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# 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 $\beta$- 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, nematicidal, helmintic, 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; nematicidal; immunomodulatory; neutraceuticals

## 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 14$^{th}$ 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 *Lactarious sanguiffus* 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 fuscosuccinea* 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. Triterpinoids, 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 $\beta$ - 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, $\gamma$ - Pyrrolidinone, Indolinone, Sesquiterpene, Phenoxazone, Quaternary, Isoindolinone, Quinolone, Racemic, Cytochalasin, Hetero - spirocyclic $\gamma$ - 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 | *Laccaria vinaceoavellanea* | Exhibited phosphodiesterase inhibitory activities | (11) |
| 2 | Cytochalasin alkaloids | Armochaetoglobins S - Z | *Chaetomium globosum* 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 | *Laccaria proxima* | Showed herbicidal activities against *Lepidium sativum* | (13) |
| 4 | Diketopiperazine alkaloid | Rosellin A and B | *Mycena rosella* | Root exposure to rosellin bleached the leaves of *Lepidium sativum* plants act as herbicide and protects from predators. | (14) |
| 5 | Diketopiperazine alkaloids | 12$\beta$ hydroxyverruculogen TR-2, Fumitremorgin C and Methylthiogliotoxin | Mycelia of the basidiomycete *Hericium erinaceum* | Showed potential antioxidant activity | (15) |
| 6 | Hetero-spirocyclic γ -lactam alkaloids | Pseurotin A, Cerevisterol, FD-838 and Herierin IV | Mycelia of the basidiomycete *Hericium erinaceum* | Inhibited the growth of 2 fungal diseases, *Botrytis cinerea* and *Glomerella cingulata.* | (15) |
| 7 | Indole alkalaoids | 1H-indole-3-carboxylic acid; 1-(1,1-dimethyl-2-propenyl) methyl ester | *Aporpium caryae* | Showed Antifungal activity on *Cladosporium cucumerinum* | (16) |
| 8 | Indole alkaloid | Macrolepiotin | *Macrolepiota neomastoidea* | Displayed cytotoxicity activities | (17) |
| 9 | Indole alkaloid | flazin | *Boletus umbriniporus* | Showed biological activities like antioxidant, antimicrobial, antiparasitic, antiviral | (18) |
| 10 | Indole alkaloid | Psilocin | *Psilocybe cubensis* | Used for drug discovery in central nervous system disorder | (19) |
| 11 | Indole alkaloid | Sciodole, 1,7 - bi-5-methoxy-2,4dimethylindole | *Tricholoma sciodes* | Pharmacological activities like anticancer, antimicrobial, antiviral, antimalarial, antitubercular, anti-inflammatory | (20) |
| 12 | Indole alkaloid | Sinensines B - E | *Ganoderma sinense* | Function in protecting the injury induced | (21) |
| 13 | Indole alkaloid | Harmane and Norharmane | *Hygrophorous eburneus* | Used as acetylcholinesterase inhibitors, exhibited pharmacological and neurotransmitters tests with monoamine oxidase - A and topoisomerase | (22) |
| 14 | Indole alkaloid | Echinuline | *Lentinus strigellus* | Antimycobacterial activity | (23) |
| 15 | Indole alkaloid | Brunneins A- C | *Cortinarius brunneus* | Showed cholinesterase enzyme inhibition | (24) |
| 16 | Indole alkaloid | Norharmane | Fruiting bodies of the *Hygrophorus hyacinthinus* | Antimycobacterial activities | (24) |
| 17 | Indole alkaloids | Gymnopilin K | *Gymnopilus spectabilis* | Exhibited noticeable cytotoxicity toward some human cancer cell lines | (25) |
| 18 | Indole alkaloids | agrocybenine | *Agrocybe cylindracea* | Showed anticancer activity | (26) |
| 19 | Indole alkaloids | Strobilurins A and B | *Strobilurus tenacellus* | Showed antifungal and antibacterial activity | (27) |
| 20 | Indole alkaloids | 6-hydroxy-1H-indole-3-carboxaldehyde, and 6-hydroxy-1H-indole-3-acetamide | *Agrocybe cylindracea* | Inhibited lipid peroxidation in rat liver microsomes, with $IC_{50}$ values of 4.1 and 3.9 µg/mL. | (28) |

