



RESEARCH ARTICLE

Mushroom alkaloids as nutraceuticals, bioactive and medicinal properties: a preliminary review

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Abstract

Mushroom alkaloids are quite interesting due to their distinct secondary metabolites. Alkaloids are a class of secondary metabolites that are found in different types of organisms. The primary focus of this study is the alkaloids that were taken out of the mushrooms. Mainly the mushrooms alkaloids are classified as 2 groups like indoles and isoxazoles. In the present paper 68 distinct alkaloids produced from mushrooms were attempted to be listed under 24 distinct groups; i.e. 24 alkaloids were kept under Indole group, 5 different alkaloids were kept under β - carboline group and pyrroloquinoline group, 4 different alkaloids were kept under pyrrole group and 3 different alkaloids were mentioned under quinoline groups. Mushrooms were used as food in many parts of the world. The alkaloids obtained from mushrooms showing different bioactivities like antimicrobial, anticancer, anti-diabetic, hepatoprotective, anti-inflammatory, antioxidant, immunomodulatory, anti-obesity, anti-ageing, nematocidal, helminthic, against cardiovascular disease and as antiasthmatic agent. Mushrooms were widely used in the traditional medicine of many countries like china, India, Taiwan, Japan etc. these mushrooms became great resources for many groups of alkaloids with bioactivities which should be useful in present day modern clinical and pharmacological research. The present review aims at listing the applications of mushroom alkaloids in different fields like medicine, health science, pharmacy etc.

Keywords

alkaloids; bioactivities; antimicrobial; nematocidal; immunomodulatory; nutraceuticals

Introduction

Throughout the world, gourmet haute cuisine has been associated with mushrooms, mostly due to their unique and exquisite flavor. There are more than 2000 species of mushrooms in the world, but only around 25 are widely consumed as food and just a few are utilized in entrepots. The different species of fungi are members of the Ascomycetes or Basidiomycetes order. These orders of fungi are widely distributed and can be found in moist wood, animal manure after a strong rain and soils rich in organic matter and hums (1).

Mushroom taxonomy

The fleshy, spore-connected fruiting bodies of fungus, commonly found above ground on soil or on their food source are called mushrooms or toadstools. The name "mushroom" is most commonly applied to fungi

belonging to the Basidiomycota, Agaricomycetes order, which is determinate by the farmed white button mushroom *Agaricus bisporus*. The mushroom is classified into 3 parts: the stem (stipe), the cap (pileus) and the gills (lamella) on the bottom of the pileus. These gills produce tiny spores that let the fungus spread out throughout the surface of its host or the earth (2).

Mushroom morphology

The labels "bolete" "puffball," "stinkhorn" and "morel" are typically applied to forms that deviate from the determinate morphology, while the gilled mushrooms themselves are sometimes referred to as "Agarics." The French term "Mousseron," which refers to moss, is where the word "mushroom" and its variants originate. It was unclear how toxic and edible fungus was portrayed. The word "toadstool" first appeared in English usage in the 14th century, referring to a stool used by toads, possibly to denote a deadly fungus that was unstable.

Primary metabolites from mushrooms

The mass of fruiting bodies in mushrooms is estimated to be between 50 and 65 % on a dry weight basis, with free sugars making up approximately 11 % of the total. Eighty percent of all sugars are made up of mannitol, also referred to as mushroom sugar (3). The main component of dry matter in mushrooms is protein. The protein content of mushrooms is dependent upon the type of mushroom, size of the pileus, time of harvest and composition of the substratum. In general, mushrooms have higher protein contents than most other vegetables and plants; the *Lactarius sanguifusus* contains 15.20 to 18.87 % protein. All of the necessary amino acids required by an adult are present in mushrooms. Mushrooms have a lower fat content than protein and carbs. The majority of the fats in mushroom fruiting bodies are unsaturated fatty acids. Mushroom species differ in their fat content. Linolenic acid, an important fatty acid, can be found in mushrooms (4).

