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Exploration of medicinal impact of wild edible mushrooms by Indian scientific fraternity

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ABSTRACT

Mushrooms have been appreciated since ancient times as an extraordinary source of food and curative agents. Even today, they are considered as an integral part of primary healthcare by many indigenous communities inhabiting particularly in India, one of the mega-diverse countries of the world. Consequently, the bio-resources have attracted significant attention of Indian scientists where the earliest article was on the antibacterial effect reported in the year 1945 by Prof. Sahay Ram Basu. Gradually a growing body of research enhanced the area inspiring me to summarize the current state of knowledge on medicinal attributes of wild edible macrofungi of the country. So far, around 121 species have shown exciting health benefits where *Astraeus hygrometricus, Auricularia delicata, Coprinus atramentarius, Hericium erinaceus, Macrocybe gigantea, M. lobayensis, Pleurotus pulmonarius, Russula alatoreticula, R. albonigra, R. cyanoxantha, R. densifolia, R. pseudocyanoxantha, R. senecis,* and *R. violepies* revealed immense potential. Most of them possess strong antioxidant properties; while, other reported bioactivities are antimicrobial, anticancer, immune-stimulatory, anti-diabetic, hepato-protective, anti-inflammatory, cardio-protective, and anti-ulcer effects. The future study hence should be directed towards active compound isolation and validation of the bioactivity in vivo for the development of pharmaceuticals, functional foods and nutraceuticals improving our health, and fostering local food-based economies.

Keywords: Anticancer property, Antimicrobial effect, Antioxidant activity, Edible mushrooms of India, Immune-regulation

INTRODUCTION

India, the seventh and second-largest country in the world and Asia respectively, occupies about 3.28 million km^2 total geographical area encompassing over 7500 km stretched coastline and around 15,000 km elongated land frontier (Singh, 2020). Lying in the tropical belt, the subcontinent currently accounts for almost 0.8 million km^2 forest and tree cover spanning 24.62% of the country's entire zone (FSI, 2021). Such a vast landscape of the nation causes immense climatic and edaphic variations resulting in a great range of vegetation types. Indeed, India is eighth among the top 10 most biodiverse countries with a high level of endemism harbouring enumerable exciting taxa (Ahmad *et al.,* 2017; Salunkhe *et al.,* 2018). One of such matrices is mushrooms, a fascinating group of higher fungi, which grow abundantly in various kinds across different states of India. Manoharachary *et al.* (2005) have depicted that the number of genera belonging to *Basidiomycetes* reported from India between 1905 and 1995 is 232. On the other hand, Deshmukh (2004) described that approximately 850 species have so far been recorded from the country. Interestingly, many of these myco-resources are highly prized as gourmet cuisine due to unique health-promoting effects and thus play an important role in the food security of local inhabitants. Besides, they have also gained enormous acceptance in traditional healthcare practices owing to various therapeutic advantages. In this context, the scientific investigation could lead not only to valorisation of the macrofungal species but also to unveiling novel bioactive components effective against various human diseases (Khatua and Acharya, 2021; Khatua *et al.,* 2018, 2021).

As a result, there has been a significant study on medicinal attributes of fungi naturally occurring in India where Prof. Sahay Ram Basu paved the way during early 1940s by searching antibacterial effects of polypores (Bose, 1940, 1945, 1946). Over time, several other researchers have enriched the area of myco-medicine as evident by the steady increase in the number of published manuscripts, particularly since the onset of the 21st century (**Fig. 1a,b**). The sum total of related original research articles has currently surpassed 200 focusing on a range of therapeutic activities as shown in **fig. 2a,b.** Congregation of all these data is hence highly required to provide an insight and help scholars to design future investigations. The present review thus aimed to discuss the current status and progress on understanding the medicinal prospect of wild and edible macrofungi of India contributed by native scientists. Added to this, perspective on the forthcoming research direction has also been demonstrated to promote the application of mushrooms from our beloved country for the betterment of humankind on a real scale.

ANTIOXIDANT ACTIVITY

Free radicals such as reactive oxygen species (ROS) lack a full complement of electrons and thus they steal electrons from other molecules contributing to the development of several chronic diseases. While they are naturally produced by our body, they can also be generated through outside factors like cigarette smoke, pesticides, and environmental pollutants. Antioxidants are chemicals that lessen or prevent the effects of free radicals (Khatua and Acharya, 2021). Sometimes, there are more ROS than antioxidants inside the body which results in a condition known as oxidative stress. Replenishing antioxidants in the body, then, may help to protect against such damage. Mushrooms are ascribed to contain unusually high amounts of antioxidants and thus could bolster our health (Khatua *et al.,* 2018).