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

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

Poliovirus is recognized to cause poliomyelitis, characterized by a final concretization of flaccid paralysis. Poliomyelitis occurs in poor nations. *Agaricus brasiliensis* has antiviral action against poliovirus 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*, *Grifolafrondsa* 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, Pleurotous 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*are 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 frondose, 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 $EC_{50}$. From the chemical analysis is got to know that, nematicidal activity of extracted fungus is due to the presence of tridecanoic, tetradecanoic,

linolelaidic, 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, nematicidal 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

**Conflict of interest:** Authors do not have any conflict of interests to declare..

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## References

1. Ergonul PG, Akata I, Kalyoncu F, Ergonul B. Fatty acid compositions of six wild edible mushroom species. Sci World J. 2013;4. https://doi.org/10.1155/2013/ 163964
2. Ramsbottom J. Mushrooms, toadstools: a study of the activities of fungi. London: Collins. 1954;306.
3. Wannet WJB, Hermans JHM, Drift CVDD, Camp HJMOD. HPLC detection of soluble carbohydrates involved in mannitol and trehalose metabolism in the edible mushroom *Agaricus bisporus*. J Agricult and Food Che. 2000;48(2):287–91. https://doi.org/10.1021/jf990596d
4. Waktola G, Temesgen T. Application of mushroom as food and medicine. Adv in Biotech and Microbio. 2018;11(4):2474-637. https://doi.org/10.19080/AIBM.2018.11. 555817
5. Pusztahelyi T, Holb IJ, Pocsi I. Secondary metabolites in fungus - plant interactions. Front Plant Sci. 2015;6:573. https://doi.org/10.3389/fpls.2015.00573
6. De-Leon AM, Orpilla JOV, Cruz KV, Dulay RMR, et al. Optimization of mycelial growth and mycochemical screening of *Lentinus sajor -caju* (fr.) from Banaue, Ifugao Province, Philippines. Int J Agri Tech. 2017;13(7.3):2549-67.
7. Romorosa ES, De-Guzman CT, Martin JRG, Jacob JKS. Preliminary investigation on the pharmacological properties of wood-rotting mushrooms collected from Isabela State University, Echague, Isabela, Philippines. Int J Agri Tech. 2017;13(7.3):2591-96.
8. Azeem U, Dhingra GS, Shri R. Evaluation of taxonomy, physicochemical parameters and mycochemical composition of wood decaying indian fungi *Phellinus gilvus* (Schwein.) Pat. and *Phellinus torulosus* (Pers.) Bourdot & Galzin: A Comparative Study. Int J Phytopharm Res. 2018;9(1):17-25.
9. Zhang JJ, Li Y, Zhou T, Xu PD, et al. Bioactivities and health benefits of mushrooms mainly from China. Molecules. 2016;21 (7):938. https://doi.org/10.3390/ molecules21070938
10. Hobbs C, Medicinal mushrooms. An exploration of tradition, healing and culture. Botanica Press, Summertown, Tennessee, USA; 1995.
11. Matsuda M, Kobayashi T, Nagao S, Ohta T, Nozoe S. Laccarin, a new alkaloid from the mushroom, *Laccaria vinaceoavellanea*. Heterocycles. 1996;43(3):611-17. https://doi.org/ 10.3987/COM-95 -7365
12. Chen C, Tong Q, Zhu H, Tan D, Zhang J, et al. Nine new cytochalasan alkaloids from *Chaetomium globosum* TW1-1 (Ascomycota, Sordariales). Sci Rep. 2016;6(1):1-8. https://doi.org/10.1038/ srep18711
13. Schrey H, Spiteller PE. Z- Proxamidines, Unprecedented 1,3 Diazacyclooct-1-ene alkaloids from fruiting bodies of *Laccaria proxima*. Che. 2019;25(34):8035-42. https://doi.org/10.1002/ chem.201900566

14. Lohmann JS, Nussbaum MV, Brandt W, Mulbradt J, et al. Rosellin A and B, two red diketopiperazine alkaloids from the mushroom *Mycena rosella*. Tetrahed. 2018a;74(38):5113-18. https://doi.org/10.1016/j.tet.2018.06.049

