Chapter 17
Mushroom: Nutraceutical, Mineral, Proximate Constituents and Bioactive Component

Sakshi Painuli, Prabhakar Semwal, and Chukwuebuka Egbuna

17.1 Introduction

The kingdom Fungi is a diverse group of decomposers which majorly includes moulds, yeasts and mushrooms. Mushrooms are found worldwide and are also known to be the earliest form of fungi to mankind (Okhuoya et al. 2010). Generally, they are the fruiting bodies of macroscopic filamentous fungi which are usually known for high nutritional as well as medicinal properties. There are several evidences in history which shows that mushrooms have been consumed by mankind since a long back in the form of food or medicine. The ancient civilizations of Greek, Romans, Egyptians, Japanese, Chinese and Mexicans prized mushrooms for their medicinal properties and consumed them as dietary supplement or medicinal food (Agrawal and Dhanasekaran 2019; Chang and Zhao 2002; Guzmán 2015; Hobbs 2002). According to Greeks, mushrooms are the source of strength for soldiers in battle, whereas Romans believed them as "God's food" and Chinese

S. Painuli
Department of Biotechnology, Graphic Era University, Dehradun, Uttarakhand, India

Himalayan Environmental Studies and Conservation Organization, Dehradun, Uttarakhand, India

P. Semwal (✉)
Department of Biotechnology, Graphic Era University, Dehradun, Uttarakhand, India
Uttarakhand State Council for Science and Technology, Dehradun, Uttarakhand, India

C. Egbuna
Department of Biochemistry, Faculty of Natural Sciences, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria

Nutritional Biochemistry and Toxicology Unit, World Bank Africa Centre of Excellence, Centre for Public Health and Toxicological Research (ACE-PUTOR), University of Port-Harcourt, Port-Harcourt, Rivers State, Nigeria

C. Egbuna, G. Dable-Tupas (eds.), *Functional Foods and Nutraceuticals*,
https://doi.org/10.1007/978-3-030-42319-3_17

consider them as a health food or a medicine of life. Many researchers have studied and documented that mushrooms are the reservoir of variety of nutraceuticals, nutriceuticals and bioactive compounds. During the last few decades, consumption and cultivation of mushrooms increased continuously as nutritional resource. Internationally, China is the biggest producer of mushrooms, whereas *Agaricus bisporus* is highly cultivated mushroom species followed by *Pleurotus* spp., and *Flammulina velutipes* (Valverde et al. 2015). Mushrooms are important inclusions for human diet as they contain significant amount of proximate constituents, prominent amount of minerals, proteins, vitamins and low fat contents along with several medicinally important active components (Kalač 2013; Isabel CFR Ferreira and Heleno 2017; Beelman et al. 2019). Different species of mushrooms are recognized to possess different medicinal properties like anti-tumor, neuroprotective, anti-oxidant, anti-hypoglycemic, anti-cancer, anti-bacterial, immunomodulatory, anti-inflammatory, anti-viral, anti-atherosclerotic properties, etc. (Wani et al. 2010; Thatoi and Singdevsachan 2014; Kim et al. 2008; Khatun et al. 2012; Gaglarirmak 2011; Elkhateeb et al. 2019; Cohen et al. 2014). The chapter presents an overview of the research on the nutraceutical, mineral, proximate constituents and bioactive component from beneficial mushrooms.

17.2 Proximate Analysis and Mineral Composition

The proximate composition including moisture content, crude fat content, ash content, carbohydrate content, total sugar content and energy value are given in Table 17.1. Many reports have been documented the proximate composition of edible and wild mushrooms. The water content of mushroom varies greatly, as their fruiting body get influenced by the type of species, growth and climatic condition, collection strategy and storage measures. The moisture content of mushrooms have been recorded from a range of 2.71 to 93.25 g/100 g dry weight. The lowest and highest moisture content has been recorded in *Astraeus hygrometricus* and *Pholita microsporeo,* respectively (Meng et al. 2019; Pavithra et al. 2018). Few species such as *Agaricus albertii*, *Termitomyces clypeatus*, *Russula delica*, *Hygrophorus chrysodon* and *Suillus variegates* have also showed high moisture content. The ash content generally estimates the mineral content and the value usually varies between 2.80 and 33.10 g/100 g dry weight for different mushrooms. The lowest and highest ash content has been assessed in *Ganoderma lucidum* and *Lycoperdon umbrinum* (Pereira et al. 2012; Stajic et al. 2013). While, the content of crude fat ranges between 0.18 and 17.52 g/100 g dry weight in *Bovista aestivalis* and *Amanita princeps* (Pereira et al. 2012; Srikram and Supapvanich 2017).

Carbohydrates are the major composition of mushrooms; they are basically present in the form of glycoproteins or polysaccharides. The highest and lowest carbohydrate content has been detected in *Boletus edulis* (81.00 g/100 g dry weight) and *Lepista inversa* (10.35 g/100 g dry weight), while some heterogeneity

Table 17.1 Nutraceutical and proximate profiling of few selected species of mushrooms from different regions

Species name	Moisture	Crude fat	Crude protein	Ash	Carbohydrate	Energy	Total sugar	Country	References
Agaricus albertii	90.73	1.38	19.83	22.13	56.66	318.36	05.98	Portugal	Reis et al. (2014)
Agaricus bisporus	91.64	1.67	15.43	11.36	71.53	345.10	51.08	Portugal	Reis et al. (2012)
Agaricus bisporus	–	1.56	29.14	–	51.05	–	–	India	Ahlawat et al. (2016)
Agaricus blazei	–	–	31.6	06.20	48.00	325.30	39.50	Portugal	Taofiq et al. (2019)
Agaricus comtulus	87.94	0.46	21.29	28.14	50.11	289.74	18.99	Portugal	Pereira et al. (2012)
Agaricus excellens	87.72	1.37	14.47	29.64	54.52	288.29	01.51	Portugal	Reis et al. (2014)
Agaricus subrufescens	–	02.20–15.70	37.20–50.40	–	18.00–23.90	–	–	China	Liu et al. (2019)
Amanita calyptroderma	87.43	1.46–11.61	3.58–28.49	1.34–11.82	3.56–22.16	–	–	Thailand	Srikram and Supapvanich (2017)
Amanita curtipes	80.00	8.60	06.40	17.20	67.80	347.00	15.10	Portugal	Fernandes et al. (2015)
Amanita princeps	89.67	1.81–17.52	3.16–30.59	0.47–4.55	2.18–17.04	–	–	Thailand	Srikram and Supapvanich (2017)
Amanita rubescens	–	–	21.8	7.0	–	–	–	India	Lalotra et al. (2018)
Astraeus hygrometricus	2.71–2.93	–	16.80–17.30	18.43–15.53	46.17–48.42	–	–	India	Pavithra et al. (2018)
Astraeus odoratus	84.15	1.16–7.32	4.18–26.37	0.98–10.17	3.91–20.68	–	–	Thailand	Srikram and Supapvanich (2017)
Boletus edulis	–	2.23	10.65	05.26	81.86	390.09	14.38	Portugal	Heleno et al. (2015c)
Boletus edulis	–	–	31.3	6.4	–	–	–	India	Lalotra et al. (2018)
Boletus erythropus	88.36	0.75	20.92	25.90	52.44	300.15	34.46	Portugal	Grangeia et al. (2011)
Boletus porosporus	65.57	0.96	15.74	04.20	79.11	388.01	41.26	Portugal	Leal et al. (2013)
Boletus regius	79.15	1.59	05.22	04.40	88.79	390.36	20.95	Portugal	Leal et al. (2013)
Bovista aestivalis	23.23	0.18	15.59	31.86	52.37	273.44	00.38	Portugal	Pereira et al. (2012)

(continued)

Table 17.1 (continued)

Species name	Moisture	Crude fat	Crude protein	Ash	Carbohydrate	Energy	Total sugar	Country	References
Catathelasma ventricosum	89.62	1.52	29.13	12.59	56.75	362.42	–	China	Liu et al. (2012b)
Chlorophyllum rhacodes	88.28	3.29	19.32	12.10	65.29	368.03	44.00	Portugal	Pereira et al. (2012)
Clavariadelphus pistillaris	84.22	0.59	16.27	20.77	62.37	319.88	25.36	Portugal	Pereira et al. (2012)
Clitocybe subconnexa	–	1.02	07.42	05.98	27.35	381.18	30.71	Portugal	Heleno et al. (2015a)
Coprinus comatus	–	1.80	11.84	10.07	76.29	368.72	07.25	Netherlands	Stojković et al. (2013)
Cortinarius praestans	89.16	2.58	14.56	18.89	63.98	337.34	60.88	Portugal	Pereira et al. (2012)
Craterellus cornucopioides	–	4.87	47.21	10.08	–	413.46	14.08	Croatia	Beluhan and Ranogajec (2011)
Dictyophora indusiata	–	2.6–2.7	01.90–19.50		40.20–41.60	–	–	China	Liu et al. (2019)
Entoloma clypeatum	–	6.21	27.98	09.21	–	374.80	21.50	Croatia	Beluhan and Ranogajec (2011)
Flammulina velutipes	–	6.45	27.95	07.39	–	343.69	30.10	Croatia	Beluhan and Ranogajec (2011)
Ganoderma amboinense	–	0.8–1.0	12.70–14.60	–	45.00–61.00	–	–	China	Liu et al. (2019)
Ganoderma lucidum	–	4.43	11.34	02.80	81.48	410.93	00.75	Netherlands	Stojković et al. (2014)
Geopora arenicola	–	–	23.8	9.9	–	–	–	India	Lalotra et al. (2018)
Gyromitra esculenta	85.68	0.73	14.74	32.10	52.43	275.23	06.13	Portugal	Leal et al. (2013)
Heimiella retispora	88.56	1.63–14.25	2.73–23.86	0.39–3.41	2.33–20.37	–	–	Thailand	Srikram and Supapvanich (2017)
Helvella lacunosa	82.37	2.40	04.40	21.70	71.50	325.21	04.36	Portugal	Leal et al. (2013)
Hericium coralloides	–	2.38	07.25	09.31	81.06	374.67	10.79	Portugal	Heleno et al. (2015b)

Hericium erinaceum	–	1.75	15.40	3.49	79.39	394.79	23.63	Portugal	Heleno et al. (2015b)
Hygrophorus chrysodon	92.09	3.48	15.11	26.91	54.51	309.74	07.27	Portugal	Pereira et al. (2012)
Laccaria amethystea	86.13	2.78	29.84	10.31	57.07	377.70	–	China	Liu et al. (2012b)
Lactarius citriolens	–	5.37	10.89	06.99	76.76	398.89	08.76	Portugal	Vieira et al. (2014)
Lactarius turpis	–	2.06	13.06	07.21	77.68	381.47	19.54	Portugal	Vieira et al. (2014)
Lentinula edodes	–	1.22	18.85	–	63.60	–	–	India	Ahlawat et al. (2016)
Lentinus edodes	9.00	0.67	19.50	4.82	45.42	–	–	Korea	Olawuyi and Lee (2019)
Lentinus edodes	–	1.14	16.00	06.24	76.62	380.74	15.61	Portugal	Heleno et al. (2015a)
Lycoperdon umbrinum	71.98	0.37	14.53	33.14	51.96	269.29	01.46	Portugal	Pereira et al. (2012)
Macrolepiota procera	–	2.23	24.22	05.37	–	389.46	24.40	Croatia	Beluhan and Ranogajec (2011)
Morchella deliciosa	–	–	25.6	7.0	–	–	–	India	Lalotra et al. (2018)
Morchella esculenta	90.79	2.59	11.52	11.34	74.55	367.56	15.66	Portugal	Heleno et al. (2013)
Pholita microsporeo	87.58–93.25	0.71–1.15	19.22–21.22	–	–	–	26.13–33.53	China	Meng et al. (2019)
Pleurotus eous	–	1.05	19.59	–	64.34	–	–	India	Ahlawat et al. (2016)
Pleurotus eryngii	82.59	4.36	02.09	14.95	78.60	362.00	15.63	Portugal	Reis et al. (2014)
Pleurotus geesteranu		1.71–2.26	32.70–39.80	–	29.00–42.80	–	–	China	Liu et al. (2019)
Pleurotus giganteus	–	3.10	19.20	–	64.70	364.00	–	Malaysia	Phan et al. (2019)
Pleurotus ostreatus	78.28	–	28.40	16.68	52.74	–	–	Nigeria	Ikon et al. (2019)
Pleurotus ostreatus	–	2.06–2.19	21.10–36.40	–	34.70–50.70	–	–	China	Liu et al. (2019)
Pleurotus sajorcaju	–	1.98–2.7	23.20–35.50	–	40.1–49.4	–	–	China	Liu et al. (2019)
Ramaria aurea	79.99	1.24	10.33	12.75	75.68	355.18	11.85	Portugal	Leal et al. (2013)

