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A Review of *Ganoderma lucidum* Active Compounds and their Biological Applications

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ABSTRACT

Edible and medicinal mushrooms are macro fungi that belong to the Basidiomycota or Ascomycota division. *Ganoderma lucidum* is one of these medicinal mushrooms that belong to Basidiomycota fungi and is characterized by a woody texture. This medicinal mushroom is extensively found in temperate and tropical areas across Europe, North America, and Asia. Traditionally, medicinal mushrooms have been used to enhance health and treat many infectious and dangerous illnesses. *G. lucidum* contains several active compounds, including polysaccharides, triterpenoids, steroids, sterols, nucleotides, and fatty acids, and other substances that are responsible for most of its pharmacological effects, including antibacterial, antifungal, anticancer, antioxidant, anti-diabetes, hypocholesterolemia, hepatoprotective, and other biological applications. This review focused on the current state of research on *G. lucidum* chemistry and quality control, bioactivity and its mechanism, preclinical and clinical trials, and other areas.

Introduction

Mushrooms are macro fungi that belong to the Basidiomycota or Ascomycota division. They exhibit either hypogeous or epigeous growth, reaching a size that is visible to the human eye and can be manually collected. The estimated global count of distinct mushroom species is approximately 140,000. Approximately 2000 of these species are suitable for consumption, and 25 of them are extensively cultivated and harvested for food on a commercial scale or medicine fields. Mushrooms share similarities with plants because they exhibit immobility and possess cell walls. In contrast to other organisms, fungi possess a cell wall made of chitin instead of cellulose, and they do not engage in photosynthesis. Fungi obtain nourishment and essential nutrients by absorbing them from their environment [1].

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Ganoderma lucidum is one of these mushrooms that belong to Basidiomycota fungi and is characterized by a woody texture; this medicinal mushroom is extensively found in temperate and tropical areas across Europe, North America, and Asia [2]. *G. lucidum* has different common names in several languages: Reishi in Japanese, Lingzhi in Chinese, Pipa in Spanish, and Shiny Polyporus in English [3]. This mushroom lives as a saprobic fungus on a diverse range of trees belonging to several species, primarily found in the lower part of the trunks of broad leaf trees and occasionally on conifers. The species is uncommon in its natural habitat, typically found growing at the lower part of tree trunks, sometimes nearly buried, particularly on maple trees [4].

Ganoderma is a polypore mushroom that is not suitable for consumption. It has a soft texture when fresh and a flat, corky appearance with a noticeable red varnished cap in the shape of a kidney. The pores on the underside of the mushroom can range in color from white to brown back to the specimen's age. The absence of gills on its lower surface and the release of spores through

minuscule pores classify it morphologically as a polypore [5].

Ganoderma species are classified within the division Basidiomycota, specifically in the class Homobasidiomycetes or Aphyllophorales, and the family Polyporaceae [6].

G. lucidum has been documented in the ancient practice of conventional Chinese medicine for more than 2000 years. The Chinese Pharmacopoeia documents the efficacy of this substance in alleviating cough and asthma. It is also indicated for conditions such as restlessness, sleeplessness, palpitations, lung inadequacy, and consumption [7]. However, Western civilization remained unaware of the medical properties of this mushroom until the 20th century [8]. *G. lucidum*, considered a prominent medical fungus globally, is believed to possess benefits in extending lifespan and preserving vigor. Its economic worth is predicted to exceed 2.5 billion U.S. dollars [9].

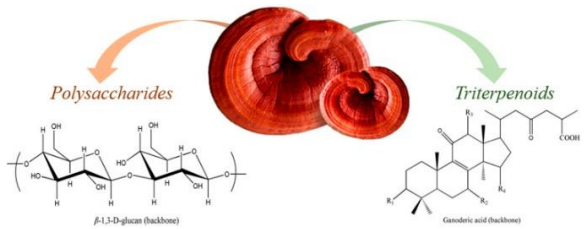
Modern studies revealed that *G. lucidum* has several active ingredients such as polysaccharides, triterpenoids, steroids, sterols, nucleotides, fatty acids, and other substances [10]. Among these substances, polysaccharides and triterpenoids are considered the primary active compounds that control most of the pharmacological actions of *G. lucidum*, including antibacterial [11], antifungal [12], anticancer [13], antioxidant [14], anti-hypertensive [15], anti-diabetes [14], hypocholesterolemia [16], hepatoprotective [17], cardioprotective [18], and neuroprotective [19].

