Review of Literature

Mushroom, the fruiting body of macrofungi is a short reproductive stage in their life cycle. Out of the 1.5 million fungi estimated in the world, approximately 14,000 species produce fruiting bodies that are large enough to be judged as mushrooms (Chang and Miles 1992). Mushrooms are important natural resources of biologically active compounds which have profound medicinal attributes to human body. The bioactive potential of mushrooms has gaining accelerated interest in modern science and the series of important findings regarding the present research are being reviewed and summarized below.

Mushroom diversity in India

In India collection and scientific investigation of mushrooms was actually started during 19th century (Kaul 2002) and continued till date. In 2004, Deshmukh reported that, in India, the total recorded mushrooms are approximately 850 species. The scientific research of mushrooms was initiated with identifying and describing *Podaxis pistillaris* (L. Pers.) by Linnaeus in the 18th century which was gathered and sent by Koening from the state of Tamil Nadu. Later, Sir J. D. Hooker made widespread collection from Assam, Darjeeling, Sikkim and Khasi hills for the publication of a series of papers by an English mycologist, Revd M.J. Berkeley between 1850 and 1882 (Natarajan 1995). The scientific research on mushrooms was divided into three phases. The first phase was between 1825 to 1899 and in addition to Berkeley and Montagne, the recorders included Fries, Léveillé, Currey, Cooke, Massee, Watt and Lloyd (Sathe 1979; Natarajan 1995). The second phase (1900-1969) initiate with the contributions of Paul Henning's which described another 32 genera and 68 species from India (Natarajan 1995). An important part of the second phase was the participation of some Indian workers in greater fungal studies in addition to European and American workers (Sathe 1979). The work on Indian fungi by E. J Butler at Pusa (Bihar) is worth mentioning, in collaboration with G. R. Bisby imperial mycologist who created 'Fungi of India', the first authoritative list

(Butler and Bisby 1931). That publication has been updated by Sarbhoy et al. (1996) until the latest issue. Distinguished Indian workers of this phase were Prof. S. R. Bose (Calcutta, West Bengal) and Prof. K. S. Thind (Punjab University, Chandigarh). The third phase of the work is said to be begun in the beginning of the 1970s, with the development of an edible mushroom industries in India being a major inducement. After that, several researchers continue their research in mushroom diversity throughout India (Patil et al. 1995; Swapna et al. 2008; Das 2010; Sachan et al. 2013). Verma and Pandro (2018) has reported 108 clavarioid fungi belonging to 17 genera distributed in India. These fungi were reported from 131 places of 13 states and the maximum diversity was observed in Uttarakhand (57) followed by Himachal Pradesh (25) and West Bengal (10).

Mushroom diversity in West Bengal

In 1921, Bose has reported a few edible species from undivided Bengal. Later Bose and Bose (1940) have prepared a list of about 28 varieties of edible species including *A. campestris, Cantharellus aurantiacus, Cantharellus cibarius, Coprinus comatus, Lentinus subnudus, Termitomyces albuminosa*, *Termitomyces microsporus, Volvariella terastia*, *Truffles* and *Boletus* sp. Two edible species, namely *Calocybe indica* and *Termitomyces eurhizus* have been reported by Purkayastha and Chandra (1974) from West Bengal. The former was a new species while the later was first recorded from India. Ten species of *Calvatia and Lycoperdon* have been incorporated in the list of edible fungi by Gupta et al. (1974). Out of the 10 species described, 7 were edible in their immature stage. Among seven edible mushroom, 3 species belong to *Calvatia,* 2 to *Lycoperdon* and one each to *Geastrum* and *Bovista.* Purkayastha devoted attention to wild edible mushrooms of West Bengal and succeeded in cultivating one of them, *Calocybe indica.* Pradhan et al. (2013) has identified 120 species, one subgenus and one variety of macrofungi from lateritic region of West

Bengal. Earlier Dutta et al. (2013) had explored altogether 34 macrofungi from West Bengal, among which 31 are used as food and the remaining for medicinal purposes.

Table I – Mushroom Diversity in West Bengal

Wild mushroom	Reference
Agaricus campestris, Cantharellus aurantiacus, Cantharellus cibarius, Coprinus comatus, Lentinus subnudus, Termitomyces microcarpus, Termitomyces albuminosa, Volvariella terastia, Truffles and Boletus sp.	Bose and Bose (1940)
Clavaria sp., *Lycoperdon* sp., *Geastrum* sp., *Bovista* sp.	Gupta et al. (1974)
Calocybe indica, Termitoyces eurrhizus	Purakaystha and Chandra (1974, 1985)
Tulostoma chudaei	Chakraborty et al. (2013)
Amylosporus campbellii, Ascobolus scatigenus, Auricularia auricular, Bolbitius sp., *Calocybe indica, Camarophyllus* sp., *Chlorophyllum rhacodes, Conocybe* sp. *Coprinus disseminates, Coprinus lagopus, Coprinus plicatilis, Coriolopsis occidentalis, Cyathus striatus, Dacryopinax spathularia, Daldinia concentrica, Dictyophora indusiata, Flavodon flavus,Ganoderma applanatum, Ganoderma colossum, Ganoderma lucidum, Geastrum saccatum, Gymnopilus dilepis, Hexagonia apiaria, Hexagonia badia, Inocybe sp., Laetiporus sulphureus, Lentinus squarrosulus, Leucocoprinus birnbaumii, Leucocoprinus cepaestipes, Lycoperdon pyriforme, Marasmiellus* sp., *Marasmius bambusiniformis, Marasmius graminum, Marasmius haematocephalus, Marasmius rotula, Marasmius siccus, Microporus xanthopus, Mutinus caninus, Omphalina* sp., *Pisolithus arhizus, Pleurotus* sp., *Pluteus ephebeus, Podoscypha petalodes, Psathyrella* sp.*Pycnoporus coccineus, Pycnoporus sanguineus, Schizophyllum commune, Sphaerobolus stellatus, Termitomyces clypeatus, Termitomyces microcarpus, Trametes leonina, Tricholoma crissum, Tricholoma giganteum, Tricholoma lobyanse, Volvariella gloiocephala, Volvariella pusilla,Volvariella volvacea, Xylaria hypoxylon*	Dutta et al. (2013)
Gymnopilus dilepis, Boletellus ananas, Polyporus brumalis, Pseudochaete tabacina, Amanita ocreata, Hygrocybe angustifolia, Pleurotus ostreatus, Pulveroboletus icterinus, Clavaria straminea, Russula subgenus, Russula heterophylla, Clavulina rugosa var. *canaliculata, Hygrophorus* sp., *Lycoperdon pusillum, Lepiota leprica,*	Pradhan et al. (2013)

