determination of antioxidant activity antioxidant compounds (phenolics and flavonoids) content, scavenging capacity on $DPPH^{\cdot}$ and reducing power have been investigated. Oxygen allows aerobic organisms to use energy stored in foodstuffs, such as carbohydrates, fats, and protein. Halliwell B, Gutteridge, (1989) revealed that it is experimentally proven that this catabolic process can generate oxygen free radicals and other reactive oxygen species (ROS) such as superoxide ($O_2^{\bullet -}$), hydroxyl radical, and hydrogen peroxide (H_2O_2). Under normal physiological conditions, the majority of free radicals are produced in the mitochondrial electron transport chain since 90% of the oxygen consumption by the body is reduced to water in the mitochondria as reported by Ames *et al* (1995). ROS have a strong tendency to extract electrons to reach a chemically more stable structure; therefore, they are capable of eliciting oxidative damage to various cellular components (Yu, 1994). Antioxidants from natural sources play a vital role in helping endogenous antioxidants to neutralize oxidative stress. Fruit bodies of mushrooms are appreciated, not only for texture and flavour, but also for their chemical and nutritional properties. Wild edible mushrooms are traditionally used in many Asian countries in both food and medicine was also proposed by Isildak *et al,* (2004); Sanmee *et al,* (2003); Manzi *et al* (1999)

Anti-Inflammatory activity

Oyster mushroom possesses a wide range of medicinal properties and different extracts of *Pleurotus pulmonarius* and *Pleurotus florida* helps on lowering the acute as well as chronic inflammation as reported by Josh *et al* (2002, 2004). Jose *et al.,* (2002) explained that the Methanolic extract of fruiting bodies of *Pleurotus pulmonaris* reduces carrageenan-induced and formalin-induced pawedema in mice when compared to the diclofenac (10 mg/kg). Bobek *et al* (2001) reported one compound 'Pleuran' isolated from oyster mushroom showing anti-inflammatory activity. Sano *et al.* (2002) demonstrated that oral or percutaneous administration of *Pleurotus eryngii* successfully suppresses the inflammation in delayed type allergy response in mice.

Antidiabetic property

Diabetes is one of the major disease worldwide and Wild *et. al.* (2004) reported that in the year 2000 about 171 million people or 2.8% of the world population suffers from severe diabetic. It causes severe morbidity and increasing cardiovascular mortality and also enhances the development of nephropathy, neuropathy as well as retinopathy (Zimmet *et. al*. 1997). There are two types of diabetes out of which type I diabetes occurs due to less amount of insulin and as a result of destructive lesions of pancreatic β-cells where as in case of type II diabetes the pancreatic β-cells and their function are preserved to some extent and injection is seldom to sustain life as reported by Kuzua *et.*

al.(2002) and Kobayashi, 1994. Windholz (1983) demonstrated that the compound Guanide related to bi-guanide class of oral antidiabetic drug was isolated from *Pleurotus* showing antihypoglycemic effect. Kim *et al* (1997) also reported that endo polymer from submerged culture of *P. ostreatus* possess hypoglycemic effect (Table 5). Aqueous extract of *P. pulmonarius* upon oral administration decrease serum glucose level in aloxan induced diabetic rats (Sachin *et al*., 2006). Lee *et al.,* (2007) and Hu *et al.,* (2006) demonstrated that mushrooms represent a major source of powerful pharmaceutical products and they are exemplary sources of natural medicines. *Pleurotus citrinopileatus,* an edible mushroom belonging to the Pleurotaceae family, has some physiological effects, including antitumor, immune enhancement, anti-hyperglycaemia.

Table 5: Different species of mushroom showing hyperglycaemic activity against different animal models

Sl No	Organism	Extract/ Fraction and Dose	Experimental model	Observations	References
1	*Agaricus bisporus*	Dehydrated fruiting body extracts 400mg/kg body wt.	Streptozotocin induced diabetic rats	Serum glucose levels decreased by 29.68 % and insulin levels increased to 78.5 %	Yamac *et al* (2010)
2	*Agaricus bisporus*	Powdered fruiting bodies 200 mg/kg for 3 weeks, p.o.	STZ-induced diabetic male Sprague-Dawley rats	Significantly reduced plasma glucose, total cholesterol, low-density lipoprotein (LDL), levels	Jeong *et al* (2010)
3	*Agaricus subrufescens*	β-glucans and enzymatic-ally produced oligo-sacchari-des	Diabetic rats	Anti-hyperglycemic; anti-hypertrigly-ceridemic, anti-hypercholes-terolemic, and anti-arteriosclerotic activity	Kim *et al,* (2005)
4	*Auricularia auricula-judae*	Water-soluble poly-saccharide from fruiting bodies 30 g/kg; in diet	Genetically diabetic KK-Ay mice	Significant effect in lowering plasma glucose, insulin, urinary glucose, and food	Yuan *et al* (1998)