Secondary metabolites from mushrooms

Plants create tiny molecules called secondary metabolites, which have a wide range of impacts on both the plant and other creatures. The growth and reproduction of the organism do not depend on these metabolites. However, these metabolites serve a variety of purposes, including defense against diseases, herbivores and pests as well as serving as indicators of microbial symbiosis with plants (5). Most of the mushrooms were capable to produce different metabolites like alkaloids, flavonoids, phenols, tannins, glycosides etc. Mycochemicals were isolated from the dried mycelial mat of *Lentinus sajor-caju* (Fr.) using hot water. It contained terpenoids, glycosides, alkaloids and saponins. Aqueous extracts of *L. sajor-caju* contained a significant level of phenolics (75.29 mg/1 g dried mycelial), but had low radical scavenging activity (31.03 %) when compared to the standard Catechin (97.41 %) (6). Mycochemicals such as alkaloids, saponins, tannins and glycosides were found in the fruiting bodies of *Ganoderma lucidum* aqueous extract; *Trametes hirsuta* had alkaloids, saponins, flavonoids and glycosides; and *Auricularia fuscossuccinea* had alkaloids, tannins and glycosides (7). Mycochemical analysis of a

hydroalcoholic extract (70 % ethanol) of hymenophores of *Phellinus gilvus* and *P. torulosus* collected from various locations in Dehradun, Uttarakhand, India, revealed the presence of carbohydrates, reducing sugars, proteins, amino acids, steroids, terpenoids, phenolic compounds, flavonoids, tannins, anthraquinone glycosides, cardiac glycosides and alkaloids (8).

Bioactivities of mushrooms

Mushrooms have been used to prevent and treat allergies, pneumonia, hepatitis, tumors and immunological illnesses. Triterpenoids, alkaloids, polysaccharides, proteins, nucleosides, enzymes and others are among the chemical substances with pharmacological functions extracted from *Ganoderma lucidum*'s mycelia and fruiting bodies. These substances have hepatoprotective, antihypertensive, antihistaminic and anticancer properties, among other things. Many articulations have been developed, patented and used as nutraceuticals or medicines. As a result of clinical research trial and error, several goods, such as syrup, injection and many others, have been commercially available (9). Scientific research demonstrated that the secondary metabolites produced by the wood decay basidiomycetes members are successfully used in pharmacy for treating diverse illnesses such as diarrhea, headaches - *Fomitopsis pinicola*, tuberculosis - *Trametes suaveolens*, bleedings - *Fomes fomentarius*, *Piptoporus betulinus*, rheumatism - *Phellinus igniarius*, cancer - *Bjerkandera fumosa*, *Ganoderma* sp., *Lentinula edodes*, *Lenzites betulina*, *Pleurotus ostreatus*, *Schizophyllum commune*, *Trametes versicolor*, liver problems - *Flammulina velutipes*, *Ganoderma lucidum*, gastric conditions - *Armillaria mellea* (10). The present review aims at listing the mushroom belongs to Ascomycotina and Basidiomycotina capable of producing different primary metabolites, secondary metabolites and different alkaloids with bioactivities and their applications as nutraceuticals, medicines, pharmacological formulations etc. The literature survey was done on different search engines like google scholar, pubmed, science direct, etc for retrieval of articles. The downloaded articles were used for compilation of mushroom alkaloids tables as well as applications of it.

Alkaloids extracted from mushrooms

Alkaloids are a secondary - metabolites, which are isolated from various organisms. In this study, we mainly concentrated on the alkaloids extracted from the mushrooms. We tried to list 66 types of alkaloids under 24 different groups of alkaloids which are extracted from mushrooms. 24 alkaloids are kept under Indole group of alkaloids, 5 different alkaloids are kept under β - carboline alkaloids and Pyrroloquinoline, 4 different alkaloids are kept under Pyrrole, 3 different alkaloids are mentioned under quinoline alkaloids, 2 different alkaloids are kept under each Isoindole, Pyridone, Isoxazole, Isoquinoline, Diketopiperazine and in Pyridine, 1 alkaloid is mentioned under Phenolic amides, Psychoactive, Novel, γ - Pyrrolidinone, Indolinone, Sesquiterpene, Phenoxazone, Quaternary, Isoindolinone, Quinolone, Racemic, Cytochalasin, Hetero - spirocyclic γ - lactam alkaloids (Table 1).

Table 1. Alkaloids of mushrooms showing nutraceutical, bioactive and medicinal activity.