15. Lu QQ, Tian JM, Wei J, Gao JM. Bioactive metabolites from the mycelia of the basidiomycete *Hericium erinaceum*. Natural Product Research. 2014;28(16):1288-92. https://doi.org/10.1080/14786419.2014.898145

16. Levy LM, Cabrera GM, Wright JE, Seldes AM. Indole alkaloids from a culture of the fungus *Aporpiumcaryae*. Phytochem. 2000;54 (8):941-43. https://doi.org/10.1016/S0031-9422(00)001217-8

17. Kim KH, Park KM, Choi SU, Lee KR. Macrolepiotin, a new indole alkaloid from *Macrolepiota neomastoidea*. J Antibiot. 2009;62:335 -38. https://doi.org/10.1038/ja. 2009.30

18. Lee YJ, Hwang BS, Song JG, Kim DW, et al. An indole alkaloid from the fruiting body of *Boletus umbriniporous*. Kore J Mycol. 2015;43 (1):68-70. https://doi.org/10.4489/KJM.2015.431.1.68

19. Rafati H, Riahi H, Mohammadi A. Enhancement of indole alkaloids produced by *Psilocybe cubensis* (Earle) Singer (Agaricomycetideae) in controlled harvesting light conditions. Int J Med Mushr. 2009;11(4):419-26. https://doi.org/10.1615/intJMedMushr.v11.i4.80

20. Sterner O. The isolation and structure determination of Sciodole, a new indole derivative from the fruit bodies of *Tricholomasciodes*. Nat Prod Lett. 2006;4(1):9-14. https://doi.org/10.1080/10575639408043885

21. Liu JQ, Wang CF, Peng XR, Qiu MH. New alkaloids from the fruiting bodies of *Ganoderma sinense*. Nat Prod Bioprospect. 2011;1:93-96. https://doi.org/ 10.1007/ s13659-011-0026-4

22. Teichert A, Lubken T, Schmidt J, Kuhnt C, Huth M, et al. Determination of beta-carboline alkaloids in fruiting bodies of *Hygrophorous* species by liquid chromatography/ electro-spray ionization tandem mass spectrometry. Phytoche Anal. 2008;19 (4):335-41. https://doi.org/10.1002/pca.1057

23. Filho BAB, Oliveira MCFD, Mafezoli J, Barbosa FG, Filho ER. Secondary metabolite production by the basidiomycete, *Lentinus strigellus*, under different culture conditions. Nat Prod Commun. 2012;7(6):771-73. https://doi.org/10.1177/ 1934578X1200700620

24. Jiang MY, Feng T, Liu JK. N - Containing compounds of macromycetes. Nat Prod Rep. 2011;28(4):783-08. https://doi.org/10.1039/c0np00006j

25. Kim KH, Choi SU, Lee KR. Gymnopilin K: a new cytotoxic gymnopilin from *Gymnopilus spectabilis*. J Antibiot (Tokyo). 2011;135-37. https://doi.org/10.1038/ja. 2011.122

26. Koshino H, Lee IK, Kim JP, Kim WG, et al. Agrocybenine, novel class alkaloid from the Korean mushroom *Agrocybe cylindracea*. Tetrahed Let. 1996;37(26):4549-50. https://doi.org/10.1016/0040-4039(96)00900-8

27. Anke T, Oberwinkler F, Steglich W, Schramm G. The strobilurins - new antifungal antibiotics from the basidiomycete *Strobilurus tenacellus*. J Antibiot (Tokyo). 1977;30(10): 806-10. https://doi.org/10.7164/antibiotics.30.806.

28. Kim WG, Lee IK, Kim JP, Ryoo IJ, et al. New indole derivatives with free radical scavenging activity from *Agrocybe cylindracea*. J Nat Prod. 1997;60(7):721-23. https://doi.org/10.1021/np970150w

29. Samchai S, Seephonkai P, Kaewtong C. Two indole derivatives and phenolic compound isolated from mushroom *Phellinus linteus*. Chin J Nat Med. 2011;9(3):173-75. https://doi.org/10.3724/SP.J.1009.2011.00173

30. Chen M, Wang SL. Two new compounds from cultures of the basidiomycete *Antrodiella albocinnamomea*. Nat Prod Res. 2015;29(21):1985-89. https://doi.org/10.1080/14786419.2015.1017493