(continued)

Table 17.1 (continued)

Species name	Moisture	Crude fat	Crude protein	Ash	Carbohydrate	Energy	Total sugar	Country	References
Russula alboareolata	86.35	0.63–4.61	4.08–29.90	1.32–10.99	3.27–22.62	–	–	Thailand	Srikram and Supapvanich (2017)
Russula cyanoxantha	89.45	0.83–7.87	5.19–49.20	0.27–2.56	1.01–9.56	–	–	Thailand	Srikram and Supapvanich (2017)
Russula delica	92.00	3.4	13.80	08.80	74.00	363.00	10.30	Portugal	Fernandes et al. (2014)
Russula emetic	87.57	0.49–3.94	4.13–33.24	1.03–8.29	3.37–27.09	–	–	Thailand	Srikram and Supapvanich (2017)
Russula virescens	86.51	1.69–12.54	3.98–29.50	0.87–5.40	2.73–27.67	–	–	Thailand	Srikram and Supapvanich (2017)
Russula virescens	92.49	1.85	21.85	11.04	62.27	365.09	11.10	Portugal	Leal et al. (2013)
Sparassis crispa	–	–	16.2	4.9	–	–	–	India	Lalotra et al. (2018)
Suillus variegates	90.77	3.31	17.57	15.36	63.76	355.12	04.85	Portugal	Pereira et al. (2012)
Termitomyces clypeatus	90.13	0.78–7.90	2.60–26.34	0.29–2.94	2.73–27.67	–	–	Thailand	Srikram and Supapvanich (2017)
Volvariella volvacea	–	0.97	38.10	–	42.30	–	–	India	Ahlawat et al. (2016)
Volvopluteus gloiocephalus	–	4.62	19.66	14.19	13.97	366.34	03.37	Portugal	Heleno et al. (2015a)
Xerocomus badius	–	4.22	08.08	07.32	80.38	391.83	11.77	Portugal	Heleno et al. (2015a)

has also observed between species (Leal et al. 2013). The energy value for mushrooms ranges between 269 and 413.46 kcal/100 g dry weight in *Lycoperdon umbrinum* and *Craterellus cornucopioides* (Beluhan and Ranogajec 2011; Pereira et al. 2012). The two major forms of sugar detected in mushrooms are mannitol and trehalose. Basically, mannitol contributes in growth and firmness of fruiting body and can vary from species to species, it is abundantly present in wild mushrooms (Kalač 2009). In wild mushrooms, mannitol ranges between 11.03 and 43.34 g/100 g dry weight, the lowest and highest values has been observed in *Lyophyllum decastes* and *Clavariadelphus truncates*, whereas in cultivated species the highest amount of mannitol has detected in *Agaricus bisporus* (64.15 g/100 g dry weight) and the lowest amount has detected in *Lentinula edodes* (49.51 g/100 g dry weight), respectively (Pereira et al. 2012; Reis et al. 2012). Trehalose, found profusely from a range of 14.21 to 25.57 g/100 g dry weight in *Pleurotus eryngii* and *Chlorophyllum rhacodes*, respectively, however in cultivated mushrooms the value of trehalose has detected to be 72.82, 42.82 and 60.51 g/100 g dry weight, the lowest and highest has been recorded in *Pleurotus eryngii*, *Coprinus comatus* and *Cortinarius praestans*, respectively (Pereira et al. 2012; Reis et al. 2012; Vaz et al. 2011). Other than mannitol and trehalose, low content of other sugars like sucrose, fructose, mannose, and arabinose has also been detected in mushrooms.

Mushrooms (wild or cultivated), are capable of accumulating micro and macro minerals in their fruiting bodies to perform several functions. The trace mineral contents for different species of mushrooms are given in Table 17.2. Few minerals like, Iron (Fe), Phosphorus (P) and Potassium (K) are abundantly present in mushroom fruiting bodies (Wang et al. 2014). The other minerals detected in mushrooms includes Calcium (Ca), Magnesium (Mg), Sodium (Na), Manganese (Mn) and Copper (Cu). The mineral content in the fruiting body depends on the type of species or on the substrate on which they are cultivated. The highest and lowest potassium content has been detected in *Macrocybe gigantea* and *Volvopluteus gloiocephalus* from a range of 1300 to 46,926 μg/g dry weight (Heleno et al. 2015a). While, the highest and lowest phosphorus content has been estimated in *Lentinus cladopus* and *Stropharia rugosoannulata* from 1005 to 7290 μg/g dry weight, respectively (Liu et al. 2012b; Mallikarjuna et al. 2012). For other elements like Mg, Cu, Mn, Fe and Zn, a huge variation in values have been reported, ranging from 88 to 2289, 1.53 to 88.8, 0.03 to 103.9, 0.02 to 6762 and 0.94 to118.84 μg/g dry weight, respectively. Along with beneficial minerals some toxic minerals like, Chromium (Cr), Lead (Pb), Cadmium (Cd) and Arsenic (As) have also been detected in fruiting bodies. These toxic elements are absent or very less in the cultivated species of mushrooms (Mallikarjuna et al. 2012).

Table 17.2 Trace elements in few selected mushrooms from different regions

Name of species	Mg	Cu	Mn	Fe	Zn	Pb	Co	Cr	Country	References
Agaricus bisporus	–	1.54	–	5.14	2.55	0.07	–	0.07	Spain	Rubio et al. (2018)
Agaricus bisporus	–	–	7.97	85.86	79.64	–	–	–	India	Ahlawat et al. (2016)
Agrocybe cylindracea	630–851	–	–	–	–	–	–	20.5–21.1	Poland	Siwulski et al. (2019)
Amanita caesarea	833.1	19.32	47.99	356.90	65.65	0.09	0.75	1.23	Greece	Ouzouni et al. (2009)
Amanita rubescens	–	39.2	33.6	105	52.3	–	–	–	India	Lalotra et al. (2018)
Armillaria mellea	1063.1	17.38	55.59	499.00	54.12	0.49	0.16	4.20	Greece	Ouzouni et al. (2009)
Armillaria tabescens	1150.7	17.47	11.18	60.40	64.45	0.79	0.14	4.37	Greece	Ouzouni et al. (2009)
Boletus aereus	0.14–0.18	0.75–0.96	0.01–0.02	0.003–0.10	0.94–1.19	–	–	–	Italy	Alaimo et al. (2018)
Boletus aureus	755.1	41.47	18.31	112.80	89.45	0.09	0.18	0.86	Greece	Ouzouni et al. (2009)
Boletus edulis	–	34.4	54.4	812	96.3	–	–	–	India	Lalotra et al. (2018)
Boletus griseus	200.0	52.00	63.00	47.00	94.00	–	1.70	0.84	China	Liu et al. (2012a)
Boletus griseus	–	29.1–35.3	16.2–16.6	484–523	75.9–121.5	–	1.2–1.8	–	China	Wang et al. (2017)
Boletus impolitus	–	9.8–16.2	16.2–41.5	672–1831	38.7–78.1	–	5.2–12.7	–	China	Wang et al. (2017)
Boletus luridus	–	26.6–34.2	17.2–18.5	288–371	118–164.5	–	3.5–8.3	–	China	Wang et al. (2017)
Boletus reticulatus	–	16.5–33.8	29.8–34.7	516–714	41.7–108.5	–	3.9–4.3	–	China	Wang et al. (2017)
Boletus speciosus	110.0	28.00	02.00	78.00	50.00	–	1.00	0.45	China	Liu et al. (2012a)

Boletus speciosus	–	32.5–70.4	12.5–13.3	568–581	115.2–187.4	–	2.8–3.7	–	China	Wang et al. (2017)
Boletus umbriniporus	–	36.3–62.6	29.2–36.4	591–816	71.1–172.9	–	4.9–7.5	–	China	Wang et al. (2017)
Cantharellus cibarius	–	16.7–56.1	–	–	69.3–94.0	0.21–0.89	–	–	Slovakia	Árvay et al. (2019)
Catathelasma ventricosum	1538.0	38.00	09.00	673.00	88.00	–	–	–	China	Liu et al. (2012b)
Clitocybe subconnexa	148.86	05.22	0.10	06.53	06.37	–	–	–	Portugal	Heleno et al. (2015a)
Clitocybe maxima	520.0	52.00	33.00	308.00	127.00	1.44	–	–	China	Liu et al. (2012b)
Clitocybe maxima	1846–2289	–	–	–	–	–	–	30.0–34.1	Poland	Siwulski et al. (2019)
Clitopilus prunulus	0.38	0.50	0.03	0.02	1.27	–	–	–	Italy	Alaimo et al. (2018)
Coprinus atramentarius	–	57.12	64.20	1183.60	288.40	–	–	–	Turkey	Bengu (2019)
Craterellus cornucopioides	978.0	43.00	27.00	413.00	61.00	–	–	–	China	Liu et al. (2012b)
Flammulina velutipes	1058–1143	–	–	–	–	–	–	20.8–21.9	Poland	Siwulski et al. (2019)
Ganoderma lucidum	427–632	–	–	–	–	–	–	14.9–17.4	Poland	Siwulski et al. (2019)
Geopora arenicola	–	88.8	50.5	267	36.5	–	–	–	India	Lalotra et al. (2018)
Hericium coralloides	134.00	00.72	0.31	77.96	04.76	–	–	–	Portugal	Heleno et al. (2015b)
Hericium erinaceus	85.57	00.22	0.09	06.77	02.11	–	–	–	Portugal	Heleno et al. (2015b)
Imleria badia	–	21.4–43.8	–	–	62.7–140.0	0.07–0.33	–	–	Slovakia	Árvay et al. (2019)
Laccaria amethystea	1482.0	36.00	35.00	211.00	59.00	0.74	–	–	China	Liu et al. (2012b)
Lactarius deliciosus	–	1.64	–	10.9	2.32	0.08	–	0.16	Spain	Rubio et al. (2018)

(continued)

Table 17.2 (continued)

Name of species	Mg	Cu	Mn	Fe	Zn	Pb	Co	Cr	Country	References
Lactarius hygrophoroides	140.0	28.00	3.70	28.00	16.00	–	2.10	1.50	China	Liu et al. (2012a)
Laetiporus sulphureus	–	5.00	19.36	162.92	28.36	–	–	–	Turkey	Bengu (2019)
Leccinum rugosiceps	–	15.1–35.7	19.3–19.7	323–449	62.1–91.6	–	0.7–2.1	–	China	Wang et al. (2017)
Lentinula edodes	–	1.53	–	10.5	2.23	0.09	–	0.15	Spain	Rubio et al. (2018)
Lentinula edodes	856–942	–	–	–	–	–	–	15.6–18.4	Poland	Siwulski et al. (2019)
Lentinula edodes	–	–	17.48	37.55	89.63	–	–	–	India	Ahlawat et al. (2016)
Leucopaxillus giganteus	84.0	50.00	60.00	510.00	85.00	–	0.72	6.30	China	Liu et al. (2012a)
Macrocybe gigantean	550.0	13.00	5.90	79.00	160.00	–	0.29	0.65	China	Liu et al. (2012a)
Melanoleuca arcuate	230.0	22.00	1.40	22.00	38.00	–	1.60	2.50	China	Liu et al. (2012a)
Morchella deliciosa	130.0	55.00	70.00	42.00	58.00	–	0.51	5.90	China	Liu et al. (2012a)
Morchella deliciosa	–	33.4	53.3	213	117	–	–	–	India	Lalotra et al. (2018)
Mycena haematopus	270.0	23.00	24.00	180.00	54.00	–	0.63	1.50	China	Liu et al. (2012a)
Pholiota nameko	–	1.73	–	10.9	1.93	0.08	–	0.10	Spain	Rubio et al. (2018)
Pleurotus eous	–	–	6.47	183.07	162.18	–	–	–	India	Ahlawat et al. (2016)
Pleurotus eryngii	699–1228	–	–	–	–	–	–	19.0–21.0	Poland	Siwulski et al. (2019)
Pleurotus ostreatus	–	1.99	–	11.0	2.91	0.10	–	0.17	Spain	Rubio et al. (2018)
Pulveroboletus ravenelii	210.0	58.00	58.00	370.00	34.00	–	0.65	5.60	China	Liu et al. (2012a)
Sparassis crispa	–	25.5	41.0	555	137	–	–	–	India	Lalotra et al. (2018)
Stropharia rugosoannulata	1135.0	29.00	59.00	195.00	102.00	0.07	–	–	China	Liu et al. (2012b)
Suillus luteus	421–1210	–	–	–	34.7–141	–	–	–	Germany	Zocher et al. (2018)