To date, many wild edible mushrooms collected from different places of India have been investigated for their antioxidant activity *in vitro* (**Table 1**). In most of the cases, organic media like methanol (Puttaraju *et al.,* 2006; Ramesh and Pattar, 2010; Singdevsachan *et al.,* 2013; Sheikh *et al.,* 2015; Ghate and Sridhar, 2017; Sharma *et al.,* 2017), ethanol

(Loganathan *et al.,* 2010; Singdevsachan *et al.,* 2013; Khaund and Joshi, 2015; Sheikh *et al.,* 2015; Sharma and Gautam, 2017), petroleum ether, chloroform, ethyl acetate (Ramya *et al.,* 2021) and hydro-ethanol solvents (Khatua and Acharya, 2021) have been used where aqueous-alcohol fractions portrayed better potential. On the other hand, water fractions such as infusion and decoction preparations from *Auricularia delicata, A. Mesenterica* (Ghosh *et al.,* 2021c), *Flammulina velutipes* (Sharma *et al.,* 2022), *Hericium erinaceus* (Ghosh *et al.,* 2021a), and *Russula brevipes* (Sharma *et al.,* 2019) have also been investigated to estimate radical scavenging property. Khatua and Acharya (2021) explored the antioxidant efficacy of crude polysaccharides isolated from specimens naturally grown in West Bengal by hot water, cold alkali, and hot alkali processes where better efficacy has been found when the aqueous condition was applied. Some authors have isolated pure compounds, homo or heteroglucan, from various taxa; although superior activity was noted in the case of extracts indicating synergistic effects of bioactive molecules (Patra *et al.,* 2012; Samanta *et al.,* 2013; Khatua and Acharya, 2021).

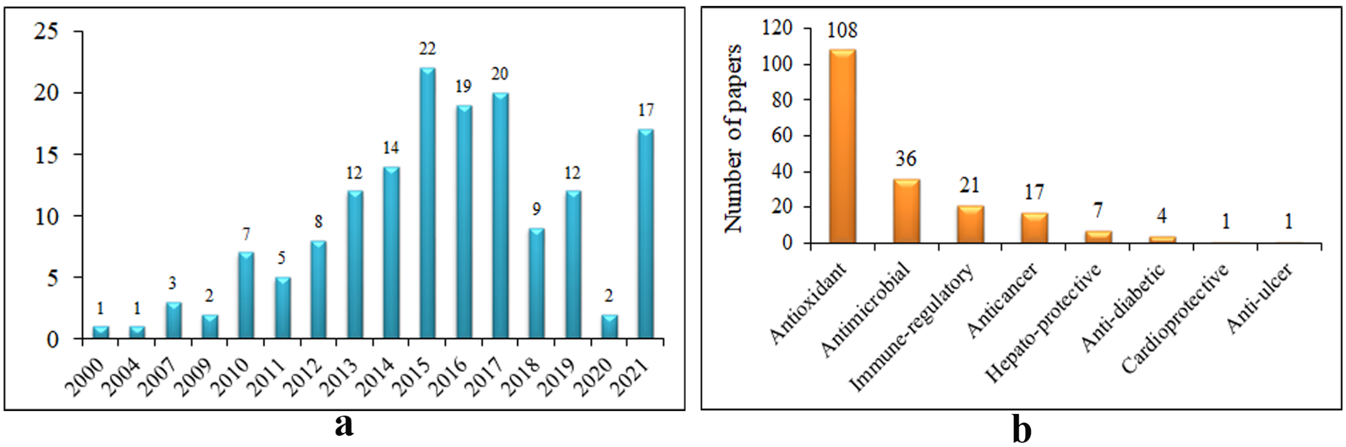

Fig 1: Overview on publications regarding edible and medicinal mushrooms native to India. (a) Year wise publications since the beginning of current century (b) Number of publications in different areas of bioactivity.

ANTIMICROBIAL ACTIVITY

At present, antibiotic resistance has been the biggest challenge threatening the health of societies. Due to the widespread availability of various antibiotics and exposure of the bacteria to these drugs for extended periods of time, multi-drug resistance can easily develop in bacteria (Shen *et al.,* 2017). Currently, at least 700,000 people die annually due to drug-resistant diseases which could cause 10 million deaths each year by 2050. Therefore, alternative antimicrobial strategies need to be developed. In regards to this case, macrofungi have exhibited potent activity against several human pathogens and thus they could be an alternate source of new antimicrobial agents (Khatua and Acharya, 2021).