31. Wittstein K, Rascher M, Rupic Z, Lowen E, Winter B, et al. Corallocins A - C, nerve growth and brain - derived neurotrophic factor inducing metabolites from the mushroom *Hericium coralloides*. J Nat Prod. 2016;79(9):2264-69. https://doi.org/10.1021/acs.jnatprod.6b00371

32. Stachel SJ, Nilges M, Vranken DLV. Synthesis and isomerization of biindolinones from *Collybia peronata* and *Tricholomas calpturatum*. J Org Chem. 1997;62(14):4756-62. https://doi.org/10.1021/jo970388p

33. Geissler T, Brandt W, Porzel A, Schlenzig D, et al. Acetyl cholinesterase inhibitors from the toadstool *Cortinarius infractus*. Bioorg Med Chem. 2010;18(6):2173-77. https://doi.org/10.1016/j.bmc.2010.01.074

34. Kumar D, Vaya D, Chundawat TS. Total synthesis of 6-hydroxymetatacarboline-d discovered from *Mycena metata* via the Pictet - Spengler reaction followed by the Horner - Wadsworth - Emmons reaction. Acs Omega. 2021;6:8933-41. https://doi.org/10.1021/ acsomega.0c06202

35. Shao D, Tang S, Healey RA, Imerman PM, et al. A novel orellanine containing mushroom *Cortinarius armillatus*. Toxicon. 2016;114:65-74. http://dx.doi.org/10.1016/j.toxicon.2016.02.010

36. Buechel E, Martini U, Mayer A, Anke H, Sterner O. Omphalotins, B, C and D, nematicidal cyclopeptides from *Omphalotus olearius*. Absolute configuration of omphalotin A. Tetrahedron. 1998;54 (20):5345-52. https://doi.org/10.1016/s00404020(98) 002099

37. Yu X, Muller WEG, Guo Z, Lin W, et al. Indole alkaloids from the coprophilous fungus *Aphanoascus fulvescens*. Fitoterpia. 2019;136. https://doi.org/ 10.1016/j.fitote.2019.05.007

38. Tsujikawa K, Kanamori T, Iwata Y, Ohmae Y, et al. Morphological and chemical analysis of magic mushrooms in Japan. Forensic Science International. 2003;138:85-90. https://doi.org/10.1016/j.forsciint.2003.08.009

39. Wang K, Bao L, Ma K, Liu N, Huang Y, et al. Eight new alkaloids with PTP1B and α - glucosidase inhibitory activities from the medicinal mushroom *Hericium erinaceus*. Tetrahedron. 2015;71 (51):9557-63. https://doi.org /10.1016/j.tet.2015.10.068

40. Kim KH, Noh HJ, Choi SU, Lee KR. Isohericenone, a new cytotoxic isoindolinone alkaloid from *Hericium erinaceum*. J Antibiot. 2012;65:575-77. https://doi.org/10.1038/ ja.2012.65

41. Quang DN, Schmidt J, Porzel A, Wessjohann L, Haid M, Arnold N. Ampullosine, a new isoquinoline alkaloid from *Sepedoniumam pullosporum* (Ascomycetes). Nat Prod Commu. 2010;5(6):869-72. https://doi.org/10.1177/1934578X 1000500609

42. Valle PD, Martinez AL, Figueroa M, Raja HA, Mata R. Alkaloids from the fungus *Penicillium spathulatum* as α - glucosidase inhibitors. Planta Medica. 2016;82(14):1286-94. https://doi.org/10.1055/s-0042-111393

43. Filer CN. Ibotenic acid: on the mechanism of its conversion to [$^3$H] muscimol. J Radioanal and Nucl Che. 2018;318: 2033-38. https://doi.org/10.1007/ s10967-018-6203-8

44. Gore MG, Jordan PM. Microbore single - column analysis of pharmacologically active alkaloids from the fly agaric mushroom *Amanita muscaria*. J Chromato A. 1982;243(2):323-28. https://doi.org/10.1016/S0021-9673(00)82424-3

45. Quang DN, Spiteller P, Porzel A, Schmidt J, et al. Alkaloids from the mushroom *Psudobaeospora pyrifera*, Pyriferines A-C. J Nat Prod. 2008;71(9):1620-22. https://doi.org/10.1021/np800365f

46. Chen Y, Lan P. Total synthesases and biological evaluation of the *Ganoderma lucidium* alkaloids Lucidimines B and C. ACS Omega. 2018;3(3):3471-81. https://doi.org/10.1021/acsomega.8b00295

47. Feng Z, Hong LW, Xin C, Shu WJ. Isolation and identification of two phenoxazone alkaloids from *Trametes cinnabarina* (Jacq.) Franeh. Nat Prod Res Dev. 2014;26(3):358-60.