Sl. No.	Type of alkaloid	Name of the alkaloid	Name of the fungal isolate	Function	Reference
1	Laccarin	Laccarin	<i>Laccaria vinaceovellanea</i>	Exhibited phosphodiesterase inhibitory activities	(11)
2	Cytochalasin alkaloids	Armochaetoglobins S - Z	<i>Chaetomium globosum</i> TW1-1	Tested for their cytotoxic activity against five human cancer cell lines and shown significant cytotoxic activities.	(12)
3	Diazacyclooctene alkaloids	E and Z - Proxamidines	<i>Laccaria proxima</i>	Showed herbicidal activities against <i>Lepidium sativum</i>	(13)
4	Diketopiperazine alkaloid	Rosellin A and B	<i>Mycena rosella</i>	Root exposure to rosellin bleached the leaves of <i>Lepidium sativum</i> plants act as herbicide and protects from predators.	(14)
5	Diketopiperazine alkaloids	12 β hydroxyverruculogen TR-2, Fumitremorgin C and Methylthioglotoxin	Mycelia of the basidiomycete <i>Hericium erinaceum</i>	Showed potential antioxidant activity	(15)
6	Hetero-spirocyclic γ -lactam alkaloids	Pseurotin A, Cerevisterol, FD-838 and Herierin IV	Mycelia of the basidiomycete <i>Hericium erinaceum</i>	Inhibited the growth of 2 fungal diseases, <i>Botrytis cinerea</i> and <i>Glomerella cingulata</i> .	(15)
7	Indole alkaloids	1H-indole-3-carboxylic acid; 1-(1,1-dimethyl-2-propenyl) methyl ester	<i>Aporpium caryae</i>	Showed Antifungal activity on <i>Cladosporium cucumerinum</i>	(16)
8	Indole alkaloid	Macrolepiotin	<i>Macrolepiota neomastoidea</i>	Displayed cytotoxicity activities	(17)
9	Indole alkaloid	flazin	<i>Boletus umbriniporus</i>	Showed biological activities like antioxidant, antimicrobial, antiparasitic, antiviral	(18)
10	Indole alkaloid	Psilocin	<i>Psilocybe cubensis</i>	Used for drug discovery in central nervous system disorder	(19)
11	Indole alkaloid	Sciodole, 1,7 - bi-5-methoxy-2,4dimethylindole	<i>Tricholoma sciodes</i>	Pharmacological activities like anticancer, antimicrobial, antiviral, antimalarial, antitubercular, anti-inflammatory	(20)
12	Indole alkaloid	Sinensines B - E	<i>Ganoderma sinense</i>	Function in protecting the injury induced	(21)
13	Indole alkaloid	Harmaine and Norharmaine	<i>Hygrophorous eburneus</i>	Used as acetylcholinesterase inhibitors, exhibited pharmacological and neurotransmitters tests with monoamine oxidase - A and topoisomerase	(22)
14	Indole alkaloid	Echinuline	<i>Lentinus strigellus</i>	Antimycobacterial activity	(23)
15	Indole alkaloid	Brunneins A- C	<i>Cortinarius brunneus</i>	Showed cholinesterase enzyme inhibition	(24)
16	Indole alkaloid	Norharmaine	Fruiting bodies of the <i>Hygrophorus hyacinthinus</i>	Antimycobacterial activities	(24)
17	Indole alkaloids	Gymnopilin K	<i>Gymnopilus spectabilis</i>	Exhibited noticeable cytotoxicity toward some human cancer cell lines	(25)
18	Indole alkaloids	agrocybenine	<i>Agrocybe cylindracea</i>	Showed anticancer activity	(26)
19	Indole alkaloids	Strobilurins A and B	<i>Strobilurus tenacellus</i>	Showed antifungal and antibacterial activity	(27)
20	Indole alkaloids	6-hydroxy-1H-indole-3-carboxaldehyde, and 6-hydroxy-1H-indole-3-acetamide	<i>Agrocybe cylindracea</i>	Inhibited lipid peroxidation in rat liver microsomes, with IC ₅₀ values of 4.1 and 3.9 μ g/mL.	(28)