As such, numerous wild and edible mushrooms of India have been inferred to possess antibacterial efficacy against both Gram-positive (*Bacillus cereus, B. subtilis, Eggerthella lenta, Micrococcus luteus, Staphylococcus aureus*) and Gram-negative bacteria (*Enterobacter aerogenes, Enterococcus faecalis, Escherichia coli, Klebsiella pneumonia, Proteus vulgaris, Pseudomonas aeruginosa, Salmonella typhi, Shigella flexneri, Vibrio alginolyticus, V. cholera, V. parahaemolyticus*) (Jegadeesh *et al.,* 2010; Ramesh and Pattar, 2010; Giri *et al.,* 2012; Manimozhi and Kaviyarasan, 2013; Singdevsachan *et al.,* 2013; Lallawmsanga *et al.,* 2016; Deka *et al.,* 2017; Khatua *et al.,* 2017; Roy Das *et al.,* 2017; Sharma and Gautam, 2017; Singha *et al.,* 2017; Khatua and Acharya, 2018, 2021; Ragupathi *et al.,* 2018). In addition, the antiviral effect of mushroom extracts has also been reported as published by Ramesh and Pattar (2010), Lallawmsanga *et al.* (2016), and Khan and Chandra (2019). Recently, the anti-leishmanial activity of *A. hygrometricus, Grifola frondosa, M. gigantea, R. albonigra,* and *Termitomyces eurhizus* have been tested as well where they exhibited promising effects for the production of novel drugs against the neglected tropical disease (Mallick *et al.,* 2014, 2015, 2016; Khatua and Acharya, 2021).

ANTI-CANCER ACTIVITY

Cancer is the second-leading reason for mortality affecting more than one-third of the worldwide population (Chatterjee *et al.,* 2016). A wide variety of factors contribute to the uncontrolled proliferation of cells such as radiation, family history, genetics, obesity, immune dysfunction, reduced physiological activity, smoking, tobacco, stressful conditions, etc. (Abdulridha *et al.,* 2020). As a result, the cases of cancer are increasing in a steady way where lung, breast, colon and prostate cancer are regarded as the most prevalent types (Asadi-Samani *et al.,* 2016). Currently, a range of techniques including chemotherapy and surgery are applied to treat the problem; however, the toxic effects on non-targeted tissue restrain the use of these methods. Thus, scientists are seeking for promising agents with lesser side effects where mushrooms are showing great hope (Khatua and Acharya, 2021).

