NARRATIVE REVIEW: METODE EKSTRAKSI *GANODERMA LUCIDUM* DAN EFEKTIVITASNYA

EXTRACTION TECHNIQUES AND EFFICACY OF GANODERMA LUCIDUM: A NARRATIVE REVIEW

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Abstrak

Ganoderma lucidum merupakan salah satu jamur obat yang telah banyak diteliti karena senyawa bioaktifnya, terutama polisakarida, triterpenoid, dan senyawa fenolik, yang menunjukkan berbagai aktivitas farmakologis. Berbagai metode ekstraksi telah dikembangkan untuk mendapatkan komponen bioaktif ini secara optimal, mulai dari teknik konvensional seperti ekstraksi air panas dan etanol hingga metode modern seperti ekstraksi ultrasonik, ekstraksi berbantuan gelombang mikro, serta kombinasi berbasis enzim. Artikel ulasan ini bertujuan untuk mengidentifikasi jenis metode ekstraksi yang digunakan pada G. lucidum dan mengevaluasi efektivitasnya berdasarkan komposisi senyawa aktif dan aktivitas biologis yang dihasilkan. Hasil kajian menunjukkan bahwa perbedaan pelarut, suhu, durasi, dan teknik pengolahan secara signifikan memengaruhi rendemen dan stabilitas komponen bioaktif. Senyawa yang diekstrak telah terbukti memiliki aktivitas antioksidan, antimikroba, hepatoprotektif, imunomodulator, dan antitumor, meskipun efektivitasnya bervariasi antar studi karena kurangnya standardisasi dalam proses ekstraksi. Ulasan ini menekankan pentingnya pemilihan metode ekstraksi yang tepat berdasarkan senyawa target, serta perlunya penelitian lebih lanjut untuk menstandarisasi proses dan membandingkan efektivitas metode secara kuantitatif. Dengan demikian, potensi terapeutik G. lucidum dapat dimanfaatkan secara lebih optimal dalam pengembangan produk kesehatan dan farmasi berbasis herbal.

Kata kunci: Ganoderma lucidum; metode ekstraksi; bioaktif; efektivitas

Abstract

Ganoderma lucidum is one of the medicinal mushrooms that has been extensively researched due to its bioactive compounds, particularly polysaccharides, triterpenoids, and phenolic compounds, which exhibit a wide range of pharmacological activities. Various extraction methods have been developed to optimally obtain these bioactive components, ranging from conventional techniques like hot water and ethanol extraction to modern methods such as ultrasonic extraction, microwave-assisted extraction, and enzyme-based combinations. This review article aims to identify the types of extraction methods used on G. lucidum and evaluate their effectiveness based on the resulting active compound composition and biological activity. The review results indicate that differences in solvents, temperature, duration, and processing techniques significantly affect the yield and stability of bioactive components. The extracted compounds have been proven to possess antioxidant, antimicrobial, hepatoprotective, immunomodulatory, and antitumor activities, although their effectiveness varies across studies due to the lack of standardisation in the extraction process. This review emphasises the importance of selecting the appropriate extraction method based on the target compounds, as well as the need for further research to standardise the process and quantitatively compare the effectiveness of the methods. Thus, the therapeutic potential of G. lucidum can be utilised more optimally in the development of herbal-based health and pharmaceutical products.

Keywords: Ganoderma lucidum; extraction method; bioactive; effectiveness

INTRODUCTION

Ganoderma lucidum (lingzhi/reishi) is one of the most widely researched medicinal mushroom species in the fields of pharmacy and biotechnology due to its diverse bioactive compounds and high therapeutic value. Various active components that have been successfully identified include polysaccharides (especially β-glucans), lanostane-type triterpenoids (such as ganoderic acids), sterols, proteins, and phenolic compounds. The diversity of these compounds contributes to the pharmacological potential of G. lucidum, which includes immunomodulatory, antioxidant, antiinflammatory, hepatoprotective, antidiabetic, and antitumor activities. Polysaccharides from G. lucidum have the ability to enhance the immune response by activating macrophages, T lymphocytes, and NK cells, as well as increasing the secretion of cytokines such as IL-2, IFN-γ, and TNF-α, making them an important candidate in the development of modern immunotherapy (1).