21	Indole alkaloids	1-methylindole-3-carbaldehyde and 7-methoxyindole-3-carboxylic acid methyl ester	<i>Phellinus linteus</i>	Utilized for inflammation treatment and variety of cancers in east Asia	(29)
22	Indole alkaloids	Methylindole-3-carboxylate	<i>Antrodia albocinnamomea</i>	No significant inhibition of protein-tyrosine phosphatase activity	(30)
23	Indole alkaloids	Corallocin A-C	<i>Hericium coralloides</i>	Found to promote neurotrophin expression in human 1321N1 astrocytes.	(31)
24	Indole alkaloids	Peronatin A - B	<i>Collybia peronata</i>	Showed enzymatic hydrolysis	(32)
25	Indole alkaloids	Infractines A and B, Infractopicrin	<i>Cortinarius infractus</i>	Exhibited acetylcholinesterase inhibiting activity	(33)
26	Indole alkaloids	Metacarbolines A - G and 6-hydroxymetatacarboline - d	<i>Mycena metata</i>	Showed limited antiproliferative activity against glioma cell lines	(34)
27	Indole alkaloids	N - oxide orellanine	<i>Cortinarius armillatus</i>	Shows antimicrobial activity	(35)
28	Indole alkaloids	Omphalotins A-I	<i>Omphalotus olearius</i>	Showed nematicidal activity against <i>Meloidogyne incognita</i>	(36)
29	Indole alkaloids	Okaramines V - Z	<i>Aphanoascus fulvescens</i>	Shown considerable to moderate cytotoxicity against the murine lymphoma cell line.	(37)
30	Indole derivative alkaloids	Psilocybin and Psilocin	<i>Psilocybe cubensis</i> and <i>Copelandia</i>	Shows Psychotherapeutic activity	(38)
31	Indolinone alkaloid	Erinacerin P and T	<i>Hericium erinaceus</i>	The compound inhibited protein tyrosine phosphatase-1B and α -glucosidase as well as cytotoxicity against K562 cells, with IC ₅₀ values ranging from 11.4 to 18.2 μ M.	(39)
32	Isoindole alkaloid	Clitocybin A	<i>Clitocybe aurantiaca</i>	Showed antioxidant activity	(24)
33	Isoindole alkaloid	Sterenins A - D	Fruiting body of <i>Hericium erinaceum</i>	Showed antimicrobial activity	(24)
34	Isoindolinone alkaloid	Isohericerin	<i>Hericium erinaceum</i>	Antitumor activity	(40)
35	Isoquinoline alkaloids	Ampullosine	<i>Sepedonium pulloporum</i>	Exhibited antifungal activity against the phytopathogenic fungus <i>Cladosporium cucumerinum</i>	(41)
36	Isoquinoline alkaloids	Benzomavin A, Quinolactacins A1, A2, B, Quinolonomide, Asperphenamate	<i>Penicillium spathulatum</i>	Functioned as a α - glucosidase inhibitors	(42)
37	Isoxazole alkaloid	Amanita muscaria	<i>Muscimol</i>	Exhibited gamma aminobutyric acid agonist activity	(43)
38	Isoxazole alkaloids	Muscimol and Ibotenic acid	<i>Amanita muscaria</i>	Pharmacologically active like intoxications	(44)
39	Novel alkaloids	Pyriferines A - C	<i>Pseudobaeospora pyriferia</i>	Antimicrobial antibacterial	(45)
40	Phenolic amides	Lucidimines B and C	<i>Ganoderma lucidum</i>	Showed antioxidative and antiproliferative activities against MCF - 7 cells	(46)
41	Phenoxazone alkaloid	Cinnabarin, Tramesanguin	<i>Trametes cinnabarina</i> (Jacq) Franeh	Exhibited antibacterial activities	(47)
42	Psychoactive alkaloid	4-phosphoryloxy-N, N - dimethyltryptamine	<i>Psilocybin mushroom</i>	Indicate a developing problem of hallucinogenic drug abuse and also have pharmacological activities	(48)
43	Pyridine alkaloid	Norsesquiterpene	<i>Flammulina velutipes</i>	Exhibited cytotoxicity against KB cells	(49)
44	Pyridine alkaloids	Militarinones B - D	<i>Paecilomyces militaris</i>	Exhibited negligible neurogenic activity in PC - 12 cells	(50)