Picture 1. Fruit body of *Ganoderma lucidum* [20]

Active compounds of *G. lucidum*

Research has focused on medicinal mushrooms, particularly their pharmacological active substances like terpenoids, lanostanoids, polysaccharides (β-glucans), polysaccharide-peptides, polysaccharide-protein complexes, lectins, sterols, alkaloids, and phenolic secondary metabolites. These compounds have been examined for their efficacy in fighting cancer, providing antioxidant effects, inhibiting tumor growth, reducing inflammation, combating microbial infections, and modulating the immune system [21].

G. lucidum has gained recognition as a substantial medicinal mushroom owing to its abundance of highly bioactive secondary metabolites with a wide range of chemical structures. The active compounds obtained from the fruiting bodies, mycelia, and spores consist of phenols, terpenoids, steroids, and nucleotides, in addition to their derivatives such as polysaccharides and glycoproteins [22]. Polysaccharides and triterpenoids serve as important indicators that are advantageous in managing many ailments [23]. The present review focused on *G. lucidum* triterpenoid (GLT) and polysaccharide (GLP) chemistry, extraction, and medical applications.



Picture 2. *G. lucidum* β-1,3-glucan and ganoderic acid [24].

Triterpenoids

Herbs have a wide distribution of triterpenoids. About 20,000 triterpenes were discovered and characterized. These triterpenes encompass structures such as dammarane, lupine, squalene, lanostane, oleanane, ursane, and hopane types [25].

The chemical compositions of GLTs are derived from lanostane, a compound formed from lanosterol through squalene cyclization during biosynthesis [26]. After cultivation, the mature fruit bodies of *G. lucidum* are harvested and subjected to a series of procedures to extract triterpenes. In 1982, the first triterpenoids, ganoderic acid A and ganoderic acid B, were isolated from *G. lucidum* [27].

Triterpenoids are a specific class of terpenes consisting of six isoprene units. They have either cyclic

or linear chemical structures, stemming from the existence of isoprene units. Ganoderic acid is a specified class of triterpenes consisting of two linear isoprenes and four cyclic isoprenes. More than 140 species of ganoderic acid were isolated from *G. lucidum* [28].

GLTs have chemical structures that are more complicated than lanostanes, which are present in other types, because triterpenoids are highly oxidized states. The triterpenoid lanostane produced from *G. lucidum* is believed to be the primary active compound responsible for some anticancer properties found in preclinical research. The triterpenoid lanostane identified in this mushroom can be categorized into two groups: ganoderic acid, which has a carboxyl group on the side chain, and ganoderma alcohol, which has a hydroxyl group on the moiety of lanostane [29]. GLTs consist of 30 or 27 carbon atoms, and a small number of these triterpenoids contain 24 carbons. Generally, GLTs may include lucidenic or ganoderic acids, which are isolated from different regions of the mushroom, including the fruit body and gill surface [30].

Extraction of GLTs

Organic solvent extraction

One of the most used extraction methods of GLTs is the usage of organic solvents such as ethanol, methanol and chloroform. It is a difficult method that needs a large amount of solvents. However, this method is commonly conducted in laboratories for GLT extraction [31].

Ultrasound extraction

This method is an alternative for the conventional organic solvent extraction. The advantages of this method include decreased solvent usage, decreased extraction periods, and enhanced extraction efficacy [31].

Microwave extraction

This method significantly decreased the required time and reached a better result. Chen, *et al.* [32] used microwave extraction to isolate GLTs. Their findings showed that the process of extraction lasted 5 min only, yielding a triterpenoid extraction efficiency of 0.968%. The suitable conditions for this method to isolate GLTs are as follows: time of 5 min, temperature of 90 °C, and 95% ethanol as a solvent [32].

Supercritical fluid method

This method employs supercritical carbon dioxide as a solvent without using any organic solvents; it is considered environmentally friendly. The active compounds remain stable during the extraction process due to the low temperature of below 35 °C. The extraction conditions are as follows: temperature of 35 °C, pressure of 15 MPa, time of 120 min, CO_2 flow rate of 1 mL/min, and back pressure temperature of 50 °C [31, 33].