Additionally, triterpenoids from G. lucidum have been reported to have antiinflammatory and antimitotic effects through the mechanism of inhibiting the NF-κB and COX-2 pathways and inducing apoptosis in various types of cancer cells, making them a key component with strong antitumor activity. This finding is supported by (2), who showed that ganoderic acids can reduce tumour cell proliferation and increase cancer cell sensitivity to conventional chemotherapy. G. lucidum polysaccharides not only possess immunomodulatory activity but also exhibit antioxidant and antidiabetic properties through mechanisms of reducing oxidative stress, enhancing glucose metabolism, and modulating gut microbiota (1). Ethanol and water extracts from G. lucidum contain phenolic compounds and sterols that play an important role in hepatoprotective and antioxidant activity through mechanisms of ROS inhibition and repair of hepatocellular damage (3).

In the last two decades, global demand for G. lucidum extracts has increased rapidly with the growth of the herbal, nutraceutical, and phytochemical-based pharmaceutical industries. However, the effectiveness of the extract is highly dependent on the extraction method used, as different techniques can yield significantly varying chemical compositions and biological activities (4). Traditional extraction methods like hot-water extraction (HWE) have long been used to obtain polysaccharides, but they have limitations such as long heating times, thermal degradation, and low efficiency for nonpolar compounds, including triterpenoids (1). To address this, various modern methods have been developed, such as ultrasonic-assisted extraction (UAE), microwave-assisted extraction (MAE), enzymeassisted extraction (EAE), supercritical fluid extraction (SFE), and subcritical water extraction (SWE), which have been reported to improve efficiency, selectivity, and maintain the stability of active compounds (5).

The combination of ethanol-water solvent and ultrasonic energy can simultaneously enhance the release of polysaccharides and triterpenoids. (6) research showed that UAE optimisation yielded polysaccharide yields of 0.63% and triterpenoid yields of 0.38%, with significant antioxidant activity compared to conventional methods. The SWE method, which utilises water at temperatures of 100– 374 °C under high pressure, is becoming an environmentally friendly approach capable of dissolving polar and semipolar compounds without the use of organic solvents. (7) showed that SWE is capable of producing high-quality polysaccharide microparticles from G. lucidum. Additionally, the enzyme-microwave assisted extraction (EMAE) method has been proven to improve polysaccharide extraction efficiency due to cell wall degradation by enzymes and accelerated diffusion by microwaves. The research by Listriyani et al. (2023) shows that EMAE yields higher results and stronger antioxidant activity compared to traditional HWE.

Although a number of extraction methods have been applied to obtain bioactive metabolites from G. lucidum, including ultrasonic-assisted extraction (UAE), traditional hot water extraction (HWE), and solvent-based methods, no single method is universally optimal for all classes of compounds and pharmacological purposes. The ultrasonic-assisted co-extraction (UACE) method with optimal conditions (ultrasonic power 210 W, temperature 80 °C, liquid/solid ratio 50 mL/g, ethanol-water solvent 50%, 100 minutes) only yielded polysaccharide extract of 0.63% and triterpenoid extract of 0.38% (compared to yields of 1.52% polysaccharide and 0.59% triterpenoid with HWE and conventional ethanol maceration) (6). This indicates that although UACE allows for "co-extraction," the efficiency or total yield may be lower than conventional methods, suggesting a trade-off between process ease and the quantity of the result. However, each extraction method has its advantages and limitations depending on the target compounds, technical parameters (temperature, time, energy intensity, solvent/solid ratio), and the final purpose (polysaccharides, triterpenoids, or other bioactive components; supplement vs. drug formulation). For example, in polysaccharide extraction, the ultrasonic method is reported to yield β-glucans with molecular weights and functional structures similar to conventional methods, but with shorter extraction times and lower temperatures, which is beneficial for maintaining the thermal stability of sensitive compounds (8). Therefore, since no single method excels in all aspects, including yield, purity, chemical composition, and bioactivity, the selection of an extraction method for G. lucidum must be done contextually, considering the nature of the target compounds, application goals, process efficiency, and production scale. Therefore, a systematic narrative review comparing the methods and results of various studies is needed so that researchers or practitioners can select and optimise extraction methods according to their needs, thereby obtaining extracts with consistent and predictable chemical profiles and biological activity.