45	Pyridone alkaloids	Epipyridone	<i>Epicoccum</i> sp.	Exhibited selective antibacterial function toward gram positive bacteria, specifically, <i>Mycobacterium vaccae</i>	(51)
46	Pyridone alkaloids	Epipyridone	<i>Epicoccum</i> sp. associated with <i>Pholiota squarrosa</i>	Induce erythropoietin in human cells	(24)
47	Pyrrole alkaloids	Phlebopines A - C, Inotopyrrole B	Fruiting bodies of the mushroom <i>Phlebopus portentosus</i>	Displayed inhibition activities on acetylcholine esterase and neuroprotection	(52)
48	Pyrrole alkaloids	4-[2-formyl-5-(hydroxymethyl)-1H-pyrrol-1yl]butanoic acid	<i>Basidiomycetes X</i> (<i>Echigoshirayukidake</i>)	In rodents, it demonstrated anti-obesity and hepatoprotective properties, as well as inhibiting atopic dermatitis in a mouse model.	(53)
49	Pyrrole alkaloids	Auxarconjugatin A - B and Rumbrin	<i>Auxar thronumbrinum</i>	Exhibited cytotoxic against an NS - 1 cell line	(24)
50	Pyrrole alkaloids	Hirsutellones A - E	<i>Hirsutella nivea</i>	Showed significant growth inhibitory activity against <i>Mycobacterium tuberculosis</i>	(54)
51	Pyrroloquinoline alkaloid	Sanguinones A and B	<i>Mycena sanguinolenta</i>	Exhibited Antifungal activities	(55)
52	Pyrroloquinoline Alkaloid	Pelianthinarubins A and B	Fruiting bodies of the mushroom <i>Mycena pelianthiana</i>	As a cofactor	(56)
53	Pyrroloquinoline alkaloid	Mycenarubin C	Fruiting bodies of <i>Mycena rosea</i>	Do not showed antibacterial, antifungal, nematocidal or cytotoxic activity	(57)
54	Pyrroloquinoline alkaloids	Mycenaflavin A - D	<i>Mycena haematopus</i>	Showed average bioactivity toward the soil bacterium <i>Azocarus toluolyticus</i> and haemotopodin B is similarly active as the antibiotic gentamicin	(58)
55	Pyrroloquinoline alkaloids	Mycenarubins A and B	<i>Mycena rosea</i>	Exhibited pharmacological activities like antimicrobial, antibiotic	(59)
56	Quaternary alkaloid	Choline and Muscarine	<i>Inocybe napipes</i>	Used in treatment of inflammatory uveitis	(60)
57	Quinoline alkaloid	Lepidamine	Fruiting bodies of Basidiomycete <i>Russula lepida</i>	Used for cardiovascular disease, prevention of neurodegeneration	(61)
58	Quinoline alkaloid	peniprequinolone	<i>Marasmius conigenus</i>	Used to treat alleviate, cure or prevent sickness like cancer and biofilm formation	(62)
59	Quinoline alkaloids	Hydroxyquinoline - 8-carboxylic acid	Fruiting body of <i>Cortinarius subtorts</i>	Showed antioxidant activity and inhibit the growth of phytopathogenic fungus <i>Colletotrichum coccodes</i>	(63)
60	Quinolone alkaloids	Penigequinolones A and B	<i>Penicillium cf. simplicissimum</i>	Nematicidal activity	(64)
61	Racemic alkaloids	Ganocochlearines C - I	Fruiting bodies of <i>Ganoderma cochlear</i>	Showed biological activities toward renal fibrosis in rat normal	(65)
62	Sesquiterpene alkaloids	Conoramides A-C	<i>Irpex consors</i>	Possess antioxidant and antibacterial activity	(66)
63	γ - lactam pyrrolidinone alkaloids	Lepiotins B - C	<i>Macrolepiota neomastoidea</i>	Showed Antifungal activities	(67)
64	β -carboline alkaloid	Brunnein - type	<i>Cyclocybe cylindracea</i>	Showed explicit radical scavenging activity	(68)
65	β -Carboline alkaloids	6-hydroxymeta carboline D	<i>Mycena metata</i>	Hindered malignant cell proliferation	(69)
66	β -carboline alkaloids	Brunneins A - C	<i>Cortinarius brunneus</i>	Showed very poor cholinesterase inhibition activities	(70)
67	β -carboline alkaloids	Harmane and Norharmane	<i>Hygrophorus eburneus</i>	Showed antioxidant effects	(63)
68	β -carboline alkaloids	Brunnein A	<i>Hygrophorus hyacinthinus</i>	Showed cholinesterase inhibition	(63)

Applications:

Mushroom as Food

Mushrooms have a unique character with a deluxescent, taste, and redolence that distinguishes them from other food crops. Mushrooms are a highly nutritious, low-calorie food that contains proteins, vitamins and minerals. Mushrooms are an important natural food source and medication. Because of their high fiber, low fat and starch content, esculent mushrooms are said to be the greatest food for obese people and diabetics trying to control hyperglycemia. They are also thought to have anti-oxidative, cardiovascular, hyper-cholesterolemic, antibacterial, liver protecting and anticancer properties (71).