Russula xerampelina, *Phellinus durissimus*, *Leucocoprinus fragilissimus*, *Microcarpus flabelliformis*, *Microporus xanthoporus*, *Tylopilus* sp., *Aureoboletus gentilis*, *Termitomyces heimii*, *Marasmius siccus*, *Phylloporus rhodoxanthus*, *Termitomyces clypeatus*, *Inocybe umbonata*, *Phellinus* sp., *Russula cyanoxantha*, *Amanita banningiana*, *Lentinus squarrosulus*, *Marasmius haematocephalus*, *Marasmius albogriseus*, *Clavariadelphus* sp.,*Marasmius leoninus*, *Coltricia cinnamomea*, *Termitomyces microcarpus*, *Clavulina cristata*, *Marasmius suthepensis*, *Amanita vaginata*, *Russula albonigra*, *Amanita vaginata*, *Astraeus hygrometricus*, *Laccaria laccata*, *Lactarius zonarius*, *Porphyrellus malaccensis*, *Russula brevipes*, *Russula delica*, *Russula emetica*, *Russula laurocerasi*	
Russula sp., *Russula senecis*, *Russula lepida*, *Termitomyces clypeatus*, *Russula albonigra*, *Russula brevipes*, *Russula cyanoxantha*, *Astraeus hygrometricus*, *Amanita hemibapha*, *Amanita vaginata*, *Amanita vaginata* var. *alba*, *Armillaria mellea*, *Auricularia auricula*, *Fistulina hepatica*, *Grifola frondosa*, *Hericeum* sp., *Coprinus comatus*, *Pholiotas quarrosa*, *Meripilus giganteus*, *Pleurotus* sp. *Calocybe indica*, *Lentinus squarrosulus*, *Pleurotus ostreatus*, *M. gigantea*, *Macrocybe lobayensis*, *Volvariella volvacea*.	Dutta and Acharya (2014)
Russula sp.	Paloi et al. (2015)
Russula kanadii	Dutta et al. (2015)
Tremella fuciformis	Ghosh et al. (2016)
Russula alatoreticula	Khatua et al. (2017)

Ethnomycological knowledge of ethnic tribes in India

The traditional uses of the mushroom are known to the aborigionals of Africa, India, Brazil and other countries. Wild mushrooms are a precious resource of non-timber forest products and have been recorded in many countries around the world (Chang and Lee 2004; Roberto et al. 2005; Sarma et al. 2010). They are sold in traditional markets (Roberto et al. 2005) or commercially exploited as food (Tanti et al. 2011) or medicines (Sachan et al. 2013). In Nigeria, Puff balls (*Lycoperdon pusilum* and *Calvatia gigantea*) are used to cure sores, abrasion or bruises, deep cut, haemorrhages and urinary infections (Buswell and Chang 1993).

Traditional mycological knowledge has demonstrated extensive and deep in most of the Indian ethnic groups, consuming approximately 283 species of wild mushroom out of 2,000 worldwide reported species (Purkayastha and Chandra 1985). Ethnomycological aspects were also dealt with by few workers in different parts of India and world over (Harsh et al. 1993; Bulakh 2001). Some of the wild edible mushrooms have also been reported from Manipur and Arunachal Pradesh of North East India (Sing and Sing 1993; Sing et al. 2002) whereas, from Assam, Baruah et al. (1971) reported few basidiomycetous fungus of Sibsagar District. In Central India *Ganoderma lucidum* is used as herbal medicine by the Baiga tribes to cure asthma and *Agaricus* sp. is used in goiter and *Lycoperdon pusilum* in wound healing and also for controlling bleeding (Rai et al. 2005). According to Tanti et al. (2011), the ethnic tribes of Nagaland, India are also using wild edible mushrooms for food purposes. Their investigation revealed that more than 12 ethnic groups of Nagaland were found to be mycophilic and have traditional mycological knowledge. A total of 13 species of fleshy fungi under 9 genera and 6 families were identified which are being used by tribes of Nagaland. Srivastava et al. (2011) conducted an ethnobotanical survey for distribution and utilization of *Termitomyces* species in Gorakhpur forest division of Uttar Pradesh, India and reported that tribal people and forest dwellers are using *Termitomyces* species as food and for medicinal purposes (used in malnutrition, weakness and their nutritional disorders). Traditional uses and medicinal potential of *Cordyceps sinensis* has been studied by Panda and Swain (2011) in Sikkim, India and found that most local traditional healers use *Cordyceps* in their herbal medicine for the treatment of 21 diseases including cancer, diabetes, bronchial asthma, tuberculosis, bronchitis, cough and cold, alcoholic hepatitis, BHP, jaundice, erectile dysfunction, among others. Besides that, seven numbers of wild mushrooms such as *Pleurotus sajor-caju*, *Termitomyces heimii*, *Termitomyces microcarpus*, *Volvariella volvacea*, *Auricularia auriculata*, *Lentinus fusipes* and *Lentinus tuber-regium* are also consumed by the Kaani tribes of Kanyakumari

district of Tamilnadu in their different recipe (Sargunam et al. 2012). Recently, a survey has been conducted by Sachan et al. (2013) on indigenous knowledge of ethnic tribes from Similipal Biosphere Reserve, Odisha for consumption of wild mushrooms as food and medicine. All these studied mushrooms are used by several tribals (Santal, Munda, Ho, Kolha, Khadia, Mankidia, Bhumija, Kudumi, Bhuyan, Bathudi) living in the Similipal forest for their food as well as herbal medicinal purposes to cure malnutrition, weakness, other nutritional disorder like diarrhoea, high blood pressure, fever, asthma among others. (Sachan et al. 2013). An investigation conducted by Pradhan et al. (2016) in Darjeeling district shows that 98 species of macrofungi were representing 72 genera, with 47 families; 58.16% were saprotrophic, 17.34% ectomycorrhizal and 10.2% were parasite. Pramanik and Chaudhuri (2017) recognized 37 species from the forest litter of Nadia district and classified into 18 genera of 12 basidiomycetes families.

Nutritional potential of mushrooms

Since ancient times man have been hunting for wild mushrooms. A number of researchers have examined the early history of the use of mushrooms in separate countries. (Rolfe and Rolfe 1925; Bano and Rajarathnam 1982; Wani et al. 2010). Rolfe and Rolfe (1925) mentioned that mushrooms like *Agaricus campestris, Morchella esculenta, Helvella crispa, Hydnum coralloides, Hypoxylon vernicosum* and *Polyporus mylittae* were used much earlier in India. Lintzel (1941) recommended that 100 to 200 g of mushrooms (dry weight) is required to maintain an optimal nutritional balance in a man weighing 70 kg. Bano (1976) proposed that mushroom food value lies between meat and vegetables. Crisan and Sands (1978) observed that mushrooms generally have 90% water, 10% dry matter with protein content of 27% to 48%, less than 60% of carbohydrate and 2 to 8% lipid content.

Much of the researches on the chemical composition of mushrooms has been carried forward, which revealed that the mushrooms can be used as a diet to combat different diseases.