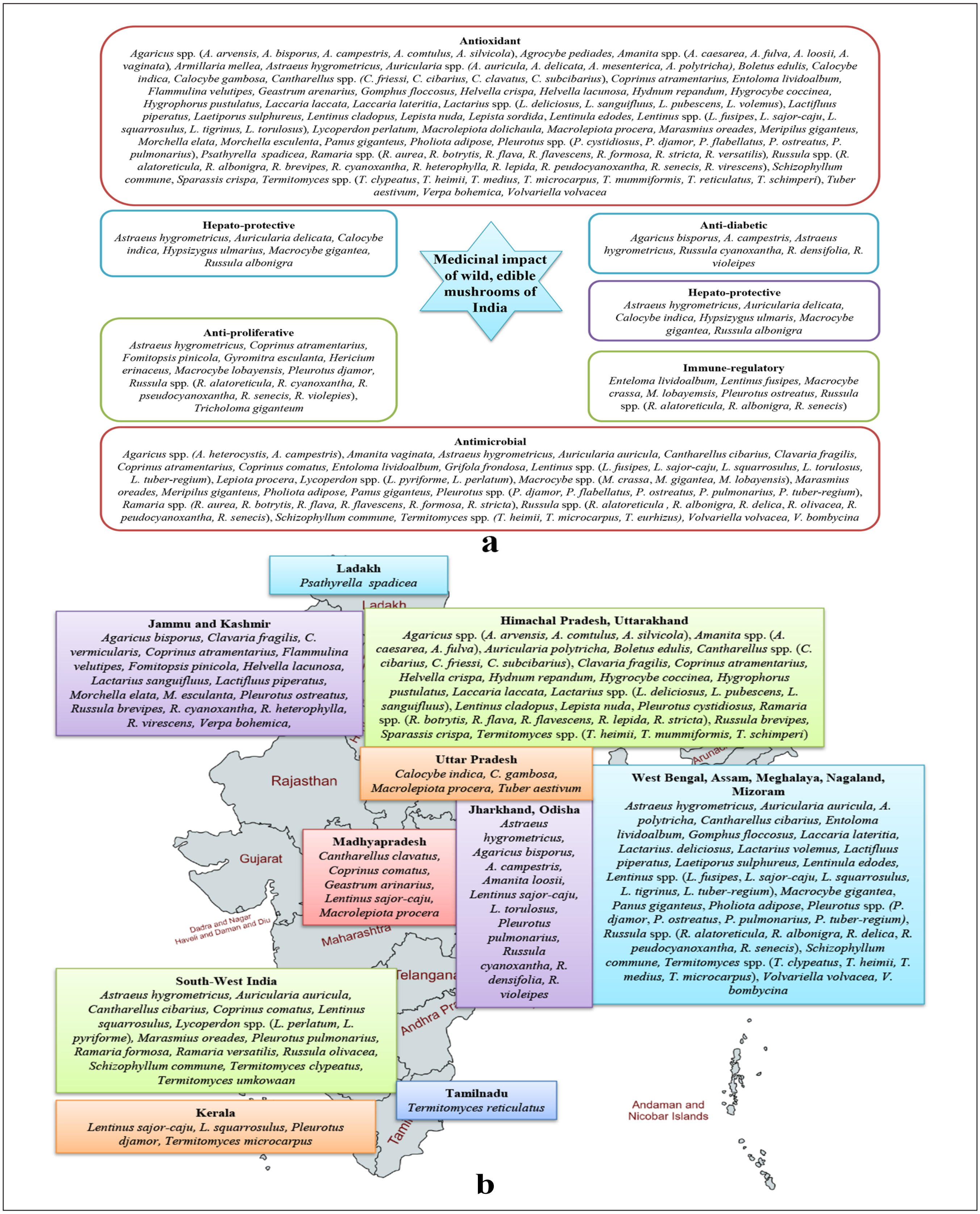

Fig 2: Overview on natural occurrence and bioactivities of edible and medicinal mushrooms native to India. (a) Publications in different therapeutic sectors (b) Geographical distribution

Based on the needs, several researchers have reported anti-proliferative and apoptotic activities of edible mushrooms native to India. At per previous studies, organic extracts from *Coprinus atramentarius* (Khan *et al.,* 2016), *Fomitopsis pinicola* (Ravikumar *et al.,* 2021), *Gyromitra esculanta* (Ahmad *et al.,* 2016), *Lentinus squarrosulus* (Roy *et al.,* 2019) and *Macrocybe lobayensis* (Khatua and Acharya, 2021) exhibited potent activity owing to low IG50 values. Whilst, ethanolic fractions from *R. alatoreticula and R. senecis* (Khatua and Acharya, 2021) executed prominent anti-cancer potency against Hep3B liver cancer cells evident by morphological changes, cell cycle halt, mitochondrial membrane potential depletion and ROS generation mediated through Bax, Bcl2 and caspase 9 intrinsic mitochondrial pathway. In a separate study, ethanolic extract from *Astraeus hygrometricus* portrayed a strong therapeutic prospect against Ehrlich's ascites carcinoma cells (Biswas *et al.,* 2012). Extending the work, two novel components such as astrakurkurone (sesquiterpenoid) and astrakurkurol (triterpenoid) were isolated from the mushroom that unveiled remarkable anti-cancer effectiveness against hepatocellular carcinoma (Nandi *et al.,* 2019).

IMMUNO-REGULATORY ACTIVITY

Our immune system serves to defend invading pathogens where macrophages play an important role in eliminating microbes from the body. Under certain conditions, the system fails to function properly, mostly when people are suffering from malnutrition, cancer, auto-immune diseases, AIDS and in aged persons. Activation of the defense mechanism by an external source, in such situation, may increase protective effect against microorganisms and help the body to fight against diseases. Mushroom derived primary metabolites, β-glucan in particular, are known to exert immune boosting property as they can stimulate functions of the monocytes (Khatua and Acharya, 2021). However, very strong and efficient immune response can cause excess inflammation and immunopathology. In this backdrop, nature derived anti-inflammatory agents may play an important role in the development of new and potent drugs (Attiq *et al.,* 2018).

Recently, Khatua and Acharya (2021) have depicted immune enhancement activity of three unique Russuloid mushrooms collected from the forest of West Bengal. For that, polysaccharides were isolated using different extraction conditions and treated with murine macrophages. The incubation augmented cellular proliferation, phagocytosis, pseudopods formation, nitric oxide and ROS production as well as synthesis of pro-inflammatory cytokines where the mode of action was mediated through TLR/NF-κB pathway (Khatua and Acharya, 2021). Further, pure polysaccharides were isolated from few potent samples namely *Entoloma lividoalbum* (Maity *et al.,* 2015), *Lentinus fusipes* (Manna *et al.,* 2017), *R. albonigra* (Nandi *et al.,* 2014) and *Tricholoma crassum* (Patra *et al.,* 2012; Samanta *et al.,* 2013) that exhibited immense immune boosting effects. In contrast to that, *Morchella elata* occurring in Kashmir Himalaya was found to possess anti-inflammatory activity (Ramya *et al.,* 2021).

HEPATO-PROTECTIVE ACTIVITY

The liver is regarded as one of the most vital organs as it plays a fundamental role in the maintenance of metabolism. However, it is highly susceptible to damage owing to continuous exposure to biological factors (bacteria, virus, and parasites), certain drugs (high doses of paracetamol) and toxic compounds. Also, autoimmune diseases and excessive alcohol consumption play a significant role in the induction of hepatic diseases (Madrigal-Santillán *et al.,* 2014). Currently, there are no effective remedies to restore hepatic function. Thus, identification of more efficient alternatives for the treatment is highly necessary (Wangkheirakpam *et al.,* 2018).