Antimicrobial Activity

Naturally, synthetically or semi-synthetically obtained substances that can destroy and inhibit the growth of microorganisms is called antimicrobials (72). *Osmoporous odoratus* had more antibacterial activity than ampicillin against *Staphylococcus aureus*, *Streptococcus pyogenes*, *Bacillus subtilis*, *Escherichia coli* and *Pseudomonas aeruginosa*. (73).

Phellinus fruiting bodies were found to be antibacterial against *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Salmonella typhi* and *Streptococcus mutans*, as well as antifungal against *Penicillium* sp., *Aspergillus fumigatus*, *Aspergillus niger*, *Aspergillus flavus* and *Mucor indicus*. (74)

Ganoderma lucidum also, showed antibacterial activity against 6 bacterial species such as *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Bacillus subtilis*, *Salmonella typhi*, *Pseudomonas aeruginosa*. (75)

Fruiting body of *Coriolus versicolor* of methanol extract was tested for its antibacterial activity against *Staphylococcus aureus* and *Salmonella enteritidis*. When *Staphylococcus aureus* was treated with mushroom extract, bacteria showed malformed cells when observed under scanning electron microscope, while *Salmonella enteritidis* showed shorter and aggregated cells along with damaged cell walls. (76)

Poliavirus is recognized to cause poliomyelitis, characterized by a final concretization of flaccid paralysis. Poliomyelitis occurs in poor nations. *Agaricus brasiliensis* has antiviral action against poliavirus type 1 in HEp-2 cell lines and proteins, peptides and poly-saccharo-peptides found in the mushroom fruiting body inhibit the Human Immunodeficiency Virus. (HIV) (77).

Anticancer Activity

Cancer is medically termed as malignant neoplasm - a disease involving uncontrolled cell growth. It is a destructive disease that spread to large areas of body via the lymphatic system or through bloodstream (78). In part of Eastern Europe, *Inonotus obliquus* have been utilized as a medicine for the cancer treatment because of the occurrence of the triterpenes and ergosterol peroxide. *Pleurotus rimosus* showed anticancer activity against Dalton's Lymphoma Ascites (DLA) cell line and also Ehrlich ascites carcinoma cell line prompted solid tumor model in mice. *Lentinus edodes*, *Schizophyllum commune*, *Grifolafrondsia* and *Sclerotinia*

sclerotiroum are known to show anticancer activity (79).

Anti-Diabetic Activity

Diabetes is a serious condition that affects millions of people throughout the world. Diabetes mellitus is a group of metabolic diseases characterized by elevated blood glucose levels caused by insulin variability within the body (80). *Pleurotus florida* contains flavonoids, alkaloids, terpenoids, tannins, saponins and phenols, all of which have anti-diabetic properties and lower blood glucose levels (81).

Ophiocordyceps sinensis is an edible and medicinal mushroom that has been used in nutraceutical medications for diabetes and antihyperglycemic properties. (82)

Grifola frondosa fruiting body extracts contain bioactive components that, when administered orally, help to reduce blood glucose levels in genetically predisposed diabetic rats. Mushrooms contain mostly -glucans and polysaccharides, which have the potential to restore pancreatic tissue activity by increasing insulin secretion by beta cells, lowering blood glucose levels. It has been shown to improve insulin sensitivity in peripheral tissues. *Agaricus blazei*, *Trametes pubescence*, *Pleurotus citrinopileatus* and *Grifola frondosa* have also been demonstrated to have hyperglycemic effects in rats (83).

Hepatoprotective Activity

The liver plays an important function in metabolism and toxic substance detoxification by reducing exposure to chemical contaminants such as medicines during disease within the body (84). *Ganoderma lucidum* protects the liver from Bacillus Calmette Guerin vaccine-induced liver injury in rats, while *Agaricus blazeimurill* has been shown to treat Hepatitis B and liver damage in humans (85).

Anti-Inflammatory Activity

Inflammation is a normal response to infection that involves both the innate and adaptive immune systems. The substance that reduces inflammation in any parts of the body is called anti-inflammatory (86). *Morchella esculenta* is known for its anti-inflammatory properties. Based on concentration, it inhibits both acute and chronic inflammation in a mouse model, which is equivalent to normal Diclofenac. *Ganoderma lucidum* is detected in carrageen-induced acute and formalin-induced chronic inflammatory conditions in mice (87).