METHOD

The literature search method in this narrative review was conducted through a systematic approach to identify relevant scientific publications related to the extraction methods of Ganoderma lucidum and the effectiveness of the resulting bioactive compounds. The article search was conducted on four major databases: PubMed, ScienceDirect, Scopus, and Google Scholar, as these are the most widely used sources in pharmaceutical, biotechnology, and phytochemical research.

The search was conducted using a combination of keywords and Boolean operators, including: "Ganoderma lucidum", "Lingzhi", "Reishi", "extraction methods", "polysaccharide extraction", "triterpenoid extraction", "ultrasonic extraction", "microwave-assisted extraction", "supercritical fluid extraction", "bioactive compounds", "pharmacological activity", as well as combinations such as:

1. "Ganoderma lucidum" AND "extraction method"
2. "Reishi" AND "bioactive compounds"
3. "Ganoderma" AND "ultrasonic extraction" OR "microwave extraction"
4. "Ganoderma lucidum extract" AND "effectiveness"

The publication years included are 2013–2024, to ensure that the literature used reflects the latest developments in extraction technology. English and Indonesian articles are included, while publications such as editorials, comments, proceedings without data, and studies that do not directly discuss extraction methods are excluded from the analysis. Inclusion criteria include:

1. Experimental research articles (in vitro or in vivo) or scientific reviews that describe extraction methods of G. lucidum.
2. Studies that assess the bioactive compounds (polysaccharides, triterpenoids, phenolics, sterols).
3. Articles that evaluate the biological effectiveness of extracts obtained through various extraction methods.
4. Research that provides quantitative data related to yield, compound concentration, or pharmacological activity.

Exclusion criteria include:

1. Articles that discuss only the cultivation of G. lucidum without addressing extraction aspects.
2. Studies that use fungal species other than G. lucidum.
3. Patent studies without accompanying laboratory data.
4. Articles that are not accessible in full-text form.

The initial search yielded approximately 280 articles from all databases. After screening based on titles and abstracts, 125 articles were considered relevant and proceeded to full-text review. Based on the evaluation of content relevance, methodological quality, information on extraction methods, and availability of biological effectiveness data, a total of 50 articles were ultimately selected as the primary sources for this narrative review. These articles consist of recent experimental studies, systematic reviews, and comparative investigations that provide substantial contributions to understanding the variation in extraction methods and their impact on the bioactive compound content of Ganoderma lucidum.

RESULTS AND DISCUSSION

Ganoderma lucidum is a medicinal mushroom from the Ganodermataceae family that has been used for a long time in traditional medicine practices in China, Japan, Korea, and various other Asian countries, primarily due to its polysaccharide and triterpenoid content, which have immunomodulatory, anti-inflammatory, and anticancer activity (9);(10). This mushroom is widely known as lingzhi or reishi, and ecologically grows naturally on dead tree trunks or decaying wood, especially in humid environments rich in lignocellulose, thus supporting the degradation of biomass by the mushroom's lignolytic enzymes (11). Morphologically, the fruiting body of G. lucidum is fan-shaped or semicircular with a surface that appears shiny like varnish (varnished appearance) and is reddish-brown in colour, a characteristic that distinguishes it from other Ganoderma species (12). The diameter of the fruiting body is generally in the range of 5–20 cm, although the size can vary depending on the type of substrate wood, humidity, and environmental conditions where it grows (13). This unique macrostructure and chemical composition make G. lucidum one of the most researched fungal species in the fields of pharmacy, biotechnology, and public health.