In order to search for an effective drug, researchers have isolated organic extracts from *A. hygrometricus* (Khatua and Acharya, 2021), *A. delicata* (Wangkheirakpam *et al.,* 2018), *Calocybe indica* (Chatterjee *et al.,* 2011), *Hypsizygus ulmaris* (Greeshma *et al.,* 2019), *M. gigantea* and *R. albonigra* (Khatua and Acharya, 2021) followed by the administration to the tasted animals where carbon tetrachloride was used to induce hepatotoxicity. The treatment diminished elevated liver function enzymes and enhanced antioxidant status. Histopathological observations further supported the hepato-protective activity indicating that the mushrooms from India could be one of the effective sources for natural gastrointestinal medicines in the future.

ANTI-DIABETIC ACTIVITY

Diabetes mellitus is a serious metabolic disorder characterised by hyperglycaemia as well as glucose intolerance affecting people both in developing and developed nations. Between the two types, Type 2 diabetes (T2DM) is a chief cause of cardio-vascular diseases and hospitalizations seeking an effective plan of management (Khatua and Acharya, 2021). It is caused by an inequality between the secretion of insulin and blood glucose absorption. Regulating plasma glucose level is thus necessary to prevent the disorder. In this context, scientists are searching for a drug or diet possessing the ability to delay the production or absorption of glucose by hindering carbohydrate hydrolyzing enzymes including α-amylase and α-glucosidase (Telagari and Hullatti, 2015).

Recently, some medicinal macrofungi from India have been reported to be useful in controlling diabetes. For instance, three wild edible *Russula* species have been depicted to inhibit α-glucosidase where water extract from *Russula violeipes* executed better potential as evident by low IC_{50} value i.e. 83 µg/ml (Panda *et al.,* 2021). In contrast, *Agaricus bisporus, A. campestris, A. hygrometricus* (Khan and Chandra, 2019), and *Pluteus cervinus* (Raju *et al.,* 2021) exhibited α-amylase inhibitory properties. In another study, Biswas and Acharya (2013) demonstrated that the administration of ethanolic extract of *A. hygrometricus* could reduce blood glucose levels in diabetic mice.

OTHER BIO-ACTIVITIES

Apart from the above-mentioned medicinal prospects, scientists have explored several other effects of wild edible mushrooms of India. For instance, ethanolic extract from *A. hygrometricus* has shown cardioprotective effect (Khatua and Acharya, 2021). Chatterjee *et al.* (2013a) has executed anti-ulcer activity of *T. Eurhizus* where the isolated water-soluble polysaccharide-rich fraction healed gastric ulceration. Singh *et al.* (2013) demonstrated that *Cordyceps sinensis* could be used in tolerating hypoxia. On the other hand, *M. elata* revealed arthritis paw edema-inhibiting effect (Ramya *et al.,* 2021).

Table 1: Medicinal attributes of various edible mushrooms collected from different places of India