Suillus luteus	–	27.8–36.2	–	–	92.3–98.8	0.16–0.34	–	–	Slovakia	Árvay et al. (2019)
Suillus luteus	–	13.36	22.84	283.24	118.84	–	–	–	Turkey	Bengu (2019)
Tricholoma matsutake	370.0	20.00	3.00	34.00	62.00	–	2.3	2.60	China	Liu et al. (2012a)
Volvariella volvacea	–	–	–	72.51	94.28	–	–	–	India	Ahlawat et al. (2016)
Volvopluteus gloiocephalus	200.19	05.01	0.13	69.91	10.89	–	–	–	Portugal	Heleno et al. (2015a)
Xerocomus spadiceus	–	19.8–28.0	29.0–103.9	1315–6762	47.5–77.8	–	7.2–25.9	–	China	Wang et al. (2017)

17.3 Nutritional and Nutraceutical Potential of Mushrooms

Nutraceuticals and nutriceuticals are considered as food or a part of diet that have therapeutic and health benefits, which helps in fighting against several diseases. They may vary from herbal products to dietary supplements, isolated nutrients, genetically engineered/designer food and processed food products like beverages, cereals and soups. There are several examples of nutritive nutraceuticals/functional food ingredients like proteins, peptides, keto acids, amino acids, polyunsaturated fatty acids (PUFA), vitamins, minerals and antioxidants (Barros et al. 2008). Mushrooms are extremely nutritious with low fat content and high protein, essential amino acid, mineral and vitamin content (Agrahar-Murugkar and Subbulakshmi 2005). Studies showed that around 35 different species of edible mushrooms are cultivated commercially, however almost 200 species of wild mushrooms are used for their medicinal properties (Beulah et al. 2013). Recently, researchers gain interests in exploring mushrooms as a functional food, as a reservoir for development of potent therapeutic products and as a rich nutraceuticals, responsible for their antioxidant, anti-microbial and anti-tumor properties (Barros et al. 2007; Çağlarırmak 2007; Elmastas et al. 2007; Gupta et al. 2018; Ribeiro et al. 2007; Salihović et al. 2019). Several researchers, have documented the therapeutic potential of nutraceutical compounds isolated from mushrooms in cure and prevention of fatal diseases like cancer, hypertension, diabetes, heart diseases and cerebral stroke (Pardeshi and Pardeshi 2009; Wasser and Weis 1999). The investigation of therapeutic and nutraceutical potential of mushrooms gives an idea that they can be future food, which provides high quality protein and minerals (Barreira et al. 2014; Cheung 2013; El Enshasy and Hatti-Kaul 2013; Heleno et al. 2015a; Khatua et al. 2013; Kumar 2015; Ruthes et al. 2016; Singh et al. 2016; Tel-Cayan et al. 2017).

17.3.1 Proteins and Peptides

Proteins are one of the major macronutrients found in a quality food. In the last few decades, researchers have studied the importance of protein, essential amino acids, peptides and their significance for nutrition and health. Particularly, the biological functions of several dietary or bioactive proteins & peptides have been studied in more detail (Walther and Sieber 2011). Proteins and peptides are substantial bioactive nutraceuticals in mushrooms which possess numerous health benefits, like improving the digestion and absorption of nutrients, enhancing immune activity and regulating enzymatic activity (Valverde et al. 2015). The protein and peptides commonly found in mushrooms are ribosome inactivating proteins (RIPs), lectins, laccases, fungal immunomodulatory proteins (FIPs), and ribonucleases (Ko et al. 1995; Munoz et al. 1997; Xu et al. 2011). Among these proteins, lectins are glycoproteins or non-immune proteins have the property of cell agglutination and binds with the carbohydrates of cell surface. It was reported that the lectins isolated from *Clitocybe nebularis*, *Pholiota adiposa*, *Narcissus tazetta*, *Xylaria hypoxylon*, *Russula lepida*, *Russula delica* and *Hericium erinaceum* possess anti-proliferative, immunomodulatory, anti-viral, anti-microbial and anti-tumor activities (Li et al. 2010; Liu et al. 2006; Ooi et al. 2010; Singh et al. 2015; Zhang et al. 2010).

Mushrooms FIPs has been extracted from *Ganoderma lucidium*, *Ganoderma microsporum*, *Flammulina velutipes*, *Volvariella volvacea*, *Antrodia camphorate*, etc., and reported with immunomodulatory activity (Xu et al. 2011). They also prevent the invasion and metastasis of tumour cells and therefore can be used as adjuvants for treating tumour (Lin et al. 2010). Bioactive protein "RIPs" belongs to enzyme class and has been extracted from several mushroom species including *Pleurotus tuberregium*, *Flammulina velutipes*, *Lyophyllum shimeiji*, *Calvatia caelata*, and *Hypsizigus marmoreus* (Lam and Ng 2001; Lin et al. 2010; Ng et al. 2003; Wang and Ng 2001a, b, 2006). They are capable to inactivate the ribosomes by removing one or more adenosine from rRNA and also they help in inhibiting the HIV-1 reverse transcriptase activity and fungal proliferation (Puri et al. 2012). Like RIPs, laccases also belong to the enzyme category, and are considered as a promising candidate in the field of industry and biotechnology. They are majorly isolated from *Pleurotus eryngii*, *Pleurotus ostreatus*, *Tricholoma mongolicum* and *Clitocybe maxima*, and reported for anti-viral and anti-proliferative activity (M EL-Fakharany et al. 2010; Wang and Ng 2006; Zhang et al. 2010). They are known as Green tool/green catalyst in the field of biotechnology and have immense applications in the field of medicine, food, cosmetics, etc. (Agrawal et al. 2018). Ribonucleases, another bioactive protein isolated from mushroom has been documented for their antimicrobial activity against *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Pseudomonas fluorescens* (Alves et al. 2013).

According to Rathore and co-workers (Rathore et al. 2017), the highest content of crude protein has observed in *Auricularia auricular* (360 g/kg dry weight), followed by *Pleurotus ostreatus* (284 g/kg dry weight) and *Lentinus edodes* (228 g/kg dry weight). The protein content from beneficial mushrooms in the past few years are shown in Table 17.1. The higher content of protein have been determined in *Agaricus subrufescens* (50.40 g/100 g dry weight), followed by *Russula cyanoxantha* (49.20 g/100 g dry weight), *Craterellus cornucopioides* (47.21 g/100 g dry weight), *Pleurotus geesteranu* (39.80 g/100 g dry weight), *Pleurotus ostreatus* (28.40 g/100 g dry weight), and *Laccaria amethystea* (29.84 g/100 g dry weight) (Beluhan and Ranogajec 2011; Ikon et al. 2019; Liu et al. 2019, 2012b; Srikram and Supapvanich 2017), whereas the lowest protein content have been reported in *Pleurotus eryngii* (2.09 g/100 g dry weight), followed by *Helvella lacunose* (4.40 g/100 g dry weight), *Boletus regius* (5.22 g/100 g dry weight), *Amanita curtipes* (6.40 g/100 g dry weight) and *Clitocybe subconnexa* (7.42 g/100 g dry weight), respectively (Fernandes et al. 2015; Heleno et al. 2015b; Leal et al. 2013; Reis et al. 2014). The research findings could confirm the anti-tumor, anti-viral and anti-inflammatory activities of proteins isolated from mushrooms (Chatterjee et al. 2017; Lin et al. 2010).

17.3.2 Amino Acids and Vitamins

The essential amino acids are vital for humans as they are not synthesized by the body, therefore they are obtained from the food. Mushrooms are ideal source of essential amino acids (Kıvrak et al. 2014). They contain all essential amino acid along with few non-essential amino acid (Manzi et al. 1999). Free amino acid are leading components of functionally active compounds, contributing for the unique flavors of mushroom (Kalač 2009; Kıvrak et al. 2014). Research findings showed the presence of 18 free amino acids in mushrooms which includes lysine, leucine, isoleucine, tryptophan, threonine, valine, methionine, histidine and phenylalanine from the class of essential amino acids and glycine, tyrosine, arginine, serine, aspartate, alanine, cysteine, glutamate and proline from non-essential amino acid group. The content of major amino acids detected in beneficial mushrooms are shown in Table 17.3. *Boletus edulis*, *Clavulina rugosa*, *Lepista nuda*, *Cantharellus tubaeformis*, *Leucopaxillus giganteus*, *Hydnum repandum*, *Russula rosea* and *Tricholoma saponaceum* showed highest (18 known amino acids) diversity of amino acids, whereas *Inonotus obliquus* showed the least (2 known amino acids) diversity of amino acids (Ayaz et al. 2011). Usually, the number of amino acids in mushroom varies between 14 and 18. Mushrooms, also known as a rich source of vitamins especially riboflavin (B2), niacin (B3), folates (B9) and traces of vitamin A, B1, B5, B12, C, D, and E in mushrooms (Anderson and Fellers 1942; Bernaś et al. 2006; Cardwell et al. 2018; Jaworska et al. 2014).

17.4 Bioactive Components

Polysaccharides are one of the most common but potent compounds extracted from mushrooms. All the polysaccharides present in mushrooms possess b-linked glucose backbone but vary from species to species on the basis of pattern and degree of branching. Most common monosaccharides found in mushrooms are glucose, fructose, xylose, galactose, mannose, trehalose, arabinose, mannitol and rhamnose (Valverde et al. 2015). The few types of polysaccharides detected in mushrooms are homopolysaccharides, heteropolysaccharides (heteroploysaccharides grifloan and lentinan), b-glucans type polysaccharides and Glucan-protein complex, respectively (Lakhanpal 2014). Polysaccharides isolated from mushrooms are well studied for their health benefits and also utilized to develop functional foods.