				intake; increased tolerance to intraperitoneal glucose loading and the hepatic glycogen content	
5	*Cordyceps militaris*	Exo-polymers produced from submerged mycelia cultures 50mg/kg for 7 days, p.o.	STZ-induced diabetic rats	Significantly decreased levels of plasma glucose, total cholesterol, triglyceride and plasma glutamate-pyruvate transaminase (GPT)	Kim *et al*, (2001)
6	*Cordyceps sinensis*	Polysaccharide fraction CSP-1, isolated from cultured mycelia 200 and 400mg/kg/ day for 7 days, p.o.	Normal; alloxan and STZ-induced diabetic rats	Significant drop in blood glucose levels and increased serum insulin levels, stimulation of pancreatic release of insulin and/or reduced insulin	Li *et al* (2003;2006)
7	*Ganoder ma lucidum*	Aqueous extract of fruiting bodies 500 and 1000 mg/kg, p.o.	Alloxan induced and normal Wistar rats	Significant hypoglycemic and antihyper-glycemic effects	Mohammed *et al* (2007)
8	*Grifola frondosa*	Powdered fruiting body 1g/day, p.o.	Genetically diabetic mouse (KK-Ay)	Reduced levels of blood glucose, insulin and triglycerides	Kubo *et al* (1994)
9	*Grifola frondosa*	Fermented G. frondosa rich in vanadium i.g. route	Alloxan- and adrenalin-induced hyperglyce mic mice	Significant decrease in blood glucose levels	Cui *et al* (2009)
10	*Lentinula edodes*	Exopolymers produced from mycelia cultures 50 mg/kg for 7 days, p.o.	STZ-induced diabetic rats	Significant reduction in plasma glucose, total cholesterol	Kim *et al* (2001)
11	*Phellinus baumii*	Crude exopolysaccharides from submerged mycelial cultures 200 mg/kg, p.o.	STZ-induced diabetic rats	Hypoglycemic effect with substantially reduced plasma glucose levels	Hwang *et al*, (2005)

12	*Phellinus baumii*	Exopolysacch-arides (EPS) produced by submerged mycelial culture 200 mg/kg for 52 days, p.o.	ob/ob mice	Reduced plasma glucose levels, increased glucose disposal, reduced blood triglyceride levels	Cho *et al* (2007)
13	*Pleurotus citrinopileatus*	Water-soluble polysaccha-rides (WSPS), extracted from submerged fermented medium 0.4 g/kg, in diet	STZ-induced diabetic rats	Reduced fasting blood glucose levels	Hu *et al*, (2006)
14	*Tremella fuciformis*	Glucuronoxyloman nan (AC) from the fruiting bodies Oral administrat-ions of the AC solution	Normal and STZ-induced diabetic mice	Significant dose-dependent hypo-glycemic activity	Kiho *et al* (1994)
15	*Pleurotus pulmonarius*	Aqueous extract of fruiting bodies 250, 500, and 1000 mg/kg, p.o.	Normal and Alloxan-induced diabetic mice	Antihyper-glycemic effect (increased glucose tolerance in both normal and diabetic mice)	Badole *et al*, (2008)
16	*Pleurotus eryngii*	Freeze-dried, powdered fruiting body Diet containing 5% freeze dried mushroom	Male db/db mice	Reduced total cholesterol, triglyceride levels, and increased high density lipoprotein cholesterol levels with improved insulin sensitivity	Kim *et al* (2010)
17	*Pleurotus ostreatus*	Powdered fruiting bodies Diet containing 4 % mushroom	Type 2 diabetic rats	Significantly lower basal and postprandial glycaemia.	Chorváthová *et al* (1993)
18	*Pleurotus ostreatus*	Ethanol extract of fruiting bodies 100 and 200 mg/kg for 30 days, p.o.	STZ - induced diabetic rats	Significant decrease of blood glucose levels, genetic alterations	Ghaly *et al* (2011)
19	*Wolfiporia extensa*	Crude extract containing dehydro- tumulosic acid, dehydro-trametenolic acid and pachymic acid	STZ-induced diabetic mice	Insulin sensitizer activity	Sato *et al*, (2002) Li *et al*, (2011)