48. Passie T, Seifert J, Schneider U, Emrich HM. The pharmacology of psilocybin. Addict Biol. 2006;7(4):357-64. https://

doi.org/10.1080/1355621021000005937

49. Xu ZY, Wu ZA, Bi KS. A novel norsequiterpene alkaloids from the mushroom - forming *Flammulina velutipes*. Chin Che Let. 2013;24 (1):57-58. http://dx.doi.org/ 10.1016/j.cclet.2012.11.012

50. Schmidt K, Riese U, Li Z, Hamburger M. Novel tetramic acids and pyridone alkaloids, militarinones B, C and D, from the insect pathogenic fungus *Paecilomyces militaris*. J Nat Prod. 2003;66 (3):378-83. https://doi.org/ 10.1021/np020430y

51. Wangun HVK, Hertweck C. Epicoccarines A, B and epipyridone: tetramic acids and pyridine alkaloids from an *Epicoccum* sp. associated with the tree fungus *Pholiota squarrosa*. Org Biomol Chem. 2007;5:1702-05. https://doi.org/10.1039/B702378B

52. Sun Z, Hu M, Sun Z, Zhu N, Yang J, et al. Pyrrole alkaloids from the edible mushroom *Phlebopus portentosus* with their bioactive activities. Molecules. 2018;23(5):1198. https://doi.org/10.3390/molecules23051198

53. Sakamoto T, Nishida A, Wada N, Nakamura Y, et al. Identification of a novel pyrrole alkaloid from the edible mushroom *Basidiomycetes -X* (Echigoshirayukidake). Molecules. 2020;25 (21):4879. https://doi.org/10.3390/molecules 25214879

54. Isaka M, Rugseree N, Maithip P, Kongsaeree P, et al. Hirsutellones A - E, antimycobacterial alkaloids from the insect pathogenic fungus *Hirsutella nivea* BCC 2594. Tetrahedron. 2005;61(23):5577-83. https://doi.org/10.1016/ j.tet.2005.03.099

55. Peters S, Spiteller P. Sanguinones A and B, blue pyrroloquinoline alkaloids from the fruiting bodies of the mushroom *Mycena sanguinolenta*. J Nat Prod. 2007a;70(8):1274-77. https://doi.org/10.1021/np070179s

56. Pulte A, Wagner S, Kogler H, Spiteller P. Pelianthinarubins A and B, red pyrroloquinoline alkaloids from the fruiting bodies of the mushroom *Mycena pelianthin*a. J Nat Prod. 2016;79(4):873-78. https://doi.org/10.1021/acs.jnatprod.5b00942

57. Himstedt R, Wagner S, Jaeger RJR, Backenkohler JMLL, et al. Formaldehyde as a chemical defence agent of fruiting bodies of *Mycena rosea* and its role in the generation of the alkaloid Mycenarubin C. Chem Bio Chem. 2020;21(11):1613-20. https://doi.org/10.1002/cbic.201900733

58. Lohmann JS, Wagner S, Nussbaum MV, Pulte A, et al. Mycenafavin A, B, C and D: pyrroloquinoline alkaloids from the fruiting bodies of the mushroom *Mycena haematopus*. Chemistry. 2018;24 (34):8609-14. https://doi.org/10.1002/chem. 201800235

59. Peters S, Spiteller P. Mycenarubins A and B, red pyrroloquinoline alkaloids from the mushroom *Mycena rosea*. Eur J Org Chem. 2007b;10:1571-76. https://doi.org/ 10.1002/ejoc.200600826

60. Unger SE, Vincze A, Cooks RG, Chrisman R, Rothman LD. Identification of quaternary alkaloids in mushroom by chromatography/secondary ion mass spectrometry. Anal Chem. 1981;53(7):976-81. https://doi.org/10.1021/ac00230a012