Lentinan, erothionine, ganoderan, pleuran, calocyban, schizophyllan and agaritine, proteoglycans are well studied polysaccharides, which are derived from *Lentinus edodes*, *Ganoderma lucidium*, *Pleurotus* species, *Calocybe indica*, *Schizophyllum commune* and *Agaricus blazei*, respectively (Badalyan 2014; Kim et al. 2005; Villares et al. 2012). These polysaccharides has been reported with antioxidant, anti-tumor, immunomodulatory, anti-viral, anti-inflammatory, anti-fatigue and anti-carcinogenic activities (Jeong et al. 2012; Kim et al. 2005; Liu et al. 2015;

Table 17.3 Amino acids in different species of mushrooms

Species name	Thr	Val	Met	Ile	Leu	Phe	Lys	His	References
Agaricus abruptibulbus	5.91	4.18	1.62	9.46	–	1.92	–	8.26	Sudheep and Sridhar (2014)
Agaricus bisporus	–	45.74	00.00	–	74.93	82.20	24.44	–	Salihović et al. (2019)
Agaricus bisporus	–	30.95	23.80	–	70.30	77.10	31.90	–	Salihović et al. (2019)
Agaricus subrufescens	11	11.9	33.5	9.8	16.8	10.9	16.6	5.5	Liu et al. (2019)
Amanita caesarea	–	16.00	00.00	–	44.60	48.92	26.00	–	Salihović et al. (2019)
Amanita hemibapha	199.9	–	114.7	184.1	373.0	392.5	241.2	234.8	Sun et al. (2017)
Antrodia camphorate	1.2	–	–	1.1	1.6	0.9	0.8	0.4	Liu et al. (2019)
Astraeus hygrometricus	4.88	5.75	1.67	4.61	1.67	2.91	7.7	2.7	Pavithra et al. (2018)
Boletinus pinetorus	125.3	–	28.2	70.1	145.0	126.6	13.2	75.8	Sun et al. (2017)
Boletus aestivalis	–	16.60	00.00	–	10.60	11.66	85.20	–	Salihović et al. (2019)
Boletus bicolor	119.1	–	19.1	45.8	25.4	40.8	61.8	102.3	Sun et al. (2017)
Boletus craspedius	28.0	–	–	–	–	–	16.5	65.3	Sun et al. (2017)
Boletus griseus	97.0	–	6.2	36.7	47.3	17.2	76.7	103.1	Sun et al. (2017)
Boletus ornatipes	116.0	–	18.2	44.4	86.3	97.3	74.4	125.9	Sun et al. (2017)
Boletus sinicus	140.5	–	–	25.0	30.8	–	171.7	81.6	Sun et al. (2017)
Boletus speciosus	132.3	–	24.7	58.3	106.8	113.9	27.0	100.6	Sun et al. (2017)
Cantharellus cibarius	–	25.30	17.67	–	65.74	72.10	65.80	–	Salihović et al. (2019)
Catathelasma ventricosum	6.07	18.52	10.82	0.22	1.39	2.44	13.42	11.49	Liu et al. (2012b)
Clitocybe maxima	7.24	2.74	–	–	0.44	6.91	0.79	27.34	Liu et al. (2012b)

(continued)

Table 17.3 (continued)

Species name	Thr	Val	Met	Ile	Leu	Phe	Lys	His	References
Craterellus cornucopioides	6.37	0.41	12.74	0.08	17.51	–	8.09	22.07	Liu et al. (2012b)
Dictyophora indusiata	0.9	2.7	0.7	0.7	1.2	0.9	1	0.4	Liu et al. (2019)
Ganoderma amboinense	3.6–4.8	3.5–4.7	33.2–36.3	2.7–3.4	4.2–5.3	2.7–3.8	3.5–3.9	1.3–1.7	Liu et al. (2019)
Hericium erinaceus	3.2	2.9	0.8	2	3.8	2.3	4.1	1.6	Liu et al. (2019)
Laccaria amethystea	12.82	7.99	2.59	–	16.83	7.31	11.97	0.72	Liu et al. (2012b)
Laccaria amethystea	0.49	13.12	10.34	2.20	2.57	–	10.32	–	Liu et al. (2012b)
Lactarius deliciosus	–	5.99	00.00	–	12.79	14.04	7.74	–	Salihović et al. (2019)
Lactarius deliciosus	131.76	122.17	25.41	47.82	109.53	133.61	208.46	278.57	Xu et al. (2019)
Lactarius piperatus	–	1.80	00.00	–	4.40	4.87	2.92	–	Salihović et al. (2019)
Lentinus edodes	10.3	9.6	29.7	7.1	11.7	8.5	10.2	3.8	Liu et al. (2019)
Lycoperdon pyriforme	–	21.72	00.00	–	65.00	71.40	50.60	–	Salihović et al. (2019)
Macrolepiota procera	–	8.42	17.67	–	35.30	38.70	70.60	–	Salihović et al. (2019)
Pholita microsporeo	0.13–0.27	0.7–0.81	1.29–1.76	0.53–0.59	1.17–1.25	0.68–0.83	0.78–0.85	0.31–0.37	Meng et al. (2019)
Pleurotus geesteranu	1.7–1.9	2.4–2.7	0.8–0.8	1.5–1.6	2.1–2.6	1.3–1.3	2.0–2.5	0.8–0.9	Liu et al. (2019)
Pleurotus ostreatus	0.8–1.4	1.6–2.4	0.5–0.8	0.6–1.2	1–1.9	0.6–1.0	0.9–1.8	0.3–0.7	Liu et al. (2019)
Pleurotus ostreatus	–	281.20	00.00	–	137.72	318.70	196.80	–	Salihović et al. (2019)
Pleurotus sajorcaju	0.8–1.5	1.6–2.3	0.4–0.9	0.7–1.3	1.1–2	0.7–1.0	0.9–1.9	0.4–0.7	Liu et al. (2019)
Pleurotus sapidus	0.4	1.8	0.2	0.8	1.4	0.8	0.3	0.4	Liu et al. (2019)
Stropharia rugosoannulata	7.44	0.35	31.94	–	–	–	7.11	2.17	Liu et al. (2012b)
Stropharia rugosoannulata	–	22.96	6.69	0.63	7.61	–	–	0.97	Liu et al. (2012b)

(continued)

Table 17.3 (continued)

Species name	Thr	Val	Met	Ile	Leu	Phe	Lys	His	References
Stropharia rugosoannulata	0.8	1.6	11.6	0.6	1.3	0.6	0.9	0.4	Liu et al. (2019)
Suillus placidus	79.6	–	–	46.3	83.4	65.5	60.5	89.3	Sun et al. (2017)
Termitomyces globulus	6.25	5.31	0.68	10.87	–	2.73	–	5.21	Sudheep and Sridhar (2014)
Termitomyces microcarpus	653.6	–	180.4	689.6	1197.3	785.8	512.1	357.5	Sun et al. (2017)
Tricholoma terreum	125.3	–	24.0	98.0	83.3	87.0	58.8	44.6	Sun et al. (2017)
Tricholomopsis lividipileata	86.9	–	38.6	74.3	118.3	79.1	99.4	34.1	Sun et al. (2017)
Xerocomus	187.2	–	6.0	76.8	160.5	83.7	92.1	109.9	Sun et al. (2017)

Ma et al. 2014; Meng et al. 2016; Rathore et al. 2017). Few polysaccharides have also been discussed in the proximate analysis and mineral content section.

During last few decades researchers are more concerned about oxidative damage because the risk of oxidative species, including free radicals is increasing constantly, resulting from unhealthy habits and pollution exposure. A free radical is known as any unstable molecule which are very reactive and cause oxidative stress to body, resulting in growth of several fatal diseases like cancer, neurodegenerative disease, cardiovascular disease, etc., (Carocho and Ferreira 2013; Gutteridge and Halliwell 2000). An anti-oxidant can stabilize these free radicals and help in preventing the diseases caused by oxidative stress (Carocho and Ferreira 2013; Ferreira et al. 2009, 2015; Painuli et al. 2018, Painuli and Kumar 2016, Semwal and Painuli 2019; Stajic et al. 2013). Although, human body can prevent oxidative stress by endogenous antioxidant defense mechanism, we can also obtain anti-oxidants by inclusion of healthy food in our diet (Ferreira et al. 2009).

In this view, mushrooms are considered to be a rich source of anti-oxidants and have been extensively studied for their antioxidant properties. The antioxidants reported in mushrooms are phenolic acids, tocopherols, terpenes, carotenoids, steroids and ascorbic acid (Ferreira et al. 2009, 2015; Stajic et al. 2013). Alkaloid is one of the important class of phenolic compounds. They possess immense therapeutic properties and have been used from a long back for curing diseases. In past few years mushrooms are reported with significant content of alkaloids, which are further studied for their bioactivity. *Astraeus odoratus*, *Flammulina velutipes*, *Ganoderma sinense*, *Hericium erinaceum*, *Macrolepiotaneo mastoidea*, *Pseudobaeospora pyrifera* are examples of such mushrooms which possess alkaloids with anti-tubercular activity, cytotoxic activity, anti-cholinesterase and anti-mycobacterial activity (Arpha et al. 2012; Kim et al. 2012; Liu et al. 2010; Rhee et al. 2001; Song et al. 2009).

Terpenoids are hydrocarbon formed by the combination of different isoprene units. They are reported for various medicinal and therapeutic activities like anti-malarial, anti-cancer, anti-viral, anti-microbial, anti-inflammatory and anti-cholinesterase (Arpha et al. 2012; Kim et al. 2013; Lee et al. 2011; Liu 1995; Mann et al. 1994; Mothana et al. 2003; Shibata et al. 1998; Wang et al. 2012, 2013a, b). The major terpenoid isolated from mushroom is lanostane, a triterpenes well studied for its anti-cancer activities (Arpha et al. 2012; Kim et al. 2013; Wang et al. 2012, 2013a, b). Ganoderic, lucidenic, ganodermic, ganolucidic, ganoderols, applanoxidic acids and lucidones are terpenoids isolated from *Ganoderma lucidium* which are reported for anticancer treatments (Li et al. 2005). Terpenoids isolated from mushrooms have also been observed to their anti-mycobacterial and anti-candidal activities (Öztürk et al. 2015).

Steroid is an organic compound, resulting from the characteristic arrangement of four cycloalkane rings that are linked with each other. They play an important role in biological systems and are responsible for cell functioning. Steroids have been isolated from different species of mushrooms including *Tomophagus cattienensis*, *Fomes fomentarius*, *Ganoderma lucidum*, *Hypsizigus marmoreus* and *Sarcodon joedes*, respectively (Hien et al. 2013; Liu et al. 2013; Seo et al. 2009; Zang et al. 2013). Steroids isolated from the mushrooms have anti-microbial, cytotoxic, anti-tubercular, anti-complement and anti-viral activities (Itoh et al. 2008; Liu et al. 2013; Niedermeyer et al. 2005; Seo et al. 2009).

Phenolic compounds are the largest group of phytochemicals which are well known for their interesting pharmacological activities. Flavonoids, coumarins, anthocyanin, catechins and phenolic acid, etc., are few examples of phenolic compound. The rich source of these compounds are vegetables, fruits, herbs, seeds, juices, etc. Several mushrooms including *Albatrellus caeruleoporus*, *Boletus pseudocalopus*, *Cortinarius purpurascens*, *Ganoderma colossum*, *Ganoderma pfeifferi*, *Ganoderma fornicatum*, and *Tricholoma oriruben* have been reported with biologically active phenolic compounds (Awadh Ali et al. 2003; Bai et al. 2013; El Dine et al. 2009; Kawagishi et al. 2004; Mothana et al. 2000; Niu et al. 2006; Quang et al. 2006; Song et al. 2009; Venkateswarlu et al. 2002; Yousfi et al. 2009). Current report on antioxidant activity of wild-growing (*Agaricus campestris*, *Boletus edulis*, *Cantharellus cibarius*, *Macrolepiota procera*, *Pleurotus ostreatus*, *Russula alutacea*, and *Russula vesca*) and cultivated (*Agaricus bisporus*, *Pleurotus ostreatus*) mushrooms suggests them as a rich source of phenolics and flavonoids (Buruleanu et al. 2018). The pharmacological activities reported in phenolic compound of mushrooms are anti-cancer, anti-diabetic, anti-inflammatory, anti-microbial activities, etc., (Öztürk et al. 2015). Different biological activities of different compounds isolated from mushrooms are presented in Table 17.4.