Anti-hyperlipidemic activity

Hyperlipidemia is now a days a very high risk factor for atherosclerosis. Total lipid and cholesterol excretion increases by feeding mushroom powder. Gunde-Cimerman *et al* (2001) and Hossain *et al* (2003) explained that Mevonolin- a polysaccharide present in the fruiting body of *Pleurotus ostreatus* and *P. citrinopileatus* shows higher antihyper cholesterolemic activities. Badole *et al* (2008) also reported that *P. pulmonaris* also exhibits synergistic antihyper cholesterolemic activity when used in combination with Glyburide. According to Chang and Buswell (1996), Lovastatin isolated from the oyster mushroom an active chemical component is used in San Francisco to reduce LDL cholesterol in hypercholesteraemic patients.

Immunomodulatory activities of oyster mushroom

Oyster mushroom has been reported to have a wide range of medicinal activities and recent studies revealed that many compounds extracted from different species of oyster mushroom showing immunomodulatory activities on humoral and cell mediated immunity of human beings. Wang *et al* (2005) reported that water soluble polysaccharide extracted from the fermented *Pleurotus citrinopileatus* administered in albino mice that helps in increasing the number of macrophages, T-cells and $CD4^+$ and $CD8^+$ cells. *In Vitro* studies of mouse macrophages actively responses against the phagocytic response by the glucans isolate from *P. florida* as described by Rout *et al.* (2005) and significantly induced the proliferative response as well as phagocytic activity of fish leukocytes *in vitro* (Kamilya *et al* 2006). Sarangi *et al* (2006) stated that the proteoglycans isolated from the *Pleurotus ostreatus* showing immunomodulatory activity by elevating mouse natural killer cell cytotoxicity and by macrophage stimulation. Ngai and Ng (2004) revealed that a ribonuclease extracted from *Pleurotus sajor-caju* fruiting bodies exerts antiproliferative effect against murine splenocytes.

Antiviral Activity of oyster mushroom

In the year 2000, Brandt and Piraino stated that mushroom contains substances that show indirect antiviral effects as an immunostimulatory activity. Wang *et al* (2007) demonstrated that hot water extract of *Pleurotus sajor-caju* and *Pleurotus pulmonarius* active against human immunodeficiency virus (HIV1) reverse transcriptase. Anti-HIV activity was also demonstrated for ubiquitin like protein isolate from the fruiting body of *Pleurotus ostreatus* (Wang and Ng; 2000).

Anti-Ageing Effect

Extracts of *Pleurotus* is a very potent antiaging effect Shashoua and Adams (2004) revealed that the extract of *Pleurotus abalonus* elevate the levels of Vitamin C and E which increase the activity of catalase, superoxide dismutase and glutathione peroxidase in aged rats. Similar results were also found in case of *P. ostreatus* as reported by Jaykumar *et al* (2007).Different extracts (Water, ethanol and Methanol) of *Pleurotus* can improve the antioxidant status during ageing leads to reduce the occurrence of age associated disorders like stroke, atherosclerosis, diabetes and cirrhosis.

Hepatoprotective activity

Liver damage by hepatotoxic agents is of vital consequence because chronic liver injury leads to fibrosis, end stage cirrhosis and hepato-carcinoma. Many species of *Pleurotus* contains some active compounds like glucan, phenol and vitamin C that increase the activity of antioxidant enzymes like catalase, glutathione reductase are responsible for reduction of hepatic cell necrosis (Bobek *et al.*, 1997; Fu *et al.*, 2009). Koyama *et al* 2006 reported that hepatoprotective activity of this mushroom is exerts through the increased levels of serum aminotransferase enzymes in animals. Recently Refaie *et al* (2009) suggested that the hepatoprentive and therapeutic activity of hot water extract of *P. ostreatus* by mechanism of inhibition through preventive regimen caused less leakage of alkaline phosphatase, less pronounced increase inhepatic malondialdehyde concentration, less notable reduction in hepatic total protein activities. It was also observed that water soluble polysaccharides extracted from *P. eryngii* removes the free radicals and also increase the activities of antioxidant enzymes in liver injury mouse model (Chen *et al.*, 2012).