Polysaccharide

GLPs consist of elongated sugar molecules connected by glycosidic linkages. Different GLPs were isolated from different parts of the mushroom such as the fruit body and mycelia [34].

Several recent investigations have documented the isolation and purification of over 200 polysaccharide fractions from different parts of *Ganoderma*, including the fruit body, spore, mycelium, and culturing broth [35].

GLPs are macromolecules with a molecular weight (MW) ranging from 103 Da to 106 Da. The majority of these compounds are β-glucans, which contain monosaccharide residues as their side chains. The 3D structure of GLPs, precisely a helical shape, is responsible for several bioactivities. GLPs exhibit solubility in water but are insoluble in alcohol. The typical approach for isolating GLPs comprises extracting them with water and precipitating them with alcohol. The water-extraction product often has a low viscosity, allowing easy filtration to produce crude GLP precipitate [36].

Currently, the research on β-D-glucans mostly revolves around their activity as biological response modifiers. Key structural parameters include MW, monosaccharide compositions, glycosidic linkage quantities, main and branch chain arrangements, and varieties and quantities of alternatives. The glycosidic bonds in the main chain may consist of one type or a combination of α-(1→3) glucan, α-(1→6) glucan, mannan, and galactosan, along with α, β-glucans or other types of connections [37].

Extraction of GLPs

Hot water extraction

GLPs exhibit solubility in water and insolubility in organic solvents. Thus, hot water extraction is currently the most common method used to extract GLPs. Typically, the mushroom material is extracted using boiling water because high temperature causes the material to expand significantly, facilitating the release of chemicals within the cells and enhancing the solubility of polysaccharides. In traditional investigations, polysaccharide is obtained by extracting it with water at temperatures ranging from 95 °C to 100 °C, using a ratio of one-part material to 10–15 parts liquid, for a duration of 1 h. This process is conducted two or three times [31].

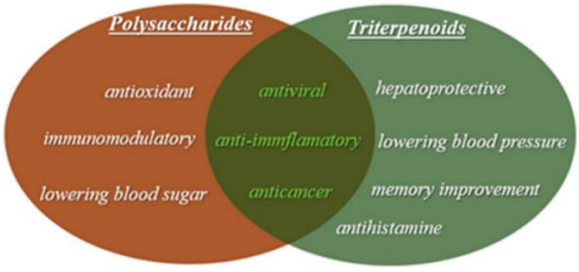
Alkaline or acid extraction

Chemical agents, such as alkaline or acid, are employed to isolate polysaccharides that have a high MW or insolubility in water [31]. According to Huang, *et al.* [38], polysaccharide production increased by twofold when a solvent containing 5.1% NaOH was used at 60.1 °C for 77.3 min.

Many novel extraction methodologies, such as ultrasonic, microwave, or high-pressure techniques and pressurized liquid extraction, can be employed to extract GLPs. The ultrasonically extracted polysaccharide has a relatively lower MW and higher amounts of polysaccharides extracted by hot water [39].

Biological applications of *G. lucidum*

The biological applications of *G. lucidum* have been documented around 4000 years ago. The health benefits of this mushroom are documented in the 16th-century "Compendium of Materia Medica" from the Ming Dynasty. It is listed in the Pharmacopoeia of the People's Republic of China and the American Herbal Pharmacopoeia [40]. Various research indicated that this mushroom exhibits numerous pharmacological effects, as illustrated in Figure 2. This review summarized some of its biological effects.



Picture 3. Biological activities of triterpenoids and polysaccharides [24].

Antibacterial activity

The past 30 years have seen a significant increase in the quest for novel therapeutic bioactive chemicals that can function as antimicrobial agents. This increase is primarily driven by the emergence of antibiotic resistance in microbes that cause diseases in humans. Although many therapeutically effective antibiotics and their partially synthetic counterparts are readily accessible, the ongoing search for novel anti-infective substances remains essential. Most medications now in use are costly or not easily accessible. A significant obstacle to their ongoing use is the emergence of resistance. Hence, novel, cost-effective medications that can exhibit prolonged efficacy are needed before the onset of resistance. The identification of novel compounds that demonstrate significant efficacy against pathogenic microorganisms, including toxigenic staphylococci, anaerobes, pseudomonas, legionellae, different fungi, and others, without developing resistance to current antibiotics, could be a valuable contribution [41]. The continuing increase in antibiotic resistance poses some considerable difficulties to the pharmacological management of bacterial illnesses. Many isolates of *Staphylococcus aureus* have developed resistance mechanisms against most antibiotics. Hence, novel, economically efficient pharmaceuticals, particularly those derived from natural sources, are urgently needed [42].