61. Tan J, Dong Z, Hu L, Liu J. Lepidamine, the first Aristolane - type sesquiterpene alkaloid from the Basidiomycete *Russula lepida*. Helvetica Chimica Acta. 2003;86(2):307-09. https://doi.org/10.1002/hlca.200390032

62. Li G, Zhang K, Xu J, Dong J, Liu Y. Nematicidal substances from fungi. Recent Pat Biotechnol. 2007;1(3):212-33. https://doi.org/10.2174/187220807782330165

63. Teichert A, Schmidt J, Porzel A, Arnold N, Wessjohann L. (Iso)-quinoline alkaloids from fungal fruiting bodies of *Cortinariu ssubtortus*. J Nat Prod. 2008;71(6):1092-94. https://doi.org/10.1021/np8000859

64. Kusano M, Koshino H, Uzawa J, Fujioka S, et al. Nematicidal alkaloids and related compounds produced by the fungus *Penicillium* cf. *simplicissimum*. Biosci Biotech and Bioche. 2014;64 (12):2559-68. https://doi.org/10.1271/ bbb.64.2559

65. Wang XL, Dou M, Luo Q, Cheng LZ, et al. Racemicalkaloids from the fungus *Ganoderma cochlear*. Fitoterapia. 2017;116:93-98. https://doi.org/ 10.1016/j.fitote.2016.11.011

66. Kim JY, Ki DW, Lee YJ, Ha LS, et al. Consoramides A-C, new zwitterionic alkaloids from the fungus *Irpex consors*. Mycobio. 2021;49(4):434-37. https://doi.org/10.1080/12298093.2021.1924926

67. Kim KH, Lee K, Park KM, Kim WK, Lee KR. Isolation of γ-lactam alkaloids from the *Macrolepiota neomastoidea*. Korean Che Soc. 2008;29(8):1591-93. https://doi.org/10.5012/bkcs.2008.29.8.1591

68. Kruzselyi D, Vetter J, Ott PG, Darcsi A, Beni S, et al. Isolation and structural elucidation of a novel brunnein - type antioxidant beta-carboline alkaloid from *Cyclocybe cylindracea*. Fitoterapia. 2019;137:104-80. https://doi.org/10.1016/j.fitote.2019.104180

69. Jaeger RJR, Lamshoft M, Gottfried S, Spiteller M, Spiteller P. HR - maldi - MS imaging assisted screening of beta - carboline alkaloids discovered from *Mycena metata*. J Nat Prod. 2013;76 (2):127-34. https://doi.org/10.1021/np300455a

70. Teichert A, Schmidt J, Porzel A, Arnold N, Wessjohann L. Brunneins A - C, beta-carboline alkaloids from *Cortinarius brunneus*. Journal of Natural Products. 2007;70(9):1529-31. https://doi.org/10.1021/np070259w

71. Ho LH, Zulkifli NA, Tan TC. Edible mushroom: nutritional properties, potential nutraceutical values, and its utilisation in food product development. An introduction to mushroom. Published by Intech Open. 2020;10. https://doi.org/10.5772/intechopen.91827

72. Shari Honari RN. BSN topical therapies and antimicrobials in the management of burn wounds. Critical Care Nursing Clinics of North America. 2004;16(1):1-11. https://doi.org/10.1016/j.ccell.2003.09.008

73. Sivakumar R, Vetrichelvan T, Rajemdran NN, Devi MI, et al. Antibacterial activity of mushroom *Osmoparous odoratus*. Ind J Pharmace Sci. 2006;68(4):523-24. https://doi.org/10.4103/ 0250-474x.27836

74. Hur JM, Yang CH, Han SH, Lee SH, et al Antibactreial effect of *Phellinus linteus* against methicillin resistant *Staphylococcus aureus*. Fitoterapia. 2004;75(6):603-05. https://doi.org/10.1016/j.fitote.2004.06.005

75. Yoon SY, Eo SK, Kim YS, Lee CK, Han SS. Antimicrobial activity of *Ganoderma lucidum* extract alone and in combination with some antibiotics. Arch Pharm Res. 1994;17(6):438-42. https://doi.org/10.1007/BF02979122