Table 17.4 Biological activities of few beneficial mushrooms from different regions

Species name	Bioactivities	References
Agaricus bisporus	Antioxidant, Antimicrobial	Özcan and Ertan (2018)
Agaricus bisporus	Infectious diseases	Soković et al. (2014)
Agaricus bisporus	Diabetic mellitus	Calvo et al. (2016)
Agaricus blazei	Anti-cancer	Taofiq et al. (2019)
Agaricus brasiliensis	Infectious diseases	de Sousa Cardozo et al. (2014)
Agaricus brasiliensis	Cytoprotective	Fang et al. (2016)
Agaricus brasiliensis	Anti-HSV-1, HSV-2	de Sousa Cardozo et al. (2014)
Agrocybe aegerita	Anti-influenza	Ma et al. (2017)
Agrocybe cylindracea	Antioxidant	Rathee et al. (2012)
Amanita rubescens	Antioxidant	Lalotra et al. (2018)
Auricularia auriculajudae	Infectious diseases	Cai et al. (2015)
Auricularia auriculajudae	Hypertension	Ardigò (2017)
Auriporia aurea	Anti-influenza (H1N1)	Krupodorova et al. (2014)
Boletus edulis	Antioxidant, Antimicrobial	Özcan and Ertan (2018)
Boletus edulis	Antioxidant	Lalotra et al. (2018)
Boletus edulis	Antimicrobial	Salihović et al. (2019)
Boletus spp.	Antioxidant	Yuswan et al. (2015)
Cantharellus cibarius	Antioxidant, Antimicrobial	Özcan and Ertan (2018)
Cantharellus cibarius	Antimicrobial	Salihović et al. (2019)
Cordyceps militaris	Bladder, Leukemia Cancers	Patel and Goyal (2012)
Cordyceps sinensis	Bladder, Colon, Leukemia, Liver Cancer	Wang et al. (2016)
Cortinarius caperatus	Antioxidant	Zacchigna (2017)
Craterellus cornucopioides	Antioxidant, Antimicrobial	Özcan and Ertan (2018)
Craterellus cornucopioides	Antioxidant	Palacios et al. (2011)
Craterellus cornucopioides	Antioxidant, Antimicrobial, Cytotoxicity	Kosanić et al. (2019)
Entoloma lividoalbum	Cytoprotective	Lima et al. (2016)
Flammulina velutipes	Anti-influenza	Krupodorova et al. (2014)
Fomes fomentarius	Anti-influenza	Krupodorova et al. (2014)
Fomitopsis pinicola	Antifungal, antitumor	Scaglione (2017)
Ganoderma adspersum	Antimicrobial, Antioxidant	Shomali et al. (2019)
Ganoderma lucidum	Anti-influenza	Krupodorova et al. (2014)
Ganoderma lucidum	Antioxidant, improve hormone production	Scaglione (2017)
Ganoderma lucidum	Virologic and clinical efficacy	Scaglione (2017)
Ganoderma pfeifferi	Anti-HSV-1	Lindequist et al. (2015)

(continued)

Table 17.4 (continued)

Species name	Bioactivities	References
Ganoderma pfeifferi	Anti-influenza	Lindequist et al. (2015)
Geopora arenicola	Antioxidant	Lalotra et al. (2018)
Grifola frondosa	Cytoprotective	Berven et al. (2015)
Grifola frondosa	Bladder, Prostate, Stomach Cancer	Patel and Goyal (2012)
Grifola frondosa	Anti-enterovirus	Zhao et al. (2016)
Hericium erinaceus	Cytoprotective	Cheng et al. (2016)
Hohenbuehelia serotina	Anti-HIV-1	Zhang et al. (2014)
Hydnum repandum	Antioxidant, Antimicrobial	Özcan and Ertan (2018)
Hypsizygus marmoreus	Antioxidant, Anti-inflammatory	Jang et al. (2013)
Inonotus hispidus	Antimicrobial, Antioxidant	Shomali et al. (2019)
Inonotus obliquus	Antioxidant	Rathee et al. (2012)
Inonotus obliquus	Anti-HIV-1	Shibnev et al. (2015)
Inonotus obliquus	Anti-HSV-1	Polkovnikova et al. (2014)
Inonotus obliquus	Anti-influenza (H3N2, H5N6)	Tian et al. (2017)
Lactarius deliciosus	Antioxidant	Xu et al. (2019)
Lentinula edodes	Antioxidant	Chowdhury et al. (2015)
Lentinula edodes	Antioxidant	Olawuyi and Lee (2019)
Lentinula polychrous	Antioxidant	Attarat and Phermthai (2015)
Lentinula squarrosulus	Antioxidant	Attarat and Phermthai (2015)
Lentinus edodes	Anti-influenza	Krupodorova et al. (2014)
Lyophyllum shimeji	Anti-influenza	Krupodorova et al. (2014)
Macrolepiota dolichaula	Cytoprotective	Samanta et al. (2015)
Morchella deliciosa	Antioxidant	Lalotra et al. (2018)
Phellinus baumii	Anti-influenza (H1N1, H5N1,H3N2)	Li et al. (2011)
Pleurotus abalonus	Anti-HIV-1	Li et al. (2011)
Pleurotus eryngii	Breast Cancer	Xue et al. (2015)
Pleurotus eryngii	Cervix, Colon Cancer	Milovanović et al. (2014)
Pleurotus eryngii	Anti-influenza	Krupodorova et al. (2014)
Pleurotus Florida	Antioxidant	Ganeshpurkar et al. (2015)
Pleurotus giganteus	Antioxidant	Phan et al. (2019)
Pleurotus nebrodensis	Cytoprotective	Hai-Yan et al. (2015)
Pleurotus ostreatus	Anti-microbial	Ikon et al. (2019)
Pleurotus tuber-regium	Diabetic mellitus	Wu et al. (2014)
Rozites caperata	Anti-HSV-1	Yan et al. (2015)
Russula chloroides	Antimicrobial, Antioxidant	Shomali et al. (2019)
Sarcodon imbricatus	Antimicrobial, Antioxidant	Shomali et al. (2019)
Schizophyllum commune	Anti-influenza	Krupodorova et al. (2014)
Sparassis crispa	Antioxidant	Lalotra et al. (2018)
Trametes versicolor	Anti-mutagenic, Antioxidant	Milovanovic et al. (2015)
Trametes versicolor	Anti-influenza	Krupodorova et al. (2014)
Tylopilus ballouii	Cytoprotective	Lima et al. (2016)

17.5 Conclusion

Presently, the global production of cultivated mushrooms has exceeded ten million tons and is continuously increasing, with China being the largest producer. More than 2000 mushroom species are safe and eatable. Further, mushrooms can help in boosting the economic growth in a society. Worldwide, both cultivated and wild species of mushrooms are consumed as they possess distinctive and unique taste, texture and smell along with low calorific values and high fibre content. They synthesize active compounds with broad spectrum of biological activities. *In vitro* studies, clinical trials and animal studies validated the traditional knowledge and indicated the immense potential of mushroom-derived compounds and products, for the suppression and treatment of various diseases. The present chapter covers the information on proximate content, proteins, vitamins, minerals, bioactive compounds and potential benefits of medicinal mushrooms. Mushrooms can be consumed as tonics, medicines, nutritional products, etc. and can be used as cosmetics and natural bio-control agents. In view of promising outcomes, additional efforts are required to explore the ability of mushrooms as functional food along with the therapeutic potential. The major tasks comprise the understanding of clinical trials, development of mushroom derived products with standardized protocols, and their sustainable production under appropriate environment.

References

Agrahar-Murugkar D, Subbulakshmi G (2005) Nutritional value of edible wild mushrooms collected from the Khasi hills of Meghalaya. Food Chem 89:599–603

Agrawal DC, Dhanasekaran M (2019) Medicinal mushrooms: recent progress in research and development. Springer, Singapore

Agrawal K, Chaturvedi V, Verma P (2018) Fungal laccase discovered but yet undiscovered. Bioresour Bioprocess 5:4

Ahlawat O, Manikandan K, Singh M (2016) Proximate composition of different mushroom varieties and effect of UV light exposure on vitamin D content in Agaricus bisporus and Volvariella volvacea. Mushroom Res 25:1–8

Alaimo M, Dongarrà G, LA Rosa A, Tamburo E, Vasquez G, Varrica D (2018) Major and trace elements in Boletus aereus and Clitopilus prunulus growing on volcanic and sedimentary soils of Sicily (Italy). Ecotoxicol Environ Saf 157:182–190

Alves MJ, Ferreira IC, Dias J, Teixeira V, Martins A, Pintado M (2013) A review on antifungal activity of mushroom (basidiomycetes) extracts and isolated compounds

Anderson E, Fellers CR (1942) The food value of mushrooms (Agaricus campestris). Proc Am Soc Hortic Sci 41:301–304

Ardigò W (2017) Auricularia auricula-judae and Polyporus umbellatus effectively contrast arterial hypertension: a clinical study. In: Gargano ML, Venturella G (eds) Book of abstracts: the 9th international medicinal mushrooms conference (IMMC9), Palermo

Arpha K, Phosri C, Suwannasai N, Mongkolthanaruk W, Sodngam S (2012) Astraodoric acids A–D: new lanostane triterpenes from edible mushroom Astraeus odoratus and their anti-mycobacterium tuberculosis H37Ra and cytotoxic activity. J Agric Food Chem 60:9834–9841

Árvay J, Hauptvogl M, Šnirc M, Gažová M, Demková L, Bobuľská L, Hrstková M, Bajčan D, Harangozo Ľ, Bilčíková J (2019) Determination of elements in wild edible mushrooms: levels and risk assessment. J Microbiol Biotechnol Food Sci 8:999
Attarat J, Phermthai T (2015) Bioactive compounds in three edible Lentinus mushrooms. Walailak J Sci Technol (WJST) 12:491–504
Awadh Ali NA, Mothana RA, Lesnau A, Pilgrim H, Lindequist U (2003) Antiviral activity of Inonotus hispidus. Fitoterapia 74:483–485
Ayaz FKA, Chuang LT, Torun H, Colak A, Seslia E, Presley J, Smith BR, Glew RH (2011) Fatty acid and amino acid compositions of selected wild-edible mushrooms consumed in Turkey. Int J Food Sci Nutr 62:328–335
Badalyan SM (2014) Potential of mushroom bioactive molecules to develop healthcare biotech products. Proceedings of the 8th International Conference on mushroom biology and mushroom products (ICMBMP8), 2014. Yugantar Prakashan Pvt, Ltd New Delhi, pp 373–378
Bai M-S, Wang C, Zong S-C, Lei M, Gao J-M (2013) Antioxidant polyketide phenolic metabolites from the edible mushroom Cortinarius purpurascens. Food Chem 141:3424–3427
Barreira JC, Oliveira MBP, Ferreira IC (2014) Development of a novel methodology for the analysis of ergosterol in mushrooms. Food Anal Methods 7:217–223
Barros L, Calhelha RC, Vaz JA, Ferreira IC, Baptista P, Estevinho LM (2007) Antimicrobial activity and bioactive compounds of Portuguese wild edible mushrooms methanolic extracts. Eur Food Res Technol 225:151–156
Barros L, Cruz T, Baptista P, Estevinho LM, Ferreira IC (2008) Wild and commercial mushrooms as source of nutrients and nutraceuticals. Food Chem Toxicol 46:2742–2747
Beelman RB, Kalaras MD, Richie JR, J. P. (2019) Micronutrients and bioactive compounds in mushrooms: a recipe for healthy aging? Nutr Today 54:16–22
Beluhan S, Ranogajec A (2011) Chemical composition and non-volatile components of Croatian wild edible mushrooms. Food Chem 124:1076–1082
Bengu AS (2019) Some elements and fatty acid profiles of three different edible mushrooms from Tokat province in Turkey. Prog Nutr 21:189–193
Bernaś E, Jaworska G, Lisiewska Z (2006) Edible mushrooms as a source of valuable nutritive constituents. Acta Sci Pol Technol Aliment 5:5–20
Berven L, Karppinen P, Hetland G, Samuelsen ABC (2015) The polar high molecular weight fraction of the Agaricus blazei Murill extract, AndoSan™, reduces the activity of the tumor-associated protease, legumain, in RAW 264.7 cells. J Med Food 18:429–438
Beulah GH, Margret AA, Nelson J (2013) Marvelous medicinal mushrooms
Buruleanu LC, Radulescu C, Georgescu AA, Danet FA, Olteanu RL, Nicolescu CM, Dulama ID (2018) Statistical characterization of the phytochemical characteristics of edible mushroom extracts. Anal Lett 51:1039–1059
Çağlarirmak N (2007) The nutrients of exotic mushrooms (Lentinula edodes and Pleurotus species) and an estimated approach to the volatile compounds. Food Chem 105:1188–1194
Cai M, Lin Y, Luo Y-L, Liang H-H, Sun P (2015) Extraction, antimicrobial, and antioxidant activities of crude polysaccharides from the wood ear medicinal mushroom Auricularia auricula-judae (higher basidiomycetes). Int J Med Mushrooms 17:591–600
Calvo MS, Mehrotra A, Beelman RB, Nadkarni G, Wang L, Cai W, Goh BC, Kalaras MD, Uribarri J (2016) A retrospective study in adults with metabolic syndrome: diabetic risk factor response to daily consumption of Agaricus bisporus (white button mushrooms). Plant Foods Hum Nutr 71:245–251
Cardwell G, Bornman JF, James AP, Black LJ (2018) A review of mushrooms as a potential source of dietary vitamin D. Nutrients 10:1498
Carocho M, Ferreira IC (2013) A review on antioxidants, prooxidants and related controversy: natural and synthetic compounds, screening and analysis methodologies and future perspectives. Food Chem Toxicol 51:15–25
Chang S, Zhao M (2002) Products of medicinal mushrooms as a good source of dietary supplements. Edible Fungi China 21:5–6