Scientists examined the methanolic, chloroform, acetone, and aqueous extracts of *G. lucidum* against many bacterial strains. They discovered that these extracts exhibited antibacterial properties against various bacteria, such as *Corynebacterium diphtheria*, *Escherichia coli*, *Enterobacter aerogenes*, *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Salmonella* sp. [43]. Heleno, *et al.* [44] demonstrated that specific extracts of *G. lucidum* exhibited greater antibacterial efficacy than some antibiotics. The findings of their study indicated that *G. lucidum* has the ability to impede the progression of many bacterial infections.

Terpenes, lectins, polysaccharides, and other similar substances are classified as antimicrobial agents. They exert their effects on the plasma membrane of

bacteria, as described by Quereshi, *et al.* [45]. The chemicals included in *G. lucidum* can impede the growth of 15 different types of G+ve and G-ve bacteria. According to Shah, *et al*. [46], some chemicals, including ganomycin and triterpenoids of *G. lucidum*, have a wide range of antibacterial action.

The aqueous and methanol extracts of *G. lucidum* fruiting bodies remarkably have antimicrobial effects against many bacterial isolates, including *S. aureus*, *Streptococcus mutans*, *E. coli*, *P. aeruginosa* and *Salmonella typhi*. The highest inhibition zone was 31 mm for *S. typhi* and *S. aureus* when using the aqueous extract of *G. lucidum* fruiting bodies (200 mg concentration). The lowest inhibition zone of 10 mm was observed with *E. coli* when 50 mg of the extract was used [47].

Antifungal activity

G. lucidum was utilized for several decades as a therapeutic approach and for enhancing overall well-being. The global utilization of traditional medicine has surged due to the emergence of new illnesses, antifungal resistance, high costs associated with synthetic drugs, and their adverse effects [12].

Some scientists demonstrated the antifungal activity of the methanol extract of *G. lucidum*. The highest inhibition zone of 30 mm was seen when 200 mg of the extract was tested against *Mucor indicus*. In comparison, the lowest zone of inhibition of 3 mm was obtained with 50 mg of the extract against *Aspergillus flavus* [47].

Bitew and Abate [48] successfully extracted two antifungal drugs, antibiotic 201A and antibiotic 201B, from a submerged culture of *G. lucidum*. These drugs have undergone biological characterization. The antifungal activity was discussed, including efficacy against pathogenic yeasts and molds, which cause diseases. Currently, several antifungal medicines derived from microorganisms or created synthetically are being used for therapeutic purposes. These antifungal drugs vary in their activity, potency, and mechanism of action. As a result, the treatment of many fungal infections is now unsatisfactory.

An Iraqi scientist employed varying quantities of *G. lucidum* extract as an inhibitory agent for the internal air-conditioning (AC) systems of 10 vehicles to prevent fungal development. The most prevalent fungal species associated with AC systems are *Penicillium*, *Rhizopus*. *Aspergillus niger*, and *A. flavus*. However, the antifungal action of various concentrations of *G. lucidum* inhibited fungal growth in varying degrees. The antifungal activity exhibited a dose-dependent behavior, with 25 mg/mL concentration showing a significantly larger inhibitory zone than other concentrations [49].

G. lucidum has diverse biologically active chemicals that exhibit efficacy against various plant diseases. The antifungal efficacy of five concentrations of the pure extracts of this fungus was assessed. The experimental pathogens included several fungal plant pathogens: *Fusarium sp.*, *Pestalotiopsis palmarum*, *Alternaria solani Colletotrichum capsici*, *Colletotrichum gloeosporioides*, and *Colletotrichum coccodes*. Among them, the highest inhibition level amounting to 46.73% was recorded in *A. solani*. The 100% pure extract of *G. lucidum* exhibited the most significant percentage of growth inhibition against several test pathogens [50].

Antiviral activity

The emergence of antiviral treatment resistance is becoming a growing issue among individuals with weakened immune systems due to the continuous replication of viruses and prolonged exposure to drugs, resulting in the development of resistant strains [51].