76. Matijasevic D, Pantic M, Raskovic B, Pavlovic V, et al. The antibacterial activity of *Coriolus versicolor* methanol extract and its effect on ultrastructural changes of *Staphylococcus aureus* and *Salmonella enteritidis*. Front Microbio. 2016;7:1226. https://doi.org/10.3389/fmicb.2016.01226

77. Godoi AMD, Galhardi LCF, Lopes N, Rechenchoski DZ, et al. Evidence - based complementary and alternative medicine. 2014;6. https://doi.org/10.1155/2014/712634

78. Liu X, Raju P. *In vitro* cancer model for drug testing in comprehensive biotechnology (second edition). 2011;5:543-49. https://doi.org/10.1016/B978-0-08-088504-9.00502-X

79. Mishra V, Tomar S, Yadav P, Singh MP. Promising anticancer activity of polysaccharides and other macromolecules derived from Oyster mushroom (*Pleurotus* sp.). International J of Biological Macromolecules. 2021;182:628-37. https://doi.org/10.1016/ j.ijbiomac.2021.05.102

80. Ewald N, Bretzel RG. *Diabetes mellitus* secondary to pancreatic diseases (Type 3c) - Are we neglecting an important disease? European Journal of Internal Medicine. 2013;24(3):203-06. https://doi.org/10.1016/j.ejim.2012.12.017

81. Ravi B, Renitta RE, Prabha ML, Issac R, Naidu S. Evaluation of antidiabetic potential of oyster mushroom (*Pleurotus ostreatus*) in alloxan induced diabetic mice. Immunopharmacol

Immunotoxicol. 2013;35(1):101-09. https://doi.org/10.3109/08923973.2012.710635

82. Sirisidthi K, Kosai P, Jiraungkoorskul W. Antihyperglycemic activity of *Ophiocordyceps sinensis*. Indian J Agric Res. 2015;49 (5):400-06. https://doi.org/10.18805/ ijare.v49i5.5801

83. Xiao C, Jiao C, Xie Y, Ye L, et al. *Grifola frondose* GF5000 improves insulin resistance by modulation the composition of gut microbiota in diabetic rats. J Func Foods. 2021;77. https://doi.org/10.1016/j.j.ff.2020.104313

84. Ilyas U, Katare DP, Aeri V, Naseef PP. A review on hepatoprotective and immunomodulatory herbal plants. Pharmacogn Rev. 2016;10 (19):66-70. https://doi.org/10.4103/0973-7847.176544.

85. Zhao C, Fan J, Liu Y, Guo W, et al. Hepatoprotective activity of *Ganoderma lucidum* triterpenoids in alcohol induced liver injury in mice, aniTRAQ - based proteomic analysis. Food Chem. 2019;271:148-56. https://doi.org/10.1016/j.foodchem.2018.07.115

86. Azab A, Nassar A, Azab AN. Anti-inflammatory activity of natural products. Molecules. 2016;21(10):1321. https://doi.org/10.3390/molecules21101321.

87. Nitha B, Meera CR, Janardhanan KK. Anti-inflammatory and antitumour activities of cultured mycelium of morel mushroom, *Morchella esculenta*. Cur Sci. 2007;92:235-39. https://www.jstor.org/stable/24096695

88. Rajeswer Rao V. Antioxidant agents in advances in structure and activity relationship of coumarin derivatives. 2016;137-50. https://doi.org/10.1016/B978-0-12-803797-3.00007-2

89. Wong KL, Chao HH, Chan P, Chang LP, Liu CF. Antioxidant activity of *Ganoderma lucidum* in acute ethanol-induced heart toxicity. Phytothe Res. 2004;18(12):1024-26. https://doi.org/10.1002/ptr.1557

90. Wang PY, Zhu XL, Lin ZB. Antitumor and immunomodulatory effects of polysaccharides from broken spore of *Ganoderma lucidum*. Front Pharmacol. 2012;3:135. https://doi.org/10.3389/fphar.2012.00135

91. Vasatova M, Pudil R, Horacek JM, Buchler T. Current applications of cardiac troponin T for the diagnosis of myocardial damage. Advances in Clinical Chemistry. 2013;61:33-65. https://doi.org/10.1016/B978-0-12-407680-8.00002-6