Mushrooms have a rich dietary value that includes high levels of protein, vitamins, fibres, minerals, trace elements and low calories and cholesterol (Agrahar-Murugkar and Subbulakshmi 2005; Wani et al. 2010)

Protein is an important constituent of mushrooms (Agrahar-Murugkar and Subbulakshmi 2005; Wani et al. 2010). The protein content of mushrooms relies on the composition of the size of pileus, substratum, time of harvest and species of mushrooms (Bano and Rajarathnam 1982). Samajipati (1978) was reported that the protein present in dried mycelium of *Agaricus campestris, Agaricus arvensis, Morchella esculenta* and *Morchella deliciosa* are 30.16, 28.16, 34.7 and 29.16 % respectively. Protein content in *Pleurotus* sp. has been documented to range between 8.9 and 38.7% on dry weight basis (Bano and Rajarathnam, 1982). Purkayastha and Chandra (1985) examined 14 to 27% crude protein on dry weight basis in *Agaricus bisporus, Lentinus subnudus, Calocybe indica* and *Volvariella volvacea* on the basis of dry weight. The protein content in the fruiting bodies of *Lactarius delicious* and *Lactarius sanguiffus* were found to be 14.71 to 17.37 % and 15.20 to 18.87 % respectively (Sharma et al. 1988).Nutritional analysis of two edible wild mushrooms (*Schizophyllum commune* and *Lentinula edodes*) from northeast India have been studied by Longvah and Deosthale (1998) and reported that protein content of *Lentinula edodes*(26%) is much higher than *Schizophyllum commune* (16%). Nutritional values of seven wild edible mushrooms were investigated by Agrahar-murugkar and Subbulakshmi (2005) which are commonly consumed in the Khasi hills of Meghalaya and stated that 27.3, 27.5, 21.1, 24.1, 21.1, 21.2, 19.0% protein content present in *Calvatia gigantea, Clavulina cinerea, Clavunila cibarius, Ramaria brevispora, Russula integra, Gomphus floccosus* and *Lactarius quieticolor*, respectively. Pushpa and Purushothama (2010) have analysed the nutritional value of five mushroom species and found that 21.60, 41.06, 27.83, 26.25, 18.31% protein in *Calocybe indica, Agaricus bisporus, Pleurotus florida, Russula delica* and *Lyophyllum decastes*

respectively. The proximate composition of *Volvariella bombycine* was analysed by Jagadeesh et al. (2010) and it was found that 25.5% and 28.3% crude protein present in mycelia and its fruit body. Nutrient composition of *Lentinus tuber-regium* in both wild and cultivated type were analysed by Manjunathan and Kaviyarasan (2011) and cultivated range was discovered greater protein concentrations (25%) than the wild one (18.07%). Johnsy et al. (2011) analysed the nutritional values of 10 edible mushrooms from Western Ghats of Kanyakumari district and described that edible mushrooms are highly valued as a moral source of protein ranged from 28.93 to 39.1% of dry weight. Nutrient content of 15 selected mush-rooms of Nagaland, India have been studied by Kumar et al. (2013) and found that all of them contain within the range of 22.50 to 37.80% protein. Salamat et al. (2017) has analysed the protein content of five selected mushrooms and found that *Lentinus edodes* and *Volvariella volvacea* possessed the highest content of protein i.e. 23% each while the lowest concentration of protein (16% w/w) was recorded in *Ganoderma lucidum.*

The carbohydrate content of the mushroom represents 50-65 percent on a dry weight basis of the bulk of the fruiting bodies (*Schizophyllum commune* and *Lentinus edodes*) from northeast India have been documented by Longvah and Deosthale (1998) and stated that 64.4% carbohydrate content present in *Lentinus edodes* and 68% in *S. commune* (16%). Pushpa and Purushothama (2010) have analysed the carbohydrate content in *Calocybe indica, Agaricus bisporus, Pleurotus florida, Russula delica* and *Lyophyllum decastes* which showed carbohydrate 49.20, 28.38, 32.08, 34.88, 34.36% respectively. Nutrient composition of *L. tuber-regium* in both wild and cultivated type were analysed by Manjunathan and Kaviyarasan (2011) and found 58.05 and 55.8% carbohydrate in cultivated variety and in wild variety respectively. Nutritional values of wild mushrooms have been reported by Johnsy et al. (2011) and found moral source of carbohydrates ranged from 33.23% in *A. auricula* to 50.2% in *Lentinus tuber-regium.* Kumar et al. (2013) reported the carbohydrate contents of 15

selected mushrooms from Nagaland, India ranged from 32.43% in *Schizophyllum commune to* 52.07% in *Boletus aestivalis*. Recently total carbohydrate contents of two wild mushrooms was studied by Singdevsachan et al. (2013) and found highest in *Lentinus sajor-caju* (68.24%) and lowest in *Lentinus. torulosus* (64.95%). The nutritional value of *Morchella* species like *Morchella crassipes, Morchella esculenta, Morchella hortensis, Morchella conica* and *Morchella elata* was reported, with 7.5- 11.52 g protein, 2.2-3.9 g fat, 6.7-14.6 g ash and 74.55-80.5 g carbohydrates per 100 g DW, with 10 g dry matter and 355-386 kcal in 100 g fresh weight (Vieria et al. 2016).

The lipids present in the fruiting bodies of mushrooms are dominated by unsaturated fatty acids. The variation of lipid content 2.04% in *Suillus granulatus*, 3.66% in *Suillus luteus* and 2.32% in *Agaricus campestris* was determined by Singer (1961). Crude lipid content in the range of 1.08 to 9.4% with an average of 2.85% has been reported in *Pleurotus* species (Bano and Rajarathnam 1982). On fresh weight basis, the lipid content of *Pleurotus* species 0.10 to 0.19% has been reported by Rai et al. (1988). Lipid content of fresh *Agaricus bisporus* (Lange) Sing and *Pleurotus ostreatus* (Jacq: Fr.) Kumm was analysed by Manzi et al. (2001) and found to be 0.3 and 0.4 g/100 g, respectively. From northeast India Longvah and Deosthale (1998) has reported similar crude lipid content (2%) were similar in two edible wild mushrooms (*Schizophyllum commune* and *Lentinus edodes*). Agrahar-murugkar and Subbulakshmi (2005) also reported the lipid content (ranged from 1.0% in *Calvatia gigantea* to 5.3% in *Ganoderma floccocus*) of seven different wild mushrooms collected from the Khasi hills of Meghalaya. Kavishree et al. (2008) have analysed total lipid and fatty acid contents of twenty-three mushroom species of naturally grown different geographic locations of India and species were found to contain 0.6-4.7% total lipid. These mushroom species were also high in unsaturated fatty acids (52-87%), compared to saturated fatty acids. Pushpa and Purushothama (2010) have also analysed the lipid content of five mushrooms which were

4.96, 2.12, 1.54, 5.38, 2.14% in *Calocybe indica, Agaricus bisporus, Pleurotus florida, Russula delica,* and *Lyophyllum decastes* respectively. Manjunathan and Kaviyarasan (2011) stated that the lipid content in the refined variety (1.54%) of *Lentinus tuber-regium* was lower than that in the wild one (1.6%). Johnsy et al. (2011) revealed very less amounts of lipid ranging from 1.17% to 2.58%. Further lipid contents of two wild mushrooms was determined by Singdevsachan et al. (2013) and found lowest amount of lipids (2.42 and 1.36%) in both studied mushrooms *Lentinus sajor-caju* and *Lentinus torulosus* respectively. Research on the chemical composition of *Polyporus squamosus* was conducted by Mocan et al. (2017) and found a very good low-fat amounting about 1.46 g/100 g d/w.