The usefulness of *G. lucidum* in treating numerous internal disorders have been shown for hundreds of years, and its effectiveness in antiviral efficacy is gradually gaining attention. By using advancements in modern pharmacology, numerous researchers have successfully identified and extracted various active compounds from *G. lucidum*. Some of these compounds have been tested and proven effective in inhibiting viruses, in laboratory conditions (*in vitro*) and living organisms (*in vivo*). An initial investigation indicated that triterpenoids can protect liver tissues against damage [52].

Multiple investigations indicated that *G. lucidum* exhibits potential as a prospective applicant for the creation of diverse antiviral medicines. Genomic sequencing revealed that *G. lucidum* has antiviral properties against various viruses, including herpes, influenza, Epstein-Barr, and hepatitis. Notably, it has

demonstrated efficacy against the virulent and hazardous HINI strain of influenza [24].

Some scientist evaluated antiviral compounds derived from basidiomycetes. They synthesized 10 substances from *G. lucidum*, consisting of two substances soluble by water and eight chemicals soluble with methanol. The activity of these compounds toward five viral strains, including influenza A virus (Flu A), vesicular stomatitis virus (VSV), herpes simplex virus types 1 (HSV-1) and 2 (HSV-2), was assessed using plaque reduction test and the cytopathic effect inhibition test. Five chemical compounds from water-soluble substances and methanolic-soluble substances markedly suppressed the cytopathic effects of HSV and VSV. The results suggest the potential for creating antiviral drugs from Basidiomycota fungi [53].

Dengue virus infection is recognized to induce severe health complications in humans, and no pharmaceutical treatment has been approved. Identifying that GLTs suppress NS2B-NS3 protease activity was proposed as an important step toward discovering dengue virus inhibitors. Twenty-two GLTs, including ganoderic acid C2, ganosporeric acid A, ganodermanontriol, and lucidumol A, were estimated to inhibit the viral protease compared with standard inhibitor 1,8-dihydroxy-4,5-dinitroanthraquinone [54].

In late 2019, the new COVID-19 was specified as the cause of pneumonia in China. Subsequently, it has precipitated substantial global issues due to its rapid transmission among individuals, leading to a pervasive worldwide pandemic. Convalescent plasma and hyperimmune immunoglobulin have beneficial effects in treating COVID-19. *G. lucidum* significantly reduces the harmful effects of COVID-19 on hematological parameters. Therefore, this mushroom can be used to treat corona virus infections [55].

Anticancer activity

Cancer is the primary contributor to mortality in economically advanced nations, and in poor countries, it ranks as the second most common reason of death [56]. Despite the continuous advancement of current medical technologies and the development of novel synthetic medications, the rates of cancer incidence and death over the past decade have few variations. The adverse effects of systemic chemotherapy employed in cancer treatment are frequently profound. Oncologists have traditionally prioritized tumor treatment, causing impairment to the host and the immune system. Hence, advancing novel chemical compounds to fight cancer is extremely important. Phytochemicals derived from natural herbs are advantageous sources for exploring anticancer drugs [57, 58].

Ganoderma extracts and treatments can prevent cell cycle at different stages, hence impeding the proliferation of several cancer cell types. Polysaccharide extracts induce immunological responses by activating the generation of different cytokines and the mobilization of the cells of the immune system. Scientific investigations have supported the anticancer properties and anti-metastatic effects of *Ganoderma*-derived substances through in vivo experiments. *Ganoderma* extracts have been found to exhibit chemo-preventive effects in several cancer cell lines. The findings indicate that the concurrent administration of this mushroom with traditional radiation or chemotherapy has beneficial effects [59].

Empirical evidence indicates that GLTs possess various anticancer characteristics. The suppressive properties of GLTs on the metastasis and proliferation of cancer cell lines have been proven through experimentation. The underlying mechanism is understood to be related to the interruption of the cell cycle and the stimulation of programmed cell death. GLTs have demonstrated not only their ability to kill cancer cells but also their capacity to inhibit invasion and angiogenesis [60, 61].