Sl no	Name of mushroom	1	2	3	4	5	6	Reference
1	*Agaricus arvensis*	+	-	-	-	-	-	Sharma and Gautam, 2016
2	*Agaricus bisporus*	+	+	-	-	+	-	Sheikh *et al*., 2015; Khan and Chandra, 2019
3	*Agaricus campestris*	+	+	-	-	+	-	Khan and Chandra, 2019
4	*Agaricus comtulus*	+	-	-	-	-	-	Sharma and Gautam, 2015
5	*Agaricus heterocystis*	-	+	-	-	-	-	Manimozhi and Kaviyarasan, 2013
6	*Agaricus silvicola*	+	-	-	-	-	-	Sharma and Gautam, 2015
7	*Agrocybe pediades*	+	-	-	-	-	-	Khatua and Acharya, 2021
8	*Amanita caesarea*	+	-	-	-	-	-	Sharma and Gautam, 2015, 2016
9	*Amanita fulva*	+	-	-	-	-	-	Sharma and Gautam, 2015
10	*Amanita loosii*	+	-	-	-	-	-	Rajoriya and Gupta, 2015
11	*Amanita vaginata*	+	-	-	-	-	-	Khatua and Acharya, 2021
12	*Armillaria mellea*	+	-	-	-	-	-	Khatua and Acharya, 2021
13	*Astraeus hygrometricus*	+	+	+	+	+	-	Pavithra *et al*., 2016; Singha *et al*., 2017; Khan and Chandra, 2019; Khatua and Acharya, 2021
14	*Auricularia auricula*	+	+	-	-	-	-	Karun *et al*., 2016; Deka *et al*., 2017; Ao and Deb, 2019; Khatua and Acharya, 2021
15	*Auricularia delicata*	+	+	-	+	-	-	Wangkheirakpam *et al*., 2018; Ghosh *et al*., 2021c
16	*Auricularia mesenterica*	+	-	-	-	-	-	Ghosh *et al*., 2021c
17	*Auricularia polytricha*	+	+	-	-	-	-	Puttaraju *et al*., 2006; Lallawmsanga *et al*., 2016; Ao and Deb, 2019
18	*Boletus edulis*	+	-	-	-	-	-	Puttaraju *et al*., 2006
19	*Calocybe indica*	+	-	-	+	-	-	Chatterjee *et al*., 2011; Vishwakarma *et al*., 2016
20	*Calocybe gambosa*	+	-	-	-	-	-	Vishwakarma *et al*., 2016
21	*Cantharellus friessi*	+	-	-	-	-	-	Kumari *et al*., 2011
22	*Cantharellus clavatus*	+	-	-	-	-	-	Puttaraju *et al*., 2006
23	*Cantharellus cibarius*	+	+	-	-	-	-	Puttaraju *et al*., 2006; Ramesh and Pattar, 2010; Khaund and Joshi, 2015; Pattnaik *et al*., 2018
24	*Cantharellus subcibarius*	+	-	-	-	-	-	Kumari *et al*., 2011
25	*Clavaria fragilis*	+	+	-	-	-	-	Sharma and Gautam, 2016; 2017
26	*Clavaria vermicularis*	+	+	-	-	-	-	Sharma and Gautam, 2016; 2017
27	*Coprinus atramentarius*	+	+	+	-	-	-	Sheikh *et al*., 2015; Khan *et al*., 2016; Sharma and Gautam, 2016
28	*Coprinus comatus*	-	+	-	-	-	-	Deshmukh *et al*., 2014; Ragupathi *et al*., 2018
29	*Cordyceps sinensis*	+	+	-	-	-	-	Mamta *et al*., 2015
30	*Entoloma lividoalbum*	+	-	-	-	-	+	Khatua and Acharya, 2021
31	*Flammulina velutipes*	+	-	-	-	-	-	Sharma *et al*., 2022
32	*Fomitopsis pinicola*	-	-	+	-	-	-	Ravikumar *et al*., 2021
33	*Geastrum arenarius*	+	-	-	-	-	-	Puttaraju *et al*., 2006
34	*Gomphus floccosus*	+	-	-	-	-	-	Dasgupta *et al*., 2015; Khaund and Joshi, 2015
35	*Grifola frondosa*	+	+	-	-	-	-	Khatua and Acharya, 2021
36	*Gyromitra esculanta*	-	-	+	-	-	-	Ahmad *et al*., 2016
37	*Helvella crispa*	+	-	-	-	-	-	Puttaraju *et al*., 2006
38	*Helvella lacunose*	+	-	-	-	-	-	Shameem *et al*., 2016
39	*Hericium erinaceus*	+	+	+	-	-	-	Ghosh *et al*., 2021a,b
40	*Hydnum repandum*	+	-	-	-	-	-	Puttaraju *et al*., 2006
41	*Hygrocybe coccinea*	+	-	-	-	-	-	Sharma and Gautam, 2015; 2016
42	*Hygrophorus pustulatus*	+	-	-	-	-	-	Sharma and Gautam, 2016
43	*Hypsizygus ulmaris*	-	-	-	+	-	-	Greeshma *et al*., 2019
44	*Laccaria laccata*	+	-	-	-	-	-	Sharma and Gautam, 2015
45	*Laccaria lateritia*	+	-	-	-	-	-	Khaund and Joshi, 2015
46	*Lactarius deliciosus*	+	-	-	-	-	-	Puttaraju *et al*., 2006; Khaund and Joshi, 2015;
47	*Lactarius pubescens*	+	-	-	-	-	-	Sharma and Gautam, 2015, 2016
48	*Lactarius sanguifluus*	+	-	-	-	-	-	Puttaraju *et al*., 2006; Sharma *et al*., 2017
49	*Lactarius volemus*	+	-	-	-	-	-	Khaund and Joshi, 2015
50	*Lactifluus piperatus*	+	-	-	-	-	-	Sharma *et al*., 2017; Ao and Deb, 2019
51	*Laetiporus sulphureus*	+	-	-	-	-	-	Ao and Deb, 2019; Khatua and Acharya, 2021
52	*Lentinula edodes*	+	-	-	-	-	-	Ao and Deb, 2019
53	*Lentinus cladopus*	+	-	-	-	-	-	Sharma and Gautam, 2015
54	*Lentinus fusipes*	+	-	-	-	-	+	Manna *et al*., 2017
55	*Lentinus sajor-caju*	+	+	-	-	-	-	Puttaraju *et al*., 2006; Singdevsachan *et al*., 2013; Deshmukh *et al*., 2014; Lallawmsanga *et al*., 2016; Acharya *et al*., 2107b; Pattanayak *et al*., 2018; Ao and Deb, 2019; Kandasamy *et al*., 2020; Khatua and Acharya, 2021
56	*Lentinus squarrosulus*	+	+	+	-	-	-	Puttaraju *et al*., 2006; Pal *et al*., 2010; Das *et al*., 2017; Ghate and Sridhar, 2017; Roy Das *et al*., 2017; Ao and Deb, 2019 Roy *et al*., 2020
57	*Lentinus tigrinus*	+	-	-	-	-	-	Ao and Deb, 2019
58	*Lentinus torulosus*	+	+	-	-	-	-	Singdevsachan *et al*., 2013
59	*Lentinus tuber-regium*	+	+	-	+	-	-	Dandapat *et al*., 2015; Das *et al*., 2017; Roy *et al*., 2017
60	*Lepista nuda*	+	+	-	-	-	-	Dighe and Agate, 2000; Sharma and Gautam, 2015