Several researches had been carried out to evaluate the ash content and crude fibres present in various edible mushroom species. Jagadeesh et al. (2010) have reported the ash contents from mycelia and fruit body of mushroom (*Volvariella bombycina*) and found that the ash content is higher in the fruit body. Only 12.80% ash was noticed in *Calocybe indica* (Pushpa and Purushothama 2010). Ash profile of different species of *Pleurotus* were also analysed by Jhonsy et al. (2011) and reported that the ash contents were the highest in *P. ostreatus* (10.17%) whereas in other species ranging from 5.57%to 5.73% in *Pleurotus roseus* and *Pleurotus sajor-caju* respectively. Ash content of *Termitomyces heimii* and *Termitomyces microcarpus* was determined by Jhonsy et al. (2011) and found that ash content is higher in *Termitomyces heimii* (16.8%). Manjunathan et al. (2011) has analysed *Lentinus tigrinus* from Tamilnadu and found that mushroom appear to be rich in ash. Kumar et al. (2013) has reported that *Agaricus arvensis* contains 0.18 % ash. Muthu and Shanmugasundaram (2016) reported that crude fibre value of *Agrocybe aegerita* was 8.05 mg/100g. Crude fibre in most mushrooms are comparably higher than most legumes except groundnut and soybeans grown in West Africa (Aletor and Aladetimi 1989). The crude fibre and the total ash content of

Pleurotus ostreatus were calculated to be 0.12% and 1.5% respectively (Kajendran et al. 2018)

Fatty acids in mushrooms

Fatty acids in the form of phospholipids are important components of the lipid bi-layer of the cell membrane of all cells. Many researchers have studied the fatty acid composition of several mushrooms and elucidated their nutritional roles in the human diet. Barros et al. (2007b) reported that the major fatty acids of *Agaricus arvensis, Lactarius deliciosus, Leucopaxillus giganteus, Sarcodon imbricatus, and Tricholoma portentosum* were linoleic acid and oleic acid. Fakas et al. (2008) observed palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and gamma-linolenic (C18:3) fatty acids in the biomass produced by the fungus *Cunninghamella echinulata.* Thirteen fatty acids were detected by using GC and GC–MS in *Agaricus* species tested herein. The dominants were found to be linoleic acid (61.82–67.29%) and palmitic acid (12.67– 14.71%). The complete unsaturated proportions of fatty acids range from 77.44 to 79.72 %. The hexane extracts of mushroom found oleic (6.07–8.11%), palmitoleic (4.16–5.12%), and stearic acids (3.72–3.97%). Dimitrijevic et al. (2018) tested eleven mushroom species and found that the mushrooms have higher content of unsaturated fatty acids (36 – 84.3 %) than saturated one (13.26 – 63.5 %).

Phenolic compound and their Antioxidant properties

Many researchers investigated that a number of mushrooms having medicinal properties occurring in India and found promising antioxidant properties in most of them. Extracts from fruiting bodies and mycelia of *Ganoderma lucidum*, *Phellinus rimosus* and several *Pleurotus* sp. occurring in South India were found to possess antioxidant activity with high free radical scavenging activity (Jones and Janardhanan 2000; Ajith and Janardhanan 2001; Lakshmi et al. 2003). Methanol, ethyl acetate and aqueous extract of *Ganoderma lucidum* has been stated to efficiently scavenge the $O_2\cdot$ and ·OH radicals, however the

aqueous extract was not effective to inhibit the ferrous ion induced lipid peroxidation (Jones and Janardhanan 2000) whereas ethanol extracts of the mycelium of *Ganoderma lucidum* showed high antiperoxidative activity (Lakshmi et al. 2003). The methanol extract of fruiting bodies of *Pleurotus florida* was found to possess ·OH radical scavenging and lipid peroxidation inhibiting activities (Jose and Janardhanan 2000). The extract also showed significant reducing power and radical scavenging property as evident from ferric reducing antioxidant power (FRAP*)* and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals scavenging assay. Sheena et al. (2005) also studied the therapeutic potential of *Ganoderma lucidum* and reported that the sample obtained from South Indian tropics has greater antioxidant activity through suppression of formation capacity of the free radicals. The antioxidant properties of water and methanol extracts from fruiting bodies of 23 mushroom species that naturally cultivated at separate geographical places in India (forest area of Himachal Pradesh and Kerala) were measured by Puttaraju et al. (2006). The antioxidant property of each species was investigated for the total antioxidative stress, employing multi-mechanistic antioxidative assays such as inhibition of lipid peroxidation, free radical scavenging ability and determination of reducing power with determination of total phenolics that contribute largely to antioxidant potential. *Termitomyces heimii* was recognized as the best variety, with 37 mg of phenolics/g of sample, 418 units of reducing power ability (RPA)/g, and an IC_{50} of ~1.1 mg (dry weight)/mL, free radical scavenging activity (FRS) in the water extract followed by 11.2 mg of phenolics/g, 275 units of RPA/g, and an IC_{50} of ~2.7 mg (dry weight)/mL of FRS in the methanolic extract. Antioxidant and phytochemical properties of ethanolic extracts from the wild edible mushroom *Termitomyces reticulatus* and their individual parts (Cap and Stipe) were evaluated by Loganathan et al. (2010) through the reducing power, β-carotene bleaching, ABTS and DPPH radicals scavenging activity methods. Antioxidant properties like total phenol, β-carotene, flavonoid, and lycopene were