Antimutagenic Effect

Mutagenesis also can be influenced by the edible mushrooms and Filipic *et al* (2002) demonstrated that *Pleurotus cornucopiae* showed most effective against the antigenotoxic and bio-antimutagenic activity against *E. coli* and *S. typhimurium.* Bohi *et al* (2005) reported that dried *P. ostreatus* in diet reduces pathological changes in dimethyl hydrazine induced rats and it also mitigated genotoxicity through suppression of DNA damage induced different mutagens in Drosophila DNA repair test (Taira *et al.*, 2005).

Hypotensive activity

Miyazawa *et al.* (2008) explain that the antihypertensive activity varies in different mushroom and oyster mushroom possesses blood sugar lowering activity. In the year 2003 Miyazawa *et al* reported that the hot water extract of *P. nebrodensis* shows their activity in prevention of hypertension.

Oyster Mushroom as processed food

Human being consumes very wide range of food materials like plant, fish meat etc as well as fungi or edible mushrooms. Edible mushrooms are consumed for their nutritional as well as medicinal properties (Chocksaisawasdee *et al.,* 2010; Wan-Rosli *et al.,* 2011). Mushrooms are versatile and may be eaten freshly or cooked entirely. It is very popular for its texture, unique flavour and for its great nutritional importance. Mushrooms are very useful in reducing cholesterol lowering blood pressure and improve immune system against many diseases as suggested by Regula and Siwulski (2007). Sanchez (2010) stated that mushrooms are of great demand for their taste, texture and for the economical as well as ecological importance. He also reported that *Pleurotus ostreatus* is the second most cultivated mushroom in the world followed by *Agaricus bisporus* which constitute about 25% of total world's production. Chye *et al* (2008) explained that freshly oyster mushroom contains low fat content about 0.38-2.28% indicated low calorific value and consisting about more than 80% moisture content. Strmiskova *et al* (1992) stated that oyster mushroom is a good source of biologically valuable substances for human nutrition as it contains about 90% water, protein, all types of vitamin wide range of mineral contents and very low amount of fat. On the other hand, Kotawaliwale *et al* (2007) reported that dry mushrooms consists about more that 25% proteins less than 3% lipid and almost 50% total carbohydrates. Singh *et al* (1995) stated that mushrooms have a good potential of due to its high amount of protein, dietary fibres vitamins (dry weight basis) and minerals and thus it can be dried, powdered and can be used for fortification in baked products like bread biscuits.

Application of spent mushroom Substrate for crop improvement

Mushroom cultivation is an eco-friendly process to convert the waste biological materials to a nutritive food. However after harvesting of the mushroom, the waste mushroom substrates can be harmful for environment for pollution stated by Bayers (1996). Uncontrolled disposal of SMC may pose a problem to the environment. This problem may include foul odour and other problems associated with air pollution. It is therefore, necessary to recycle this so called useless material to an utilizable .The demand for organic residues and compost has also increased several folds considering the ill effects of synthetic inorganic fertilizers. Jonathan *et al*, (2011) defined spent mushroom substrate (SMS) as the leftover of wastes after different flushes of mushrooms have been harvested. Fasidi *et al.,* (2008) also defined spent substrate as the bi-product of mushroom industry, after several flushes harvested. The weathered SMC are those that undergo further decomposition for several weeks before their utilization by farmers as soil conditioner (Jonathan *et al*., 2006). Ahlawat *et al.,* (2005) stated that the recycling of spent mushroom substrate for its utilization as manure is the alternative way to get rid of the environmental contamination due to spent mushroom substrate. Recycling of spent substrate as manure is now very popular for cultivation of different cereals and horticultural crops. Gupta *et al* (2004) and Pill *et al* (1993) explained that spent substrates are rich in organic matter and moderate nutrient load near neutral pH and the presence of beneficial microbial population make the spent substrate suitable for crop improvement. Ahlawat *et al.,* (2007) incorporation of composted SMS not only improves the soil quality, neutralize the soil acidity but it also helps in cultivation in the bare lands. Yohalem *et al* (1996) stated that SMS is a potential biocontrol agent against certain foliar and soil borne diseases and also a potential to bioremediate several agricultural grade fungicides and pesticides (Ahlawat *et al.,* 2010). Ahalawat *et al* (2009) also stated that spent mushroom substrate also helps in increasing the yield and improvement in plant health while used as singly or in combination of other organic fertilizers. The spent mushroom substrate was evaluated against some farm yard manure and chemical fertilizer on *Pisum sativum* and it was observed that SMS influences the growth of the plant in compare to other treatments and also the quality as well as the quantity of pods increase (Ahlawat *et al.,* 2011).