92. Guillamon E, Lafuente AG, Lozano M, Arrigo AG, et al. Edible mushrooms: role in the prevention of cardiovascular diseases. Fitoterapia. 2010;81(7):715-23. https://doi.org/10.1016/j.fitote.2010.06.005

93. Quirt J, Hildebrand KJ, Mazza J, Noya F, Kim H. Asthma. Allergy Asthma Clin Immunol. 2018;14 (Suppl 2):50. https://doi.org/10.1186/s13223-018-0279-0

94. Cahng YC, Hsiao YM, Hung SC, Chen YW, et al. Alleviation of *Dermatophagoides microceras*-induced allergy by an immunomodulatory protein, FIP-fve, from *Flammulina velutipes* in mice. Biosci Biotech and Bioche. 2015;79(1):88-96. https://doi.org/10.1080/ 09168451.2014.956682

95. Safaei M, Sundararajan EA, Driss M, Boulila W, Shapi'i A. A systematic literature review on obesity: Understanding the causes and consequences of obesity and reviewing various machine learning approaches used to predict obesity. Computers in Biology and Medicine. 2021;136: https://doi.org/10.1016/j.compbiomed.2021.104754

96. Yunita EP, Yuniar AM, Kusumastuty I, Maghfirotun A, Handayani D. The effects of beta-glucan extract from oyster mushroom (*Pleurotus ostreatus*) on expression of serum malondialdehyde in sprague dawley rats induced by HFHF diet. J Phy: Confe Series. 2020;1665. https://doi.org/10.1088/1742-6596/1665/1/012035

97. Liu JK. Antiaging agents: safe interventions to slow aging and healthy life span extension. Nat Prod Bio Prospect. 2022;12:18. https://doi.org/10.1007/s13659-022-00339-y

98. Weng Y, Xiang L, Matsuura A, Zhang Y, et al. Ganodermsides A and B, two novel anti-aging ergosterols from spores of a medicinal mushroom *Ganoderma lucidum* on yeast via UTH1 gene. Bioorga and Med Che. 2010;18(3):999-02. https://doi.org/10.1016/j.bmc.2009.12.070

99. Zhang H, Wang ZY, Zhang Z, Wang X. Purified *Auricularia auricular* - judae polysaccharide (AAP I-a) prevents oxidative stress in an ageing mouse model. Carbohyd Poly. 2010;84(1):638-48. https://doi.org/10.1016/j.carbpol.2010.12.044

100. Lee CH, Lee YY, Chang YC, Pon WL, Lee SP, et al. A carnivorous mushroom paralyzes and kills nematodes via a volatile ketone. Sci Adv. 2023;9(3):4809. https://doi.org/10.1126/sciadv.ade4809.

101. Ferreira JM, Carreira DN, Braga FR, Soares FEDF. First report of the nematicidal activity of *Flammulina velutipes*, its spent mushroom compost and metabolites. 3 Biotech. 2019;9(11):410. https://doi.org/10.1007/s13205-019-1951-x

102. Matos AFID, Greesler LT, Giacometi M, Barasuol BM, et al. Nematocidal effect of oyster culinary-medicinal mushroom *Pleurotus ostreatus* (Agaricomycetes) against *Haemonchus contortus*. Int J Med Mushr. 2020;22(11):1089-98. https://doi.org/10.1615/ IntJMedMushrooms.2020036364

103. R.Edith,S.Meignanalakshmi,K.Vijayarani,M.Balagangatharathilagar. *In vitro* evaluation of antiparasitic activity of oyster mushroom (*Pleurotus ostreatus*) protein hydrolysates against *Haemonchus contortus* larvae. The Pharma Innovation Journal. 2023;12(3):5882-85.

104. Dube M, Llanes D, Saoud M, Rennert R, et al. *Albatrellus confluens* (Alb. and Schwein.) Kotl. and Pouz.: Natural fungal compounds and synthetic derivatives with *in vitro* anthelmintic activities and antiprolifertaive effects against two human cancer cell lines. Molecules. 2022; 27(9):2950. https://doi.org/10.3390/molecules27092950

105. Badarina I, Putranto HD, Sulistyowati E. *In vitro* anthelmintic activity of the extract of coffee husk fermented with *Pleurotus ostreatus* for *Ascaridia galli*. Animal Prod. 2017; 19(1):55-60. https://doi.org/10.20884/1.jap.2017.19.1.595