The utilization of GLTs in conjunction with some cancer chemical drugs leads to flexible outcomes, which vary depending on the specific cell type and the proportion of triterpenoids to chemotherapeutic medicines. GLTs were found to have the ability to increase the sensitivity of cancer cells to the chemical's cancer drugs. This effect was accomplished by stimulating oxidative stress (OS), promoting an increase in OS levels, DNA damage, and stimulating apoptosis. In other cases, using GLTs along with chemical drugs led to a significant decrease in tumor growth in mice, with a growth of human hepatoma cells. These triterpenoids

exhibited cytotoxicity on drug-sensitive and -resistant small-cell lung cancer cells [62, 63].

Anti-OS activity

OS is a condition that arises from an equilibrium between the generation of reactive oxygen species (ROS) and the protective anti-oxidative defense systems. This equilibrium is accountable for the flexible reactions, which involve the initiation of an anti-oxidative response. Subsequently, malfunction and cellular harm develop due to antioxidant deficiency. This condition is associated with various human diseases, including aging, infertility, immunosuppression, tumors, gastrointestinal disorders, and renal disorders such as urinary tract infections. Antioxidants are compounds that can reduce harmful free radicals and protect against illnesses [64, 65].

The chemoprotective activity of *G. lucidum* may be linked to its antioxidant activities from the OS caused by ROS [66].

GLPs have a protecting effect against lipid peroxidation and oxidative DNA damage. They can reduce iron-stimulated lipid peroxidation and oxidative DNA damage [66].

GLPs exhibited antioxidant activity in diabetic rats induced by streptozotocin. GLPs can also effectively enhance nonenzymic/enzymic antioxidants and decrease lipid peroxidation [67].

Another study showed that GLPs exhibited superior reducing power, DPPH radical scavenging ability, and oxygen radical scavenging ability, suggesting that *G. lucidum* may serve as a natural source of antioxidant materials [68].

Antidiabetic activity

GLPs and GLTs have demonstrated antidiabetic effects. Several studies showed that GLPs exhibited antidiabetic effects in mice by increasing the levels of insulin and decreasing the levels of sugar in the blood. GLPs have the ability to block protein tyrosine phosphatase enzyme and fight diabetes. They can also suppress aldose reductase and a-glucosidase enzymes and reduce hyperglycemia. The protein Ling Zhi-8, which is isolated from *G. lucidum*, effectively reduced the infiltration of lymphocytes and stimulated the detection of insulin antibodies in diabetic mice [69].

GLPs can increase the functions of hepatic glucokinase, phosphofructokinase, and glucose-6-phosphate dehydrogenase enzymes. They also inhibited the level of glycogen synthetase enzyme, leading to a decrease in the generation of liver glucose [70].

Another study showed that GLPs at three doses can reduce the mRNA expression levels of several important enzymes involved in glycogenolysis or gluconeogenesis and increase body weight and serum insulin levels while reducing blood lipid levels. GLPs reduced glucose levels in the blood serum and balance of insulin in mice with type II diabetes induced by a high-fat diet [71].

Low-MW GLPs demonstrated antidiabetic effects by protecting pancreatic cells from death and stimulating the regeneration of B cells by increasing the expression levels of some proteins [72].

Hypocholesterolemic activity

Hypercholesterolemia is a hereditary condition affecting the metabolism of lipoproteins, resulting in abnormally increased levels of LDL in the blood. This sickness is characterized by the presence of tendon xanthomas and an increased susceptibility to developing coronary heart disease at an earlier age than usual. Hypercholesterolemia is a global public health issue. A global population of 10,000,000 individuals has hypercholesterolemia, predominantly consisting of heterozygotes. Without proper preventative measures, roughly 85% of males and 50% of females with hypocholesterolemia experience a cardiovascular disease before 65 years of age [73].

Mice fed with high-cholesterol diet were administered with standardized *G. lucidum* extracts, and the results were compared with those of the animals administered with simvastatin. The extracts were evaluated for their effect on blood biochemical indicators, lipid levels, cholesterol metabolite, and the form of normal flora. The intake of these extracts led to a notable decrease in several cholesterol levels, including total cholesterol, LDL, and triglyceride. *G. lucidum* extracts significantly reduced cholesterol and triglycerides. The observed effects were linked to decreasing the activity of genes responsible for producing fat and genes associated with transporting cholesterol out of the body [74].

Rahman, *et al.* [16] discovered that administering *G. lucidum* by using hot water extraction of 200 mg/kg body weight dose led to a reduction in cholesterol, LDL, and triacylglycerol in the plasma while simultaneously increasing HDL level. The above findings propose that this mushroom has the capacity to be used as a hypocholesterolemic medication to impede problems related to cardiovascular diseases.