61	*Lepista sordida*	+	-	-	-	-	-	Khatua and Acharya, 2021
62	*Lycoperdon perlatum*	+	+	-	-	-	-	Ramesh and Pattar, 2010
63	*Lycoperdon pyriforme*	-	+	-	-	-	-	Ragupathi *et al*., 2018
64	*Macrocybe crassa*	+	-	-	-	-	+	Patra *et al*., 2012; Samanta *et al*., 2013; Khatua and Acharya, 2014; Acharya *et al*., 2015b
65	*Macrocybe gigantea*	+	+	+	+	-	-	Banerjee *et al*., 2007; Chatterjee *et al*., 2013b; Das *et al*., 2017; Roy *et al*.,
66	*Macrocybe lobayensis*	+	+	+	-	-	+	Khatua *et al*., 2017; Khatua and Acharya, 2018; Ghosh *et al*., 2019; Khatua *et al*., 2019
67	*Macrolepiota dolichaula*	+	-	-	-	-	+	Samanta *et al*., 2015
68	*Macrolepiota procera*	+	-	-	-	-	-	Puttaraju *et al*., 2006; Vishwakarma *et al*., 2016
69	*Marasmius oreades*	+	+	-	-	-	-	Ramesh and Pattar, 2010
70	*Meripilus giganteus*	+	-	-	-	-	-	Khatua and Acharya, 2021
71	*Morchella elata*	+	-	-	-	-	+	Ramya *et al*., 2021
72	*Morchella esculenta*	+	-	-	-	-	-	Wagay and Vyas, 2011 ; Thakur and Lakhanpal 2014; Shameem *et al*., 2015; Sheikh *et al*., 2015
73	*Oudemansiella canarii*	+	-	-	-	-	-	Acharya *et al*., 2019b
74	*Panus giganteus*	+	+	-	-	-	-	Lallawmsanga *et al*., 2016
75	*Pholiota adipose*	+	+	-	-	-	-	Lallawmsanga *et al*., 2016
76	*Pleurotus cystidiosus*	+	-	-	-	-	-	Sharma and Gautam, 2015; Panda *et al*., 2017
77	*Pleurotus djamor*	+	+	-	-	-	-	Puttaraju *et al*., 2006; Lallawmsanga *et al*., 2016
78	*Pleurotus flabellatus*	+	-	-	-	-	-	Khatua and Acharya, 2021
79	*Pleurotus ostreatus*	+	+	-	-	-	-	Joshi *et al*., 2014; Sheikh *et al*., 2015; Acharya *et al*., 2016b; Deka *et al*., 2017; Singha *et al*., 2017
80	*Pleurotus pulmonarius*	+	+	-	-	+	-	Ramesh and Pattar, 2010; Lallawmsanga *et al*., 2016; Khan and Chandra, 2019
81	*Pleurotus tuber-regium*	-	+	-	-	-	-	Deka *et al*., 2017
82	*Pluteus cervinus*	+	-	-	-	+	-	Raju *et al*., 2021
83	*Psathyrella spadicea*	+	-	-	-	-	-	Yangdol *et al*., 2016
84	*Ramaria aurea*	+	-	-	-	-	-	Khatua *et al*., 2015; Khatua and Acharya, 2021
85	*Ramaria botrytis*	+	+	-	-	-	-	Sharma and Gautam, 2017; Khatua and Acharya, 2021
86	*Ramaria flava*	+	+	-	-	-	-	Sharma and Gautam, 2017
87	*Ramaria flavescens*	+	+	-	-	-	-	Sharma and Gautam, 2017
88	*Ramaria Formosa*	+	+	-	-	-	-	Ramesh and Pattar, 2010
89	*Ramaria stricta*	+	+	-	-	-	-	Sharma and Gautam, 2017
90	*Ramaria subalpina*	+	-	-	-	-	-	Acharya *et al*., 2017a
91	*Ramaria versatilis*	+	-	-	-	-	-	Dattaraj *et al*., 2020
92	*Russula alatoreticula*	+	+	+	-	-	+	Khatua *et al*., 2018; Khatua *et al*., 2021
93	*Russula albonigra*	+	-	-	+	-	+	Nandi *et al*., 2014; Khatua and Acharya, 2021
94	*Russula brevipes*	+	-	-	-	-	-	Puttaraju *et al*., 2006; Sharma *et al*., 2017
95	*Russula cyanoxantha*	+	+	+	-	+	+	Sharma *et al*., 2017; Khan and Chandra, 2019; Panda *et al*., 2021
96	*Russula delica*	+	+	-	-	-	-	Singdevsachan *et al*., 2014 Singha *et al*., 2017; Pattnaik *et al*., 2018
97	*Russula densifolia*	+	+	+	-	+	+	Panda *et al*., 2021
98	*Russula heterophylla*	+	-	-	-	-	-	Sharma *et al*., 2017
99	*Russula lepida*	+	+	-	-	-	-	Joshi *et al*., 2014; Sharma and Gautam, 2015
100	*Russula pseudocyanoxantha*	+	-	+	-	-	+	Khatua and Acharya, 2021; Khatua *et al*., 2021