also examined and the amount of phenol was related with the antioxidant activities. All extracts have shown strong antioxidant effects with a greater antioxidant property than the other two extracts for the whole mushroom extract (cap and stipe). Kumari et al. (2011) have investigated the antioxidant activity of *Cantharellus friessi, Cantharellus subcibarius, Cantharellus cinerius* and *Pleurotus florida* collected from North-Western Himalayan region of India including their bioactive compounds such as phenol, flavonoid, ascorbic acid and β-carotene. Among them *Cantharellus friessi* showed significantly higher antioxidant activity through β-carotene bleaching method and with the high phenol content (16.80 mg/g) than the other mushroom species. Methanolic extracts of cap and stipe of commercially obtained mushrooms *Agaricus bisporus*, *Hypsizygus ulmarius*, and *Calocybe indica* were analysed by Babu and Rao (2011) for their antioxidant activity in different chemical systems including reducing power, free radical scavenging, FRAP, superoxide scavenging, peroxide scavenging and metal chelating activities. Cap portion of *Hypsizygus ulmarius* showed excellent DPPH radical scavenging, peroxide scavenging, FRAP and reducing power abilities which may be attributed to its highest total phenol content whereas the excellent ferrous ion chelation and superoxide scavenging abilities exhibited by *Agaricus bisporus* cap may be attributed to its highest flavonoid content (Babu and Rao 2011). Free radical-growth activity has been reported to be significantly influenced by phenolic mushroom compounds (Cheung et al. 2003) and the reducing capability of mushrooms might be due to their hydrogen-donating ability (Shimada et al. 1992). Butkhup et al. (2017) evaluated the phenolic contents present in wild edible mushrooms of Thailand and reported that the phenolics, (+)-catechin and (-)-epicatechin were present in all twenty-five mushrooms. Other phenolic compounds such as quercetin, quercetin-3-O-rutinoside, myricetin, naringenin and kaempferol were also detected. Quercetin and quercetin-3-O-rutinoside were the major flavonoids ranging from 0.04–1.84 and 0.04–1.17 g/kg d/w, respectively. The highest concentrations of quercetin were seen in

Russula luteotacta (1.84 g/kg d/w) and *Volvariella volvacea* (1.83 g/kg d/w) while *Volvariella volvacea* also had the highest concentrations of quercetin-3-O-rutinoside (1.17 g/kg d/w) and myricetin (0.68 g/kg d/w).

Medicinal potential of mushrooms

Nature has been a source of medicines for thousands of years, and a large number of modern pharmaceuticals have derived from natural sources, many of them based on their use in traditional medicines (Cragg and Newman 2001). Mushrooms have been utilised in medical mycology since the Neolithic and Paleolithic eras (Samorini 2001). Aqueous extracts from *Pleurotus sajor-caju* proves good in renal failure (Tam et al. 1986). Mannentake (*Ganoderma lucidum*) are known to lower blood pressure and serum cholesterol concentration of hypertensive rats (Kabir et al. 1988). *Lentinus tigrinus* and *Ganoderma lucidium* are proved anticholesterolemic (Ren et al. 1989). *Lentinus edodes* has been used to enhance vigour, sexuality, energy and as an antiaging agent (Gareth 1990). *Ganoderma* nutriceuticals have exhibited promising antiviral effects like, anti-hepatitis B (Kino et al. 1989), anti-HIV (Kim et al. 1993; Liu and Chang 1995). *Pleurotus tuber-regium* mushroom have been used for high blood pressure, curing headache, smallpox, colds, asthma, and stomach ailments (Oso 1997; Fasidi and Olorumaiye 1994). Puffballs (*Clavatia*, *Lycoperdon*) used for healing wounds (Delena 1999). *Cordyceps sinensis* has to induce restful sleep, antiaging, as an anticancer agent and antiasthma agents further showed as a memory improvement and as sexual rejuvenator (Sharma 2008). Oyetayo (2007) stated *Pleurotus tuber-regium* used as remedy in headache, cold, stomach pain fever, constipation; *Lentinus squarullosus* for heart diseases, mumps,; *Termitomyces microcarpus* for gonorrhea; *Calvatia cyathiformis* for barreness, leucorrhea; *Ganoderma lucidum* for treating neoplasia, arthritis; *Ganoderma resinaceum* used for hyperglycemia, liver diseases (hepatoprotector); *Ganoderma applanatum* used as antioxidant and for diabetes. Jin et al. (2012) reported that the use of *Ganoderma lucidum*

mushrooms as a first-line treatment for cancer. Patel and Goyal (2013) reported that mushrooms act as anti-cancer compounds play crucial role as reactive oxygen species inducer, anti-mitotic, angiogenesis inhibitor, mitotic kinase inhibitor, topoisomerase inhibitor, leading to apoptosis, and eventually checking cancer proliferation. Awadasseid et al. (2017) reported that *Coriolus versicolor* can strengthen the immune system in the tumor bearing mice and inhibit the growth of S-180 cells directly in a dose dependent way compared with the control.

Antibacterial activity of mushrooms

The antimicrobial study carried out by Iwalokun (2007) in *Pleurotus ostreatus* using petroleum ether (PE) and acetone extract, revealed that PE extract exhibited better antimicrobial activity ranging from 3.0 -7.8 mm ZOI for Gram positive, 5.0 -8.2 mm ZOI for Gram negative bacteria and 8.1-10.8 mm ZOI for fungi when compared to acetone extract (3.0 -10.5mm ZOI). The observed antimicrobial activity in this study was attributed to amount of phenolic and terpenoids present, species and strain variations, difference in their microcidal composition and concentration, method of extraction and mechanism of actions of active principles in mushroom. Akyuz and Kirbag (2009) investigated antimicrobial activity of *Pleurotus eryngii* var. *ferulae* methanolic extract, showed excellent antibacterial efficacy (7.7-10.3 mm ZOI) against microorganisms like *Bacillus megaterium, Staphylococcus aureus, Escherichia coli, Klebsiella pneumoniae, Candida albicans, Candida glabrata, Trichophyton* and *Epidermophyton* species were observed when compared to aqueous extract. The study on *Ganoderma lucidium* mushroom revealed strong antibacterial activity showing effective zone of inhibition (mm) against *Escherichia coli* (12 mm), *Klebsiella pneumoniae* (12 mm), *Proteus mirabilis* (13 mm) and *Streptococcus* sp. (14 mm) (Etim et al. 2014).

Ethanolic extract of *Pleurotus florida* showed a minimum inhibitory concentration (MIC) at 25 mg / ml against *Escherichia coli* and *Klebsiella oxytoca* followed by *Streptococcus* sp. (50 mg / ml) and *Proteus mirabilis* (75 mg / ml), whereas in case of fungi,

ethanolic extract showed MIC at 50 mg / ml against *Epidermophyton floccosum.* Loganathan et al. (2008) has investigated the antimicrobial activity of mycelial ethanolic extracts from *Pleurotus sajor-caju, Pleurotus florida* and *Pleurotus aureovillosus* against different organisms and the most susceptible bacteria were found to be *Micrococcus flavus* (22 mm ZOI). But no ZOI were observed against other tested pathogens namely *Klebsiella pneumoniae*, *Proteus vulgaris* and *Pseudomonas aeruginosa*.

The antimicrobial activity of *Pleurotus florida* cultivated in Bangladesh was studied by Mohammad et al. (2013). The Antibiogram of extract tested against *Escherichia coli, Pleurotus aerugnosa, Salmonella typhi, Serratia marcescens, Staphylococcus aureus and Salmonella paratyphii* A showed ZOI in the range of 9.20-17 mm. The MIC of the extract was found to be highest for *Salmonella paratyphii* at 1300 µg / ml while *Serratia marcescens* and *Staphylococcus aureus* had the lowest MIC of 1000 µg / ml. The results obtained had greater amount of phenols responsible for maximum antibacterial activity.