Hepatoprotection

G. lucidum demonstrates a wide activity to protect the liver from several problems by employing various mechanisms such as regulating the activity of liver phase I and II enzymes, inhibiting β-glucuronidase, exerting antifibrotic and antiviral effects, controlling the production of nitric oxide, maintaining the balance of calcium within hepatocytes, modulating the immune system, and neutralizing free radicals. These mushroom extracts show promise for treating several chronic hepatic diseases. These extracts were used alone or in combination with other medications and when incorporated into functional foods, nutraceutical supplements, or as a complementary treatment to modern medicine [75].

The extract of *G. lucidum* demonstrated promising preventative and therapeutic effects in formaldehyde-induced liver fibrosis tests [76].

The efficacy of *G. lucidum* in protecting the liver against liver fibrosis was evaluated by quantifying the levels of liver enzymes such as AST, ALT, and ALP. ALT is an essential enzyme in developing liver fibrosis. The progression of liver fibrosis is directly correlated with the increase in the activity of liver enzymes [77].

G. lucidum possesses some remarkable benefits for lipid metabolism and liver well-being. In 2022, some researchers discovered that the ethanolic extract had a protective effect against alcohol-induced liver impairment in mice. *G. lucidum* ethanol extract not only provides excellent protection to the liver against extreme buildup of lipids and pathological alterations produced by alcohol but also suppresses abnormal increases in cholesterol levels, LDL, ALT, AST, and triglyceride [78].

Conclusion

G. lucidum is a highly significant medicinal fungus that has been utilized for thousands of years in conventional medicine to address various ailments. This medicinal mushroom has a wide range of secondary metabolites such as alkaloids, phenols, terpenes, sterols, and lectins. Triterpenoid and polysaccharide were identified as the two active chemicals with several medical actions such as antibacterial, antifungal, antiviral, anticancer, antioxidant, antidiabetic, and antihypertensive. Further research should be conducted to isolate and utilize the active compounds found in this mushroom for various biological activities and applications on different cell lines. The toxicity of these compounds must be explored to determine their suitability for the development of novel medications.

Acknowledgments

None.

Conflict of Interest

The authors declare no conflict of interest.

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مراجعة: للمركبات الفعالة للفطر *Ganoderma lucidum* وتطبيقاتها البايولوجية

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الخلاصة:

الفطريات الغذائية والطبية هي فطريات كبيرة تنتمي إلى قسم الفطريات البازيدية او الفطريات الكيسية. الفطر *Ganoderma lucidum* هو أحد هذه الفطريات الطبية التي تنتمي إلى الفطريات البازيدية، ويتميز بقوامه الخشبي؛ يوجد هذا الفطر الطبي على نطاق واسع في المناطق المعتدلة والاستوائية في جميع أنحاء أوروبا وأمريكا الشمالية وآسيا. تقليديا، تم استخدام الفطر الطبي لتعزيز الصحة وعلاج العديد من الأمراض المعدية والخطيرة. ومع ذلك، فإن الفطر الطبي *G. Lucidum* يحظى بتقدير واسع النطاق لخصائصه الطبية. يحتوي هذا الفطر على العديد من المركبات النشطة بما في ذلك السكريات المتعددة، التربينات الثلاثية، الستيرويدات، الستيرولات، النيوكليوتيدات، والأحماض الدهنية، وغيرها من المواد التي يمكن الاعتماد عليها للعديد من الفعاليات البايولوجية والطبية بما في ذلك ضد البكتريا، ضد للفطريات، مضاد للسرطان والاورام، مضادات للأكسدة، علاج مرض السكري، علاج ارتفاع كوليسترول الدم، حماية الكبد وغيرها من التطبيقات البايولوجية. الهدف من هذه المراجعة هو البحث في المواد الكيميائية للفطر *G. lucidum* ، والنشاط الحيوي وآليته، والتجارب قبل السريرية والسريرية، وغيرها من المجالات هي المواضيع الرئيسية لهذه المراجعة.

الكلمات المفتاحية: *Ganoderma lucidum*، المركبات الفعالة، التربينات الثلاثية، السكريات المتعددة، التطبيقات البايولوجية.