Chatterjee S, Sarma MK, Deb U, Steinhauser G, Walther C, Gupta DK (2017) Mushrooms: from nutrition to mycoremediation. Environ Sci Pollut Res 24:19480–19493

Cheng J-H, Tsai C-L, Lien Y-Y, Lee M-S, Sheu S-C (2016) High molecular weight of polysaccharides from Hericium erinaceus against amyloid beta-induced neurotoxicity. BMC Complement Altern Med 16:170

Cheung PC (2013) Mini-review on edible mushrooms as source of dietary fiber: preparation and health benefits. Food Sci Human Wellness 2:162–166

Chowdhury MMH, Kubra K, Ahmed SR (2015) Screening of antimicrobial, antioxidant properties and bioactive compounds of some edible mushrooms cultivated in Bangladesh. Ann Clin Microbiol Antimicrob 14:8

Cohen N, Cohen J, Asatiani MD, Varshney VK, Yu H-T, Yang Y-C, Li Y-H, Mau J-L, Wasser SP (2014) Chemical composition and nutritional and medicinal value of fruit bodies and submerged cultured mycelia of culinary-medicinal higher Basidiomycetes mushrooms. Int J Med Mushrooms 16:273–291

De Sousa Cardozo FTG, Camelini CM, Leal PC, Kratz JM, Nunes RJ, De Mendonça MM, Simões CMO (2014) Antiherpetic mechanism of a sulfated derivative of Agaricus brasiliensis fruiting bodies polysaccharide. Intervirology 57:375–383

EL Dine RS, EL Halawany AM, Ma C-M, Hattori M (2009) Inhibition of the dimerization and active site of HIV-1 protease by secondary metabolites from the Vietnamese mushroom Ganoderma colossum. J Nat Prod 72:2019–2023

EL Enshasy HA, Hatti-Kaul R (2013) Mushroom immunomodulators: unique molecules with unlimited applications. Trends Biotechnol 31:668–677

El-Fakharany EM, Haroun BM, Ng T, Redwan ERM (2010) Oyster mushroom laccase inhibits its hepatitis C virus entry into peripheral blood cells and hepatoma cells. Protein Pept Lett 17:1031–1039

Elkhateeb WA, Daba GM, Thomas PW, Wen T-C (2019) Medicinal mushrooms as a new source of natural therapeutic bioactive compounds. Egypt Pharm J 18:88–101

Elmastas M, Isildak O, Turkekul I, Temur N (2007) Determination of antioxidant activity and antioxidant compounds in wild edible mushrooms. J Food Compos Anal 20:337–345

Fang L, Zhang Y, Xie J, Wang L, Zhang H, Wei W, Li Y (2016) Royal sun medicinal mushroom, Agaricus brasiliensis (Agaricomycetidae), derived polysaccharides exert immunomodulatory activities in vitro and in vivo. Int J Med Mushrooms 18:123–132

Fernandes Â, Barreira JC, Antonio AL, Oliveira MBP, Martins A, Ferreira IC (2014) Feasibility of electron-beam irradiation to preserve wild dried mushrooms: effects on chemical composition and antioxidant activity. Innovative Food Sci Emerg Technol 22:158–166

Fernandes Â, Barreira JC, Antonio AL, Rafalski A, Oliveira MBP, Martins A, Ferreira IC (2015) How does electron beam irradiation dose affect the chemical and antioxidant profiles of wild dried Amanita mushrooms? Food Chem 182:309–315

Ferreira IC, Barros L, Abreu R (2009) Antioxidants in wild mushrooms. Curr Med Chem 16:1543–1560

Ferreira IC, Heleno SA, Reis FS, Stojkovic D, Queiroz MJR, Vasconcelos MH, Sokovic M (2015) Chemical features of Ganoderma polysaccharides with antioxidant, antitumor and antimicrobial activities. Phytochemistry 114:38–55

Gaglarirmak N (2011) Chemical composition and nutrition value of dried cultivated culinary-medicinal mushrooms from Turkey. Int J Med Mushrooms 13:351–356

Ganeshpurkar A, Pardhi P, Bhadoriya SS, Jain N, Rai G, Jain AP (2015) Antioxidant potential of white oyster culinary-medicinal mushroom, Pleurotus Florida (higher basidiomycetes). Int J Med Mushrooms 17:491–498

Grangeia C, Heleno SA, Barros L, Martins A, Ferreira IC (2011) Effects of trophism on nutritional and nutraceutical potential of wild edible mushrooms. Food Res Int 44:1029–1035

Gupta S, Summuna B, Gupta M, Annepu SK (2018) Edible mushrooms: cultivation, bioactive molecules, and health benefits. Bioactive Mol food:1–33

Gutteridge JM, Halliwell B (2000) Free radicals and antioxidants in the year 2000: a historical look to the future. Ann N Y Acad Sci 899:136–147
Guzmán G (2015) New studies on hallucinogenic mushrooms: history, diversity, and applications in psychiatry. Int J Med Mushrooms 17:1019–1029
Hai-Yan C, Chang-Lu W, Yu-Rong W, Zhen-Jing L, Mian-Hua C, Feng-Juan L, Yan-Ping S (2015) Pleurotus nebrodensis polysaccharide (PN-S) enhances the immunity of immunosuppressed mice. Chin J Nat Med 13:760–766
Heleno SA, Stojković D, Barros L, Glamočlija J, Soković M, Martins A, Queiroz MJR, Ferreira IC (2013) A comparative study of chemical composition, antioxidant and antimicrobial properties of Morchella esculenta (L.) Pers. from Portugal and Serbia. Food Res Int 51:236–243
Heleno SA, Barros L, Martins A, Morales P, Fernández-Ruiz V, Glamoclija J, Sokovic M, Ferreira IC (2015a) Nutritional value, bioactive compounds, antimicrobial activity and bioaccessibility studies with wild edible mushrooms. LWT-Food Sci Technol 63:799–806
Heleno SA, Barros L, Martins A, Queiroz MJR, Morales P, Fernández-Ruiz V, Ferreira IC (2015b) Chemical composition, antioxidant activity and bioaccessibility studies in phenolic extracts of two Hericium wild edible species. LWT-Food Sci Technol 63:475–481
Heleno SA, Ferreira RC, Antonio AL, Queiroz M-JR, Barros L, Ferreira IC (2015c) Nutritional value, bioactive compounds and antioxidant properties of three edible mushrooms from Poland. Food Biosci 11:48–55
Hien BTT, Tham LX, Quang DN (2013) Cattienoids A–C, three novel steroids from the mushroom Tomophagus cattienensis. Fitoterapia 91:125–127
Hobbs C (2002) Medicinal mushrooms: an exploration of tradition, healing, and culture. Botanica Press, Summertown, TN
Ikon G, Udobre E, Etang U, Ekanemesang U, Ebana R, Edet U (2019) Phytochemical screening, proximate composition and antibacterial activity of oyster mushroom, Pleurotus ostreatus collected from Etim Ekpo in Akwa Ibom state, Nigeria. Asian Food Sci J 6:1–10
Isabel Cfr Ferreira ÂF, Heleno SA (2017) Chemical, nutritional, and bioactive potential of mushrooms. In: Edible and medicinal mushrooms: technology and applications, pp 455–501
Itoh H, Ito H, Hibasami H (2008) Blazein of a new steroid isolated from Agaricus blazei Murrill (himematsutake) induces cell death and morphological change indicative of apoptotic chromatin condensation in human lung cancer LU99 and stomach cancer KATO III cells. Oncol Rep 20:1359–1361
Jang M-J, Lee Y-H, Ju Y-C, Kim S-M, Koo H-M (2013) Effect of color of light emitting diode on development of fruit body in Hypsizygus marmoreus. Mycobiology 41:63–66
Jaworska G, Pogoń K, Bernaś E, Skrzypczak A, Kapusta I (2014) Vitamins, phenolics and antioxidant activity of culinary prepared Suillus luteus (L.) Roussel mushroom. LWT-Food Sci Technol 59:701–706
Jeong SC, Koyyalamudi SR, Jeong YT, Song CH, Pang G (2012) Macrophage immunomodulating and antitumor activities of polysaccharides isolated from Agaricus bisporus white button mushrooms. J Med Food 15:58–65
Kalač P (2009) Chemical composition and nutritional value of European species of wild growing mushrooms: a review. Food Chem 113:9–16
Kalač P (2013) A review of chemical composition and nutritional value of wild-growing and cultivated mushrooms. J Sci Food Agric 93:209–218
Kawagishi H, Tonomura Y, Yoshida H, Sakai S, Inoue S (2004) Orirubenones A, B and C, novel hyaluronan-degradation inhibitors from the mushroom Tricholoma orirubens. Tetrahedron 60:7049–7052
Khatua S, Paul S, Acharya K (2013) Mushroom as the potential source of new generation of antioxidant: a review. Res J Pharm Technol 6:3
Khatun S, Islam A, Cakilcioglu U, Chatterje NC (2012) Research on mushroom as a potential source of nutraceuticals: a review on Indian perspective. Am J Exp Agric 2:47
Kim Y-W, Kim K-H, Choi H-J, Lee D-S (2005) Anti-diabetic activity of β-glucans and their enzymatically hydrolyzed oligosaccharides from Agaricus blazei. Biotechnol Lett 27:483–487

Kim M-Y, Seguin P, Ahn J-K, Kim J-J, Chun S-C, Kim E-H, Seo S-H, Kang E-Y, Kim S-L, Park Y-J (2008) Phenolic compound concentration and antioxidant activities of edible and medicinal mushrooms from Korea. J Agric Food Chem 56:7265–7270
Kim KH, Noh HJ, Choi SU, Lee KR (2012) Isohericenone, a new cytotoxic isoindolinone alkaloid from Hericium erinaceum. J Antibiot 65:575
Kim KH, Moon E, Choi SU, Kim SY, Lee KR (2013) Lanostane triterpenoids from the mushroom Naematoloma fasciculare. J Nat Prod 76:845–851
Kivrak İ, Kivrak Ş, Harmandar M (2014) Free amino acid profiling in the giant puffball mushroom (Calvatia gigantea) using UPLC–MS/MS. Food Chem 158:88–92
Ko JL, Hsu CI, Lin RH, Kao CL, Lin JY (1995) A new fungal immunomodulatory protein, FIP-fve isolated from the edible mushroom, Flammulina velutipes and its complete amino acid sequence. Eur J Biochem 228:244–249
Kosanić M, Ranković B, Stanojković T, Radović-Jakovljević M, Ćirić A, Grujičić D, Milošević-Djordjević O (2019) Craterellus cornucopioides edible mushroom as source of biologically active compounds. Nat Prod Commun 14:1934578X19843610
Krupodorova T, Rybalko S, Barshteyn V (2014) Antiviral activity of Basidiomycete mycelia against influenza type a (serotype H1N1) and herpes simplex virus type 2 in cell culture. Virol Sin 29:284–290
Kumar K (2015) Role of edible mushrooms as functional foods—a review. South Asian J Food Technol Environ 1:211–218
Lakhanpal T (2014) Mushroom biodiversity in India: prospects and potential. Proceedings of the 8th International Conference on Mushroom Biology and Mushroom Products (ICMBMP8), 2014, pp 7–16
Lalotra P, Bala P, Kumar S, Sharma Y (2018) Biochemical characterization of some wild edible mushrooms from Jammu and Kashmir. Proc Natl Acad Sci India Sec B Biol Sci 88:539–545
Lam S, Ng T (2001) First simultaneous isolation of a ribosome inactivating protein and an antifungal protein from a mushroom (Lyophyllum shimeji) together with evidence for synergism of their antifungal effects. Arch Biochem Biophys 393:271–280
Leal AR, Barros L, Barreira JC, Sousa MJ, Martins A, Santos-Buelga C, Ferreira IC (2013) Portuguese wild mushrooms at the "pharma–nutrition" interface: nutritional characterization and antioxidant properties. Food Res Int 50:1–9
Lee I, Ahn B, Choi J, Hattori M, Min B, Bae K (2011) Selective cholinesterase inhibition by lanostane triterpenes from fruiting bodies of Ganoderma lucidum. Bioorg Med Chem Lett 21:6603–6607
Li C-H, Chen P-Y, Chang U-M, Kan L-S, Fang W-H, Tsai K-S, Lin S-B (2005) Ganoderic acid X, a lanostanoid triterpene, inhibits topoisomerases and induces apoptosis of cancer cells. Life Sci 77:252–265
Li Y, Zhang G, Ng TB, Wang H (2010) A novel lectin with antiproliferative and HIV-1 reverse transcriptase inhibitory activities from dried fruiting bodies of the monkey head mushroom Hericium erinaceum. Biomed Res Int 2010:716515
Li N, Li L, Fang JC, Wong JH, Ng TB, Jiang Y, Wang CR, Zhang NY, Wen TY, Qu LY (2011) Isolation and identification of a novel polysaccharide–peptide complex with antioxidant, anti-proliferative and hypoglycaemic activities from the abalone mushroom. Biosci Rep 32:221–228
Lima AT, Santos MN, DE Souza LA, Pinheiro TS, Paiva AA, Dore CM, Costa MS, Santos ND, Baseia YG, Araújo RM (2016) Chemical characteristics of a heteropolysaccharide from Tylopilus ballouii mushroom and its antioxidant and anti-inflammatory activities. Carbohydr Polym 144:400–409
Lin C-H, Sheu G-T, Lin Y-W, Yeh C-S, Huang Y-H, Lai Y-C, Chang J-G, Ko J-L (2010) A new immunomodulatory protein from Ganoderma microsporum inhibits epidermal growth factor mediated migration and invasion in A549 lung cancer cells. Process Biochem 45:1537–1542
Lindequist U, Jülich W-D, Witt S (2015) Ganoderma pfeifferi–a European relative of Ganoderma lucidum. Phytochemistry 114:102–108
Liu J (1995) Pharmacology of oleanolic acid and ursolic acid. J Ethnopharmacol 49:57–68