Antimicrobial activity of *Pleurotus ostreatus* cultivated on different tropical woody substrates showed that the ethanolic extracts obtained from *Pleurotus ostreatus* exhibited good ZOI against different microorganisms ranging from 5.33-20.33 mm. The extract of *Pleurotus ostreatus* cultivated on *Pycnanthus ongoleubis* substrate exhibited a better activity against almost the organisms except *Pseudomonas aeruginosa* and *Bacillus subtilis* (Oyetayo and Ariyo 2013). However, best inhibitory effect of 18-20 mm ZOI was observed with *Staphylococcus aureus*. The MIC of extracts on the tested organisms ranged from 2.5-20 mg / ml. Highest activity was recorded as maximum against *Streptococcus* sp. (23 mm ZOI) and minimum against *Vibrio parahaemolyticus* (4 mm ZOI). However, minimum antibacterial activity was observed in chloroform extract with 11 mm ZOI against *Escherichia coli* and no activity found against *Vibrio cholera*. Further antifungal activity of extracts tested against *Trichophyton rubrum*, *Epidermophyton floccosum* and *Microsporum gypseum* was studied.

Ethanol and chloroform extract showed maximum and minimum ZOI (Oyetayo and Ariyo 2013). Gebreyohannes et al. (2019) performed antimicrobial activity of wild mushrooms *Trametes* spp. and *Microsporus* spp. against six bacterial pathogens, namely, Staphylococcus aureus (ATCC 25923), Methicillin resistant *Staphylococcus aureus* (MRSA) (ATCC 33591), *Klebsiella pneumoniae* (ATCC 13883), *Pseudomonas aeruginosa* (ATCC 27853), *Pseudomonas aeruginosa* (clinical isolate), and *Escherichia coli* (clinical isolate), as well as two yeast species called *Candida albicans* (clinical isolate) and *Candida parapsilosis* (ATCC 90018) and interestingly hot water extraction has yielded good extracts with better antimicrobial activities against all of the tested organisms.

Silver nanoparticles

The combination of silver and nanoparticles has become increasingly more popular around the world (Lee et al. 2014). The biological synthesis of nanoparticles has been explored in recent years. Many biological resources including bacteria, plants and fungi and have been employed in the synthesis of nanoparticles (Barapatre et al. 2016). In recent years, the nanomaterial biosynthesis system has gained considerable popularity as an effective alternative to chemical synthesis. To date, different fungi have been found to synthesize nanoparticles (Yadav et al. 2015). Mukherjee et al. (2008) has synthesized AgNPs using *Fusarium oxysporum* extract. Fungi produce large amounts of protein that contribute to the high productivity and stability of the particles (Saikkonen 2007, Narayanan and Sakthivel 2010, Singh et al. 2014). Moreover, compared with plant materials and other microorganisms, fungal mycelia can withstand severe environments in bioreactors or chambers. Last but not least, they are easy to handle and fabricate in downstream processing.

Antimicrobial activity of AgNPs has been observed when using *Aspergillus terreus, Pestalotiopsis* sp., *Pimelea columellifera* subsp. *pallida, Aspergillus clavatus, Trichoderma harzianum, Penicillium aculeatum, Candida albicans, Fusarium verticillioides,* and

Emericella nidulans for synthesis. The produced AgNPs could inhibit Gram positive (*Bacillus subtilis, Staphylococcus aureus, Streptococcus faecalis*) and Gram negative (*Escherichia coli, Klebsiella pneumonia, Proteus mirabilis, Pseudomonas fluorescens, Pseudomonas aeruginosa,* and *Salmonella typhi*) bacterial pathogens. The fungal-derived AgNPs showed higher antimicrobial activity against bacteria and fungi than silver ions. Smaller chemical AgNPs exhibited lower MIC than Bio-AgNPs. In addition, the capping may also be involved in the difference. Chemical AgNPs only covered with PVP exhibited higher biological activity than AgNPs with biological capping, produced by mushroom (Pereira et al. 2014). The antibacterial activity of AgNPs was tested against *Escherichia coli, Bacillus subtilis, Streptococcus faecalis, Listeria innocula* and *Micrococcus luteus* by agar well diffusion method and ZOI were found against all Gram positive and Gram negative bacteria (Mohanta et al. 2018). The antimicrobial activity was verified by a micro-broth dilution test after testing by the agar well diffusion technique, with the percentage (%) of inhibition and the minimum inhibition level (MIC) of each strain determined. Four Gram positive strains exhibited growth inhibition above 90% whereas Gram negative *Escherichia coli* exhibited growth inhibition below 90%.

Table II: List of antibacterial activity of mushroom species against pathogenic bacteria

Name of the mushroom	Pathogenic bacteria	References
Agaricus cf. nigrecentulus	*Staphylococcus saprophyticus*	Rosa et al. (2003)
Agaricus bisporus	*Staphylococcus aureus, Bacillus cereus, Bacillus subtilis*	Beattie et al. (2010)
Agaricus bisporus, Trametes gibbosa	*Staphylococcus aureus, Enterococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Streptococcus pneumoniae, Proteus vulgaris*	Waithaka et al. (2017)
Agaricus bitorquis	*Staphylococcus aureus, Bacillus cereus, Bacillus subtilis*	Ishikawa et al. (2001)
Agaricus blazei	*Salmonella typhi*	Osaki et al. (1994)
Agaricus blazei	*Staphylococcus aureus,*	Zhuqiu and

	Bacillus subtilis, *Escherichia coli*	Zhang (2001)
Agaricus blazei	*Streptococcus pneumoniae*	Bernardshaw et al. (2005)
Agaricus brasiliensis	*Streptococcus mutans UA159*, *Streptococcus sobrinus 6715*	Lund et al. (2009)
Agaricus brasiliensis	*Staphylococcus aureus*, *Bacillus cereus*, *Escherichia coli*, *Pseudomonas aeruginosa*	Mazzutti et al. (2012)
Agaricus bisaporus, *Agaricus brasiliensis*	*Listeria monocytogenes*	Stojkovic et al. (2014)
Agaricus essettei	*Staphylococcus aureus*, *Bacillus cereus*, *Bacillus subtilis*	Öztürk et al. (2011)
Agaricus silvícola	*Staphylococcus aureus*, *Bacillus cereus*, *Bacillus subtilis*	Barros et al. (2008)
Armillaria mellea	*Staphylococcus aureus*, *Bacillus cereus*, *Bacillus subtilis*	Barros et al. (2008)
Boletus spp.	*Corynebacterium lilium*	Lee et al. (1999)
Clitocybe alexandri, *Rhizopogon roseolus*	*Bacillus cereus*	Solak et al. (2006)
Clitocybe geotropa	*Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus cereus*	Yamac and Bilgili (2006)
Clitocybe geotropa	*Sarcina lutea*	Kalyoncu et al. (2010)
Clitocybe sinopica	*Xanthomonas oryzae*, *Xanthomonas malvacearum*, *Agrobacterium rhizogenes*, *Agrobacterium tumefaciens*, *Agrobacterium vitis*	Zheng et al. (2010)
Cordyceps sinesis	*Escherichia coli*, *Klebsiella pneumonia*, *Salmonella enteritidis*, *Pseudomonas aeruginosa*	Zheng et al. (2006)
Cortinarius abnormis	*Staphylococcus aureus*	Gezer et al. (2006)
Cortinarius archeri	*Staphylococcus aureus*	Dulger et al. (2002)
Cortinarius basirubencens	*Pseudomonas aeruginosa*	Beattie et al. (2010)
Cortinarius clelandii	*Staphylococcus aureus*	Barros et al. (2007b)
Cortinarius coelopus	*Staphylococcus aureus*	Barros et al.