Antioxidant Activity

Oxidation is needful in several living organisms for the synthesis of energy to fuel biological process. Nevertheless, unconstrained oxygen derived free radicals, production lead in the outset of several diseases like, rheumatid, cancer, arthritis and atherosclerosis. The substrate that prevents the oxidation of molecules inside a cell is called antioxidant (88). *Ganoderma lucidum* extremely inhibit oxygen and hydroxyl radicals but aqueous extract not able to inhibit ferrous ion induced lipid peroxidation however, mycelium ethanol extracts of *Ganoderma lucidum* is great as activity of antiperoxidative (89).

Immunomodulatory Activity

The combination of vitamin A, B, C involute, fiber, minerals and other bioactive substances in mushroom is primary

healing needful to enhance the human system against infection causing microorganisms(84). *Ganoderma lucidum* possess a high dosage of organic germanium, triterpenes and polysaccharides, these active constituents have been proven to potential, regulate, immune system and remove allergic reactions like asthma, rheumatoid, arthritis and lupus. And also, some studies on mushroom had proven that bioactive substances which are present in eatable mushroom enhance circulation of blood, enhance the functions of immune cells like macrophages, natural killer cells and T- cells and hence, decrease the formation of tumor. *Lentinus edodes* possess lentinan that stimulates the synthesis of immune system like interleukin and tumor necrosis factor which aid to control the spreading of cancer.

Ganoderma lucidum stimulated the interleukin -II synthesis because of the occurrence of ganodermic acid, which has good activity against liver cancer. Most significantly, mushrooms possess a large number of biologically active polysaccharides, which are familiar to show activity as biological response modifiers. These modifiers are compounds that initiate the body's response to diseases and infections. They possess repetitive structural properties that are the monosaccharides polymer residues connected to each other through glycosidic bond. This provides a high capacity for transferring biological data due to their variation in structure, they have ability to interlink at many points to form a large range of straight and branched molecules that will transfer various biological data (90).

Against Cardiovascular Disease

Cardiovascular disease is distinguished by the presence of high levels of low-density lipoprotein (LDL) and low levels of high-density lipoprotein (HDL), resulting in an increasing total cholesterol ratio to HDL cholesterol, which is the primary cause of cardiovascular disease onset (91). *Grifola frondosa*, *Pleurotus eryngii* and *Hypsizygus marmoreus* are used as biomarkers for atherosclerosis-prone C57BL/6J mice and they reduce total cholesterol levels in the human body. They include bioactive components that regulate cardiovascular disease in humans. The *Agaricus bisporus* and *Tricholoma matsutake* fruiting bodies of the crude extract contain bioactive inhibitory peptides that block angiotensin activity, altering the enzyme responsible for hypertension and cardiovascular disease (92).

Antiasthmatic Agent

Asthma is a respiratory disorder that affects both adults and children. Allergen exposure triggers and exacerbates asthma symptoms (93). *Flammulina velutipes* possess fungal immunomodulatory proteins. Oral administration of this protein caused chronic airway inflammation in a mouse asthma model. This allergy is dependent on the balance of type 1 T helper cells and type 2 T helper cells. *Cordyceps sphecocephala* mycelia extract was injected into ovalbumin-induced asthmatic mice's lung cells to test its anti-asthmatic activity (94).

Anti-Obesity Activities

Obesity is a critical global health issue that has been linked to the development of many diseases such as diabetes and hyperlipidemia (95). *Pleurotus florida* has been shown to have

beneficial effects against obesity; administration to rats on a high-cholesterol diet inhibits weight gain and lowers total cholesterol. Low density lipoprotein and even triglycerides are reduced, as is fat deposition within the bodies of obese mice. -glucan invenit in *Pleurotus sajor-caju* inhibits obesity in obese rats fed a high-fat diet. An *in vitro* study found that *Pleurotus eryngii* reduces pancreatic lipids. *Grifola frondosa* also inhibits pancreatic lipase by preventing the hydrolysis of 4-methylumbelliferyl (96).

Anti - Ageing Features

Aging is the gradual contraction of homeodynamic space. Biologically speaking, the survival of an organism is a continuous struggle between biochemical damage and repair (97). *Tricholoma lobayense* contains several bioactive substances in control of anti - senescence activity. Purified TLH-3 polysaccharide from the *Tricholoma lobayense* fruiting body exhibits anti - senescence activity when quantified in D-galactose -induced aged rat model.