Liu Q, Wang H, Ng T (2006) First report of a xylose-specific lectin with potent hemagglutinating, antiproliferative and anti-mitogenic activities from a wild ascomycete mushroom. Biochim Biophys Acta Gen Subj 1760:1914–1919
Liu C, Zhao F, Chen R (2010) A novel alkaloid from the fruiting bodies of Ganoderma sinense Zhao, Xu et Zhang. Chin Chem Lett 21:197–199
Liu H, Zhang J, Li T, Shi Y, Wang Y (2012a) Mineral element levels in wild edible mushrooms from Yunnan, China. Biol Trace Elem Res 147:341–345
Liu Y-T, Sun J, Luo Z-Y, Rao S-Q, Su Y-J, Xu R-R, Yang Y-J (2012b) Chemical composition of five wild edible mushrooms collected from Southwest China and their antihyperglycemic and antioxidant activity. Food Chem Toxicol 50:1238–1244
Liu H-W, Hu L, Zhang A-L, Gao J-M (2013) Steroids and phenolic constituents from the fruiting bodies of the basidiomycete Sarcodon joedes. Nat Prod Res 27:80–84
Liu J, Du C, Wang Y, Yu Z (2015) Anti-fatigue activities of polysaccharides extracted from Hericium erinaceus. Exp Ther Med 9:483–487
Liu D, Chen Y-Q, Xiao X-W, Zhong R-T, Yang C-F, Liu B, Zhao C (2019) Nutrient properties and nuclear magnetic resonance-based metabonomic analysis of macrofungi. Foods 8:397
Ma G, Yang W, Mariga AM, Fang Y, Ma N, Pei F, Hu Q (2014) Purification, characterization and antitumor activity of polysaccharides from Pleurotus eryngii residue. Carbohydr Polym 114:297–305
Ma L-B, Xu B-Y, Huang M, Sun L-H, Yang Q, Chen Y-J, Yin Y-L, He Q-G, Sun H (2017) Adjuvant effects mediated by the carbohydrate recognition domain of Agrocybe aegerita lectin interacting with avian influenza H 9 N 2 viral surface glycosylated proteins. J Zhejiang Univ Sci B 18:653–661
Mallikarjuna S, Ranjini A, Haware DJ, Vijayalakshmi M, Shashirekha M, Rajarathnam S (2012) Mineral composition of four edible mushrooms. J Chem 2013:1–5
Mann J, Davidson RS, Hobbs JB, Banthorpe D, Harborne JB (1994) Natural products: their chemistry and biological significance. Longman Scientific & Technical
Manzi P, Gambelli L, Marconi S, Vivanti V, Pizzoferrato L (1999) Nutrients in edible mushrooms: an inter-species comparative study. Food Chem 65:477–482
Meng X, Liang H, Luo L (2016) Antitumor polysaccharides from mushrooms: a review on the structural characteristics, antitumor mechanisms and immunomodulating activities. Carbohydr Res 424:30–41
Meng L, Fu Y, Li D, Sun X, Chen Y, Li X, Xu S, Li X, Li C, Song B (2019) Effects of corn stalk cultivation substrate on the growth of the slippery mushroom (Pholiota microspora). RSC Adv 9:5347–5353
Milovanović I, Stajić M, Ćilerdžić J, Stanojković T, Knežević A, Vukojević J (2014) Antioxidant, antifungal and anticancer activities of se-enriched Pleurotus spp. mycelium extracts. Arch Biol Sci 66:1379–1388
Milovanovic IN, Stanojkovic TP, Stajic MM, Brceskic ID, Knezevic AZ, Cilerdzic JLJ, Vukojevic JB (2015) Effect of selenium enrichment of Lenzites betulinus and Trametes hirsuta mycelia on antioxidant, antifungal and cytostatics potential. Curr Pharm Biotechnol 16:920–926
Mothana RA, Jansen R, Jülich W-D, Lindequist U (2000) Ganomycins A and B, new antimicrobial farnesyl hydroquinones from the basidiomycete Ganoderma pfeifferi. J Nat Prod 63:416–418
Mothana R, Ali NA, Jansen R, Wegner U, Mentel R, Lindequist U (2003) Antiviral lanostanoid triterpenes from the fungus Ganoderma pfeifferi. Fitoterapia 74:177–180
Munoz C, Guillen F, Martinez A, Martinez M (1997) Induction and characterization of laccase in the ligninolytic fungus Pleurotus eryngii. Curr Microbiol 34:1–5
Ng TB, Lam YW, Wang H (2003) Calcaelin, a new protein with translation-inhibiting, antiproliferative and antimitogenic activities from the mosaic puffball mushroom Calvatia caelata. Planta Med 69:212–217
Niedermeyer TH, Lindequist U, Mentel R, Gördes D, Schmidt E, Thurow K, Lalk M (2005) Antiviral Terpenoid constituents of Ganoderma p feifferi. J Nat Prod 68:1728–1731

Niu X-M, Li S-H, Sun H-D, Che C-T (2006) Prenylated Phenolics from Ganoderma f ornicatum. J Nat Prod 69:1364–1365

Okhuoya J, Akpaja E, Osemwegie O, Oghenekaro A, Ihayere C (2010) Nigerian mushrooms: underutilized non-wood forest resources. J Appl Sci Environ Manag 14

Olawuyi IF, Lee WY (2019) Quality and antioxidant properties of functional rice muffins enriched with shiitake mushroom and carrot pomace. Int J Food Sci Technol 54:2321–2328

Ooi LS, Ho W-S, Ngai KL, Tian L, Chan PK, Sun SS, Ooi VE (2010) Narcissus tazetta lectin shows strong inhibitory effects against respiratory syncytial virus, influenza A (H1N1, H3N2, H5N1) and B viruses. J Biosci 35:95–103

Ouzouni PK, Petridis D, Koller W-D, Riganakos KA (2009) Nutritional value and metal content of wild edible mushrooms collected from West Macedonia and Epirus, Greece. Food Chem 115:1575–1580

Özcan Ö, Ertan F (2018) Beta-glucan content, antioxidant and antimicrobial activities of some edible mushroom species. Food Sci Technol 6:47–55

Öztürk M, Tel-Çayan G, Muhammad A, Terzioğlu P, Duru ME (2015) Mushrooms: a source of exciting bioactive compounds. In: Studies in natural products chemistry. Elsevier

Painuli S, Kumar N (2016) Prospects in the development of natural radioprotective therapeutics with anti-cancer properties from the plants of Uttarakhand region of India. J Ayurveda Integr Med 7:62–68

Painuli S, Joshi S, Bhardwaj A, Meena RC, Misra K, Rai N, Kumar N (2018) In vitro antioxidant and anticancer activities of leaf extracts of Rhododendron arboreum and Rhododendron campanulatum from Uttarakhand region of India. Pharmacogn Mag 14:294

Palacios I, Lozano M, Moro C, D'arrigo M, Rostagno M, Martínez J, García-Lafuente A, Guillamón E, Villares A (2011) Antioxidant properties of phenolic compounds occurring in edible mushrooms. Food Chem 128:674–678

Pardeshi B, Pardeshi P (2009) The edible medicinal mushrooms as supportive natural nutrients: study of nonvolatile mineral contents of some edible medicinal mushrooms from India; eastern remedies for modern western maladies. Proceedings of the 5~(th) international medicinal mushroom conference, 2009

Patel S, Goyal A (2012) Recent developments in mushrooms as anti-cancer therapeutics: a review. 3 Biotech 2:1–15

Pavithra M, Sridhar KR, Greeshma AA (2018) Nutritional quality attributes of edible gasteroid wild mushroom Astraeus hygrometricus. In: Fungi and their role in sustainable development: current perspectives. Springer, Singapore

Pereira E, Barros L, Martins A, Ferreira IC (2012) Towards chemical and nutritional inventory of Portuguese wild edible mushrooms in different habitats. Food Chem 130:394–403

Phan C-W, Wang J-K, Tan EY-Y, Tan Y-S, Sathiya Seelan JS, Cheah S-C, Vikineswary S (2019) Giant oyster mushroom, Pleurotus giganteus (Agaricomycetes): current status of the cultivation methods, chemical composition, biological, and health-promoting properties. Food Rev Int 35:324–341

Polkovnikova M, Nosik N, Garaev T, Kondrashina N, Finogenova M, Shibnev V (2014) A study of the antiherpetic activity of the chaga mushroom (Inonotus obliquus) extracts in the Vero cells infected with the herpes simplex virus. Vopr Virusol 59:45–48

Puri M, Kaur I, Perugini MA, Gupta RC (2012) Ribosome-inactivating proteins: current status and biomedical applications. Drug Discov Today 17:774–783

Quang DN, Hashimoto T, Arakawa Y, Kohchi C, Nishizawa T, Soma G-I, Asakawa Y (2006) Grifolin derivatives from Albatrellus caeruleoporus, new inhibitors of nitric oxide production in RAW 264.7 cells. Bioorg Med Chem 14:164–168

Rathee S, Rathee D, Rathee D, Kumar V, Rathee P (2012) Mushrooms as therapeutic agents. Rev Bras 22:459–474

Rathore H, Prasad S, Sharma S (2017) Mushroom nutraceuticals for improved nutrition and better human health: a review. PharmaNutrition 5:35–46

Reis FS, Barros L, Martins A, Ferreira IC (2012) Chemical composition and nutritional value of the most widely appreciated cultivated mushrooms: an inter-species comparative study. Food Chem Toxicol 50:191–197

Reis FS, Barros L, Sousa MJ, Martins A, Ferreira IC (2014) Analytical methods applied to the chemical characterization and antioxidant properties of three wild edible mushroom species from Northeastern Portugal. Food Anal Methods 7:645–652

Rhee IK, VAN DE Meent M, Ingkaninan K, Verpoorte R (2001) Screening for acetylcholinesterase inhibitors from Amaryllidaceae using silica gel thin-layer chromatography in combination with bioactivity staining. J Chromatogr A 915:217–223

Ribeiro B, Valentão P, Baptista P, Seabra RM, Andrade PB (2007) Phenolic compounds, organic acids profiles and antioxidative properties of beefsteak fungus (Fistulina hepatica). Food Chem Toxicol 45:1805–1813

Rubio C, Martínez C, Paz S, Gutiérrez AJ, González-Weller D, Revert C, Burgos A, Hardisson A (2018) Trace element and toxic metal intake from the consumption of canned mushrooms marketed in Spain. Environ Monit Assess 190:237

Ruthes AC, Smiderle FR, Iacomini M (2016) Mushroom heteropolysaccharides: a review on their sources, structure and biological effects. Carbohydr Polym 136:358–375