		(2007b)
Cortinarius memoria-annae	*Staphylococcus aureus*	Barros et al. (2007b)
Cyclomyces setiporus, *Ganoderma austral*, *Ganoderma australe* *Ganoderma lingzhi*, *Ganoderma endochroum*, *Ganoderma multipileum*, *Ganoderma carnosum*, *Amauroderma calcigenum*, *Trichaptum biforme*, *Trichaptuma bietinum*, *Trametes versicolor*, *Microporus xanthopus*, *Polyporus arcularius*, *Postia stiptica*, *Phlebia tremellosa*, *Lenzites betulina* *Rigidoporus* sp.	*Propionibacterium acnes*, *Staphylococcus aureus*	Tamrakar et al. (2016)
Ganoderma lucidum	*Staphylococcus aureus*, *Bacillus cereus*, *Bacillus subtilis*	Quereshi et al. (2010)
Ganoderma lucidum, *Navesporus floccose*, *Phellinus rimosus*	*Staphylococcus aureus*, *Bacillus cereus*, *Bacillus subtilis*	Sheena et al. (2003)
Ganoderma pfeifferi	*Serratia marcescens*, *Proteus mirabilis*, *Escherichia coli*, *Bacillus subtilis*	Mothana et al. (2000)
Inonotus andersonii, *Inonotus clemensiae*, *Inonotus cuticularis*	*Propionibacterium acnes*, *Staphylococcus aureus*	Tamrakar et al. (2016)
Lactarius delicious	*Bacillus cereus*	Ishikawa et al. (2001)
Lactarius volemus	*Bacillus cereus*	Barros et al. (2008)
Laetiporus sulphureus	*Micrococcus luteus*	Gezer et al. (2006)
Laetiporus sulphureus	*Staphylococcus aureus*	Turkoglu et al. (2007)
Laetiporus sulphureus	*Bacillus cereus*	Turkoglu et al. (2007)
Lentinus edodes	*Staphylococcus aureus*	Hirasawa et al. (1999)
Lentinus edodes	*Staphylococcus aureus*	Hatvani (2001)
Lentinus edodes	*Bacillus cereus*	Rosa et al. (2003)
Lentinus edodes	*Proteus vulgaris*	Bender et al. (2003)

Lentinus edodes, Pleurotus ostreatus	*Staphylococcus aureus*	Hearst et al. (2009)
Lepista nuda *Leucopaxillus giganteus*	*Bacillus cereus*	Kalyoncu et al. (2010)
Leucopaxillus albissimus	*Stenotrophomonas maltophilia,* *Burkholderia cenocepacia,* *Burkholderia cepacia,* *Burkholderia multivorans,* *Cytophaga johnsonae,* *Achromobacter xyloxidans,* *Acinetobacter baumannii,* *Pseudomonas aeruginosa*	Schwan et al. (2010)
Macrolepiota procera	*Bacillus cereus*	Barros et al. (2008)
Mircoporus spp. *Trametes* spp.	*Escherichia coli, Klebsiella pneumoniae,* *Pseudomonas aeruginosa,* *MRSA, Staphylococcus aureus,*	Gebreyohannes et al. (2019)
Morchella costata	*Sarcina lutea*	Kalyoncu et al. (2010)
Paxillus involutus	*Sarcina lutea*	Kalyoncu et al. (2010)
Phellinus sp.	*Bacillus cereus*	Barros et al. (2007b)
Pleurotus eryngii var. eryngii, *Pleurotus eryngii var. ferulae,* *Pleurotus ostreatus,* *Pleurotus sajor-caju,* *Terfezia boudieri,* *Agaricus bisporus*	*Bacillus megaterium,* *Staphylococcus aureus,* *Escherichia coli,* *Klebsiella pneumoniae*	Akyuz and Kirbag (2009)
Pleurotus ostreatus	*Bacillus cereus*	Gezer et al. (2006)
Pleurotus ostreatus	*Sarcina lutea*	Kalyoncu et al. (2010)
Pleurotus sajor-caju	*Pseudomonas aeruginosa*	Ngai and Ng (2004)
Pseudoplectania nigrella	*Bacillus thuringiensis,* *Corynebacterium diphtheria,* *Corynebacterium jeikeium,* *Enterococcus faecalis,* *Enterococcus faecium*	Mygind et al. (2005)
Pycnoporus sanguineus	*Escherichia coli*	Smânia et al. (1995)
Pycnoporus sanguineus	*Proteus vulgaris,* *Salmonella typhi*	Smânia et al. (1995)
Pycnoporus sanguineus	*Escherichia coli,* *Klebsiella pneumonia,* *Pseudomonas aeruginosa*	Quang et al. (2006)

Ramaria botrytis	*Bacillus cereus*	Hearst et al. (2009)
Ramaria flava	*Bacillus cereus*	Barros et al. (2007b)
Ramaria flava	*Micrococcus flavus, Micrococcus luteus*	Öztürk et al. (2011)
Rhizopogon roseolus	*Bacillus cereus*	Hearst et al. (2009)
Sarcodon imbricatus	*Bacillus cereus*	Barros et al. (2007b)
Sparassis crispa	*Bacillus cereus*	Barros et al. (2007b)
Sparassis crispa	*Sarcina lutea*	Kalyoncu et al. (2010)
Terfezia boudieri, Amanita brunnescens, Lactifluus vellereus	*Bacillus subtilis*	Dog˘an et al. (2013)
Tricholoma portentosum	*Bacillus cereus*	Barros et al. (2007b)
Tyromyces duracinus	*Staphylococcus saprophyticus*	Rosa et al. (2003)
Xylaria intracolarata	*Salmonella enteritidis*	Quang et al. (2006)

Mushroom polysaccharides and their bioactivity

Mushroom polysaccharides exist as a structural component of fungal cell wall polysaccharides and their conjugates are the major constituent for the bioactivities of some mushroom species. Polysaccharides are divided into two distinct categories, homopolysaccharides and heteropolysaccharides, on the basis of monosaccharide composition. Earlier studies suggested that homopolysaccharides, particularly glucans, are the only polysaccharide with medicinal properties. However, heteropolysaccharides also showed imperative biological activities (He et al. 2017). The detailed mechanisms of bioactivities related to structure in heteropolysaccharides remain largely unexplored, although the biological roles of glucans and glycans have been well established. PS composition and combination are clearly correlated with pharmaceutical activities (Lo et al. 2011; Li et al. 2016; Xu et al. 2014). Polysaccharides also showing antitumor activity have been isolated

from the fruiting bodies, cultured mycelia and culture filtrates of *Boletus edulis*, *Collybia radicata* var. *furfuracea* and *Clitopilus abortivus*. These polysaccharides showing antitumor activity have a great variety of chemical composition, structure and antitumor activity. The extracted polysaccharides from mushrooms indicating antitumor activity was first reported by Lucas (1957). Some studies on those polysaccharides are shown in table III.