101	*Russula olivacea*	-	+	-	-	-	-	Ragupathi *et al*., 2018
102	*Russula senecis*	+	+	+	-	-	+	Khatua and Acharya, 2021
103	*Russula vesca*	+	+	-	-	-	-	Singdevsachan *et al*., 2014
104	*Russula violepies*	+	+	+	-	+	+	Panda *et al*., 2021
105	*Russula virescens*	+	-	-	-	-	-	Sharma *et al*., 2017
106	*Schizophyllum commune*	+	+	-	-	-	-	Tripathi and Tiwary, 2013 ; Lallawmsanga *et al*., 2016; Debnath *et al*., 2017; Deka *et al*., 2017; Ragupathi *et al*., 2018; Ao and Deb 2019; Khatua and Acharya, 2021
107	*Sparassis crispa*	+	-	-	-	-	-	Puttaraju *et al*., 2006; Joshi and Sagar, 2014
108	*Termitomyces clypeatus*	+	-	-	-	-	-	Pattanayak *et al*., 2015; Ghate and Sridhar, 2017; Khatua and Acharya, 2021
109	*Termitomyces eurrhizus*	+	+	-	-	-	-	Singdevsachan *et al*., 2014
110	*Termitomyces heimii*	+	+	+	-	-	-	Puttaraju *et al*., 2006; Singha *et al*., 2017; Ao and Deb 2019; Khatua and Acharya, 2021; Singha *et al*., 2021
111	*Termitomyces medius*	+	-	-	-	-	+	Khatua and Acharya, 2021; Mitra *et al*., 2021
112	*Termitomyces microcarpus*	+	-	-	-	-	-	Puttaraju *et al*., 2006; Rajoriya and Gupta, 2015; Khatua and Acharya, 2021
113	*Termitomyces mummiformis*	+	-	-	-	-	-	Puttaraju *et al*., 2006
114	*Termitomyces reticulatus*	+	-	-	-	-	-	Loganathan *et al*., 2010
115	*Termitomyces schimperi*	+	-	-	-	-	-	Puttaraju *et al*., 2006
116	*Termitomyces umkowaan*	+	-	-	-	-	-	Karun *et al*., 2016
117	*Tricholoma saponaceum*	+	-	-	-	-	-	Khaund and Joshi, 2015
118	*Tuber aestivum*	+	-	-	-	-	-	Vishwakarma *et al*., 2016
119	*Verpa bohemica*	+	-	-	-	-	-	Shameem *et al*., 2015; Sheikh *et al*., 2015
120	*Volvariella bombycina*	-	+	-	-	-	-	Jagadeesh *et al*., 2010
121	*Volvariella volvacea*	+	+	-	-	-	-	Acharya *et al*., 2016b; Singha *et al*., 2017; Khatua and Acharya, 2021

1: Antioxidant 2: Antimicrobial 3: Anti-proliferative 4: Hepato-protective 5: Anti-diabetic 6: Immune-regulatory.

CONCLUSION AND FUTURE PROSPECTS

In sum, wild edible mushrooms of India could be explored in development of potent functional foods and multi-target complementary medicines to treat oxidative stress, cancer, diabetes, ulcer, hepatic disorders, microbial infection, and immune related health hazards. However, most of the assays have been carried out with extracts where mechanisms underlying the properties remained elusive. Further studies are hence needed for the isolation of active compounds and validation of their effect in animal models in order to develop natural products and their derivatives for human ailment prevention. Such extensive work might leave a mark on valorisation of local mushrooms boosting regional food-based economies. Despite possessing such a huge impact, there are enumerable species of edible mushrooms, native to India, that have not yet been investigated for their effectiveness; thus there is a huge opportunity for young generations to indulge themselves in macrofungal research. Alongside, strong collaboration among scientists belonging to different arenas spanning from taxonomy, biochemistry, molecular biology, and pharmacy as well as R&D sectors is highly required for fruitful application.

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