Salihović M, Šapčanin A, Pehlić E, Uzunović A, Špirtović-Halilović S, Huremovićd M (2019) Amino acids composition and antioxidant activity of selected mushrooms from Bosnia and Herzegovina. Kemija u industriji: Časopis kemičara i kemijskih inženjera Hrvatske 68:97–103

Samanta S, Nandi AK, Sen IK, Maity P, Pattanayak M, Devi KSP, Khatua S, Maiti TK, Acharya K, Islam SS (2015) Studies on antioxidative and immunostimulating fucogalactan of the edible mushroom Macrolepiota dolichaula. Carbohydr Res 413:22–29

Scaglione GAW, Maiorana A, Prestileo T (2017) The M.O.P. therapy in HPV-related diseases of the female and male genital tract. A prospective observation clinical study. In: Gargano ML, Venturella G (eds) Book of abstracts: the 9th international medicinal mushrooms conference (IMMC9), Palermo

Semwal P, Painuli S (2019) Antioxidant, antimicrobial, and GC-MS profiling of Saussurea obvallata (Brahma Kamal) from Uttarakhand Himalaya. Clin Phytosci 5:12

Seo HW, Hung TM, Na M, Jung HJ, Kim JC, Choi JS, Kim JH, Lee H-K, Lee I, Bae K (2009) Steroids and triterpenes from the fruit bodies of Ganoderma lucidum and their anti-complement activity. Arch Pharm Res 32:1573

Shibata H, Irie A, Morita Y (1998) New antibacterial diterpenoids from the Sarcodon scabrosus fungus. Biosci Biotechnol Biochem 62:2450–2452

Shibnev V, Garaev T, Finogenova M, Kalnina L, Nosik D (2015) Antiviral activity of aqueous extracts of the birch fungus Inonotus obliquus on the human immunodeficiency virus. Vopr Virusol 60:35–38

Shomali N, Onar O, Alkan T, Demirtaş N, Akata I, Yildirim Ö (2019) Investigation of the polyphenol composition, biological activities, and detoxification properties of some medicinal mushrooms from Turkey. Turk J Pharm Sci 16:155–160

Singh SS, Wang H, Chan YS, Pan W, Dan X, Yin CM, Akkouh O, Ng TB (2015) Lectins from edible mushrooms. Molecules 20:446–469

Singh J, Sindhu S, Sindhu A, Yadav A (2016) Development and evaluation of value added biscuits from dehydrated shiitake (Lentinus edodes) mushroom. Int J Curr Res 8:27155–27159

Siwulski M, Rzymski P, Budka A, Kalač P, Budzyńska S, Dawidowicz L, Hajduk E, Kozak L, Budzulak J, Sobieralski K (2019) The effect of different substrates on the growth of six cultivated mushroom species and composition of macro and trace elements in their fruiting bodies. Eur Food Res Technol 245:419–431

Soković M, Ćirić A, Glamočlija J, Nikolić M, VAN Griensven L (2014) Agaricus blazei hot water extract shows anti quorum sensing activity in the nosocomial human pathogen Pseudomonas aeruginosa. Molecules 19:4189–4199

Song J, Manir MM, Moon SS (2009) Cytotoxic grifolin derivatives isolated from the wild mushroom Boletus pseudocalopus (Basidiomycetes). Chem Biodivers 6:1435–1442

Srikram AS, Supapvanich S (2017) Proximate compositions and bioactive compounds of edible wild andcultivated mushrooms from Northeast Thailand. Agric Nat Resour 50:432–436
Stajic M, Vukojevic J, Knezevic A, Duletic Lausevic S, Milovanovic I (2013) Antioxidant protective effects of mushroom metabolites. Curr Top Med Chem 13:2660–2676
Stojković D, Reis FS, Barros L, Glamočlija J, Ćirić A, Van Griensven LJ, Soković M, Ferreira IC (2013) Nutrients and non-nutrients composition and bioactivity of wild and cultivated Coprinus comatus (OF Müll.) Pers. Food Chem Toxicol 59:289–296
Stojković DS, Barros L, Calhelha RC, Glamočlija J, Ćirić A, VAN Griensven LJ, Soković M, Ferreira IC (2014) A detailed comparative study between chemical and bioactive properties of Ganoderma lucidum from different origins. Int J Food Sci Nutr 65:42–47
Sudheep NM, Sridhar KR (2014) Nutritional composition of two wild mushrooms consumed by the tribals of the Western Ghats of India. Mycology 5:64–72
Sun L, Liu Q, Bao C, Fan J (2017) Comparison of free total amino acid compositions and their functional classifications in 13 wild edible mushrooms. Molecules 22:350
Taofiq O, Rodrigues F, Barros L, Peralta RM, Barreiro MF, Ferreira IC, Oliveira MBP (2019) Agaricus blazei Murrill from Brazil: an ingredient for nutraceutical and cosmeceutical applications. Food Funct 10:565–572
Tel-Cayan G, Ozturk M, Duru ME, Turkoglu A (2017) Fatty acid profiles in wild mushroom species from Anatolia. Chem Nat Compd 53:351–353
Thatoi H, Singdevsachan SK (2014) Diversity, nutritional composition and medicinal potential of Indian mushrooms: a review. Afr J Biotechnol 13:523–545
Tian J, Hu X, Liu D, Wu H, Qu L (2017) Identification of Inonotus obliquus polysaccharide with broad-spectrum antiviral activity against multi-feline viruses. Int J Biol Macromol 95:160–167
Valverde ME, Hernández-Pérez T, Paredes-López O (2015) Edible mushrooms: improving human health and promoting quality life. Int J Microbiol 2015:1–14
Vaz JA, Barros L, Martins A, Santos-Buelga C, Vasconcelos MH, Ferreira IC (2011) Chemical composition of wild edible mushrooms and antioxidant properties of their water soluble polysaccharidic and ethanolic fractions. Food Chem 126:610–616
Venkateswarlu S, Ramachandra M, Sethuramu K, Subbaraju GV (2002) Synthesis and antioxidant activity of hispolon, a yellow pigment from Inonotus hispidius
Vieira V, Barros L, Martins A, Ferreira I (2014) Expanding current knowledge on the chemical composition and antioxidant activity of the genus Lactarius. Molecules 19:20650–20663
Villares A, Mateo-Vivaracho L, Guillamón E (2012) Structural features and healthy properties of polysaccharides occurring in mushrooms. Agriculture 2:452–471
Walther B, Sieber R (2011) Bioactive proteins and peptides in foods. Int J Vitam Nutr Res 81:181
Wang H, Ng T (2001a) Isolation of pleuturegin, a novel ribosome-inactivating protein from fresh sclerotia of the edible mushroom Pleurotus tuber-regium. Biochem Biophys Res Commun 288:718–721
Wang H, Ng TB (2001b) Isolation and characterization of velutin, a novel low-molecular-weight ribosome-inactivating protein from winter mushroom (Flammulina velutipes) fruiting bodies. Life Sci 68:2151–2158
Wang H, Ng T (2006) Purification of a laccase from fruiting bodies of the mushroom Pleurotus eryngii. Appl Microbiol Biotechnol 69:521–525
Wang S-J, Li Y-X, Bao L, Han J-J, Yang X-L, Li H-R, Wang Y-Q, Li S-J, Liu H-W (2012) Eryngiolide A, a cytotoxic macrocyclic diterpenoid with an unusual cyclododecane core skeleton produced by the edible mushroom Pleurotus eryngii. Org Lett 14:3672–3675
Wang S-J, Bao L, Han J-J, Wang Q-X, Yang X-L, Wen H-A, Guo L-D, Li S-J, Zhao F, Liu H-W (2013a) Pleurospiroketals A–E, Perhydrobenzannulated 5, 5-Spiroketal Sesquiterpenes from the edible mushroom Pleurotus cornucopia e. J Nat Prod 76:45–50
Wang S, Bao L, Zhao F, Wang Q, Li S, Ren J, Li L, Wen H, Guo L, Liu H (2013b) Isolation, identification, and bioactivity of monoterpenoids and sesquiterpenoids from the mycelia of edible mushroom Pleurotus cornucopiae. J Agric Food Chem 61:5122–5129

Wang X-M, Zhang J, Wu L-H, Zhao Y-L, Li T, Li J-Q, Wang Y-Z, Liu H-G (2014) A mini-review of chemical composition and nutritional value of edible wild-grown mushroom from China. Food Chem 151:279–285

Wang P-W, Hung Y-C, Li W-T, Yeh C-T, Pan T-L (2016) Systematic revelation of the protective effect and mechanism of Cordycep sinensis on diethylnitrosamine-induced rat hepatocellular carcinoma with proteomics. Oncotarget 7:60270

Wang X, Liu H, Zhang J, Li T, Wang Y (2017) Evaluation of heavy metal concentrations of edible wild-grown mushrooms from China. J Environ Sci Health B 52:178–183

Wani BA, Bodha R, Wani A (2010) Nutritional and medicinal importance of mushrooms. J Med Plants Res 4:2598–2604

Wasser SP, Weis AL (1999) Medicinal properties of substances occurring in higher basidiomycetes mushrooms: current perspectives. Int J Med Mushrooms 1:31–62

Wu G-H, Hu T, Li Z-Y, Huang Z-L, Jiang J-G (2014) In vitro antioxidant activities of the polysaccharides from Pleurotus tuber-regium (Fr.) Sing. Food Chem 148:351–356

Xu X, Yan H, Chen J, Zhang X (2011) Bioactive proteins from mushrooms. Biotechnol Adv 29:667–674

Xu Z, Fu L, Feng S, Yuan M, Huang Y, Liao J, Zhou L, Yang H, Ding C (2019) Chemical composition, antioxidant and Antihyperglycemic activities of the wild Lactarius deliciosus from China. Molecules 24:1357

Xue Z, Li J, Cheng A, Yu W, Zhang Z, Kou X, Zhou F (2015) Structure identification of triterpene from the mushroom Pleurotus eryngii with inhibitory effects against breast cancer. Plant Foods Hum Nutr 70:291–296

Yan N, He F, Piraino FF, Xiang H, Chen J, Wang Y, Liu X (2015) Antiviral activity of a cloned peptide RC28 isolated from the higher basidiomycetes mushroom Rozites caperata in a mouse model of HSV-1 keratitis. Int J Med Mushrooms 17:819–828

Yousfi M, Djeridane A, Bombarda I, Duhem B, Gaydou EM (2009) Isolation and characterization of a new hispolone derivative from antioxidant extracts of Pistacia atlantica. Phytother Res 23:1237–1242

Yuswan M, Al-Obaidi JR, Rahayu A, Sahidan S, Shazrul F, Fauzi D (2015) New bioactive molecules with potential antioxidant activity from various extracts of wild edible Gelam mushroom (Boletus spp.). Adv Biosci Biotechnol 6:320

Zacchigna MAT, Beltrame G, Cateni F, Procida G (2017) Mycochemical study of polysaccharides from edible mushroom Cortinarius caperatus (Gypsy mushroom). In: Gargano ML, Venturella G (eds) Book of abstracts: the 9th international medicinal mushrooms conference (IMMC9), Palermo.

Zang Y, Xiong J, Zhai W-Z, Cao L, Zhang S-P, Tang Y, Wang J, Su J-J, Yang G-X, Zhao Y (2013) Fomentarols A–D, sterols from the polypore macrofungus Fomes fomentarius. Phytochemistry 92:137–145

Zhang G-Q, Wang Y-F, Zhang X-Q, Ng TB, Wang H-X (2010) Purification and characterization of a novel laccase from the edible mushroom Clitocybe maxima. Process Biochem 45:627–633

Zhang R, Zhao L, Wang H, Ng TB (2014) A novel ribonuclease with antiproliferative activity toward leukemia and lymphoma cells and HIV-1 reverse transcriptase inhibitory activity from the mushroom, Hohenbuehelia serotina. Int J Mol Med 33:209–214

Zhao C, Gao L, Wang C, Liu B, Jin Y, Xing Z (2016) Structural characterization and antiviral activity of a novel heteropolysaccharide isolated from Grifola frondosa against enterovirus 71. Carbohydr Polym 144:382–389

Zocher A-L, Kraemer D, Merschel G, Bau M (2018) Distribution of major and trace elements in the bolete mushroom Suillus luteus and the bioavailability of rare earth elements. Chem Geol 483:491–500