Table III: Source, Type and Bioactivity of Some Mushroom Polysaccharides

Mushroom	Type of polysachcharide	Bioactivity	References
Lentinus edodes	Mannoglucan, polysaccharide-protein complex,	Immunomodulating, antitumor, antiviral	Chihara et al. (1970)
Schizophyllum commune	Glucan, schizophyllan	Antitumor	Yamamoto (1981)
Auricularia auricula	Glucan	Hyperglycemia, immunomodulating, antiflammatory, antiradiative	Ukai et al. (1982)
Tremella fuciformis	Heteroglycan	Hyperlipidemia, immunomodulating, antitumor.	Huang (1982)
Flammulina velutipes	Glucaneprotein complex, glycoprotein	Antitumor, antiflammatory, antiviral, immunomodulating	Zeng (1990)
Dictyophora indusiata	Heteroglycan, mannan, glucan	Antitumor, hyper-lipidemia	Hara et al. (1991)
Pleurotus ostreatus	Glycoprotein	Antitumor, hyperglycemia, antioxidant	Solomko (1992)
Trametes robiniophila	Proteoglycan	Immunomodulating, hepatoprotective, anticancer	Zhang (1995)
Morchella esculenta	Hyperglycemia, antitumor	Heteroglycan	Duncan et al. (2002)
Tremella aurantialba	Heteroglycan	Immunomodulating, hyperglycemia	Liu et al. (2003)
Polystictus versicolar	Heteroglycan, glycopeptide, Krestin	Immunomodulating, antitumor, antiflammatory	Cui and Chisti (2003)
Polypours umbellatus	Glucan	Antitumor, immunomodulating	Yang et al. (2004)
Inonotus obliquus	Glucan	Antitumor, immunomodulating	Kim et al. (2005)

Termitomyces stritatus	D-glucose, D-galactose, D-mannose, L-fucose	Immunomodulating	Mondal et al. (2006)
Termitomyces robustus	D-glucose, D-galactose, D-mannose, L-fucose	Immunomodulating	Mondal et al. (2008)
Volvariella volvacea	Glucan	Immuno activation	Maity et al. (2013)
Entoloma lividoalbum	Heteroglycan	Antioxidant, human lymphocyte protector	Maity et al. (2014a)
Russula albonigra	Heteroglycan	Antioxidant, Immunostimulant	Nandi et al. (2014)
Inonotus obliquus	Mannose, Rhamnose, Xylose	Antioxidant activity	Xu et al. (2014)
Flammulina velutipes	Rhamnose	Antioxidant activity	Zhao et al. (2015)
Hirsutella sp.	Mannose, Glucose	Antioxidant activity	Lei et al. (2015)
Pleurotus eryngii	Mannose, Rhamnose, Galactose	Antioxidant activity	He at al. (2016)
Agrocybe cylindracea	Glucose, Galactose	Antioxidant activity	Liu et al. (2016)
Ganoderma lucidum	Rhamnose	Antioxidant activity	Zhang et al. (2016)
Cordyceps sinensis	Glucose, Galactose, Mannose	Antioxidant activity	Wang et al. (2017)
Grifola frondosa	*β*-D-glucan	Antitumor, immunomodulation, antioxidation, anti-hyperglycemia	He at al. (2017)
Ganoderma lucidum	Polysaccharide	Hypolipidemic antioxidant, antiapoptic	Liang et al. (2019)

In silico approaches on bactericidal mechanism

In silico study involves computer modelling or computer simulation to find a new antagonist or agonists for a target. Multidrug resistance is one of the major challenges for the healthcare systems worldwide. Antibiotic-resistant infections are increased upto two-fold in mortality compared to antibiotic-susceptible infections (Cosgrove and Carmeli 2003). The

docking study using the crystal structure of human aldose reductase complex with NADP+ and IDD-type inhibitor (PDB: 2IKI) was performed by Steuber et al. (2007) and it was observed that the incorporation of a cyano group at the α-position of *p*-coumaric acid will increase the binding affinity with two more hydrogen bonds. A structure activity relationship (SAR) study was designed by Alves et al. (2013) to analyse the differential effects of bioactive compounds on two strains of *Staphylococcus aureus* by determining the chemical structure patterns of the evaluated compounds. The molecular docking study was also performed by Alves et al. (2013) using 3D crystal structure of penicillin binding protein [(PBP2a), (PDB: IQVV)] to understand the inhibitory mechanism of phenolic compounds with activity against methicillin-susceptible *Staphylococcus aureus* (MRSA). It was noted that a superimposition of the docking positions for the three benzoic acid derivatives like vanillic acid, 2,4-dihydroxybenzoic acid and syringic acid.

Docking study was done by Alves et al. (2014) for 34 compounds in order to determine their affinity to bacterial proteins (PBP1a from *Acinetobacter baumannii*, Alr from *Escherichia coli*, IARS and Ddl from *Thermus thermophilus*, DNA gyrase subunit B and DHFR from *Staphylococcus aureus*, and Topo IV and DHPS from *Streptococcus pneumoniae*) which are known targets for some antibiotics. After validation of molecular docking followed by virtual screening revealed that some mushroom compounds like enokipodins, ganomycins and austrocortiluteins have the main mechanism of action is the inhibition of cell wall synthesis. Sharma et al. (2017) has synthesized the *p*- coumaric acid derivatives, docked and evaluated the bioactivities. The structure activity relationship exhibited enhancement of antibacterial activity against *Bacillus subtilis* and *Staphylococcus aureus* due to substitution with fluoro group at phenyl ring attached to hydroxybenzamide ring.

In this scenario, the present Ph.D. thesis work has been designed to study the seasonal diversity and bioactive potentials of selected mushrooms occurring in Gurguripal ecoforest on the basis of following objectives -

1. Study of seasonal mushroom diversity in Gurguripal ecoforest.
2. Extraction of bioactive compounds from selected Mushrooms.
3. Study of antibacterial potential of mushroom extracts against pathogenic bacteria.
4. Purification and chemical characterisation of antibacterial compounds.
5. Efficacy enhancement of the antibacterial compound.