The pure *Ganoderma lucidum* methanol extract contains 2 novel anti-reinforcement ergosterols, ganodermasidase A and B, which increase the replicative life span of *Saccharomyces cerevisiae* via modulating the expression of oxidative stress-responsive genes UTH1. Polysaccharides, polyphenolics, phenolics, selenium, vitamins, terpenoids and volatile organic compounds extracted from various medicinal mushroom fruiting bodies have been demonstrated to have significant antioxidant, anti-aging, anti-wrinkle, skin-whitening and moisturizing properties (98).

A polysaccharide derived from *Auricularia auricular* inhibits oxidative stress in D-galactose-induced old mice. Polysaccharide paste is used to make anti-aging creams, lotions and other cosmetics in the business. These polysaccharides have the ability to reverse aging by inhibiting functional enzymes responsible for skin aging such as elastase, tyrosinase, hyaluronidase and others. Additionally, these polysaccharides help to restore skin suppleness and stimulate collagen expression production (99).

Nematicidal Activity

Chemical compounds from mushrooms that kill, inhibit or repel nematodes or manipulate their behavior to mitigated crop damage is called nematicidal (100). Extracted *Flammulina velutipes* and its Spent Mushroom Compost (SMC) showed vital nematicidal activity on larvae of *Panagrellus* species. The active substances of SMC extract exhibited nematicide activity with diminish percentages of 43 and 57 percentage at 24 and 48 hours of incubation respectively. Nematicidal activity of isolated fungus and its SMC is because of enzyme activity and metabolites. SMC showed better nematicidal activity than the extracted fungus (101)

Pleurotus ostreatus is extracted by using water to study the nematicidal activity on *Haemonchus contortus* eggs and infective larvae *in vitro*. *Pleurotus ostreatus* were able to inhibit the larval hatching completely at the concentration of 2.24mg/mL and 0.73 mg/mL EC₅₀. From the chemical analysis is got to know that, nematicidal activity of extracted fungus is due to the presence of tridecanoic, tetradecanoic, linoleic, 9,15-octadecadienoic and oxalic acids. (102)

Antihelmintic Activities

Antihelminthics are a group of antiparasitic drugs that expel helminths from the body by either stunning or killing them and without causing significant damage to the host (103). Antihelmintic activity of *Albatrellus confluens* was studied by using bioassay guided isolation on *Caenorhabditis elegans*. From the chemical analysis it was cleared that, Grifolin and Neogrifolin compounds were responsible for the activity of antihelmintic (104).

In another case, *Pleurotus ostreatus* fermented coffee husk extract on *Ascaridia galli* to test the antihelmintic efficacy of 2 distinct solvents, ethanolic acid and water. An *in vitro* investigation of antihelmintic action was conducted by counting various stages of water and ethanolic extract of fermented coffee husk, such as 0 - 4 % (W/V) and compared to piperazine 0.5 % (W/V) and sodium chloride 0 and 9 %. The fermented coffee husk ethanolic extract shown superior antihelmintic action than water extract and *Ascaridia galli* mortality at a concentration of 2 % (105). *In vitro* anthelmintic potential of mushroom enzyme hydrolysates on the *H. contortus* larval development. The mushroom protein hydrolysates (MPH) were prepared from trypsin, papain and pepsin. The MPHs were used to evaluate their *in vitro* anthelmintic activity using larval development assay. The results revealed that papain mushroom protein hydrolysate showed 100 % mortality of *H. contortus* larvae compared to pepsin and trypsin mushroom hydrolysates. It is concluded that the oyster mushroom can be the potential alternate to anthelmintic drugs for the control of *H. contortus* (103).

Conclusion

Mushrooms were capable of producing over 140 natural secondary metabolites using an indole heterocycle. Secondary metabolites such as alkaloids are derived from a variety of mushrooms. We identified 68 different types of alkaloids, including 24 indoles, 5 β -carboline and Pyrroloquinoline, 4 pyrrole, and 3 quinolines. Mushroom alkaloids are used as nutrients in food. Bioactivities include antimicrobial, antiviral, nematocidal and antihelmintic action, anticancer activity, anti-diabetic activity, anti-obesity activity, anti-aging activity, etc are some of the medicinal and pharmacological functions. The mushroom alkaloids extracted from basidiocarps will be useful in pharmacological preparations and products development. So further research was required to purify, synthesizing, commercialization of these mushroom alkaloids.

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Authors' contributions

AO carried out the extensive literature survey and drafted the manuscript. NPK participated in its designing the manuscript and coordinated all the necessary correction. All authors read and approved the final manuscript.

Compliance with ethical standards

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