This mushroom is classified as a basidiomycete capable of producing a variety of secondary metabolites, particularly triterpenoids, polysaccharides (β-glucan), sterols, proteins, and bioactive peptides. These compounds contribute to its pharmacological activities, such as immunomodulatory, antioxidant, hepatoprotective, antitumor, and antidiabetic effects. Environmental factors such as humidity, substrate pH, and incubation temperature significantly affect the bioactive content of this fungus. G. lucidum can be cultivated on sawdust, lignocellulosic waste, or baglog media, making it easy to develop for pharmaceutical and health industry purposes (9);(14).

Table 1. Classification of Ganoderma lucidum

Category	Classification
Kingdom	Fungi
Subkingdom	Dikarya
Phylum	Basidiomycota
Class	Agaricomycetes
Order	Polyporales
Family	Ganodermataceae
Genus	Ganoderma
Species	Ganoderma lucidum (Curtis) P. Karst

1. Bioactive Composition of Ganoderma lucidum

   Ganoderma lucidum (GL) is widely recognized as one of the medicinal mushrooms with the richest profile of bioactive compounds and has been extensively investigated in the fields of pharmacy, biotechnology, and traditional medicine. Recent literature indicates that GL contains more than 300 bioactive constituents distributed across various groups of primary and secondary metabolites. Studies by (3), (15), (16), and (17) highlight that the dominant classes contributing to GL's biological activities include polysaccharides, triterpenoids, ganoderic acids, phenolics, sterols, bioactive proteins, and volatile compounds. The diversity of these chemical structures underlies the broad pharmacological effects of GL, such as immunomodulatory, antioxidant, anti-inflammatory, antidiabetic, antitumor, and hepatoprotective activities.

   a. Polysaccharide

      Polysaccharides are one of the most extensively studied fractions in GL. According to (18); (19); (12) and (20), GL polysaccharides are composed of: β-glucan (β-1,3; β-1,6-glucan), α-glucan and heteropolisakarida kompleks (mannose, galactose, fucose, xylose)

      The structure of these polysaccharides has varying molecular weights and different bioactivities. Various in vitro and in vivo studies have shown that GL polysaccharides can enhance cytokine production (IL-2, TNF-α), activate macrophages, stimulate NK cells, and increase phagocytosis, thus playing a significant role in immunomodulatory and antitumor effects.

b. Triterpenoid and Ganoderic Acid

Triterpenoids constitute the second largest group of metabolites in Ganoderma lucidum, with more than 150 derivatives of ganoderic acids successfully isolated to date. According to (15) and (21), these compounds possess a lanostane-type triterpene backbone that plays a critical role in inhibiting cancer cell proliferation, inducing apoptosis through caspasemediated pathways, reducing inflammatory responses, and exerting hepatoprotective effects. Furthermore, (22) reports that triterpenoid yield tends to increase under extraction approaches utilizing organic solvents such as ethanol or methanol, particularly when combined with microwave-assisted extraction techniques, which enhance cell wall disruption and compound recovery efficiency.

c. Phenolic Compound dan Antioxidant

Phenolic compounds also play a substantial role in the antioxidant activity of Ganoderma lucidum. Studies by (23), (24), and (25) identified the presence of key phenolic constituents, including flavonoids, phenolic acids, and lignin-like compounds. These phenolic fractions have been demonstrated to exhibit strong free-radical-scavenging capacity, as evidenced by DPPH and ABTS assays, enhance endogenous antioxidant enzyme activity, and protect cells against oxidative stress-induced damage.

d. Sterol, Protein Bioaktif, and Volatile Components

Several additional compounds identified in Ganoderma lucidum further enrich its pharmacological profile, including ergosterol, bioactive peptides, enzymes, and volatile constituents. (21) and (20) reported that sterols, particularly ergosterol, function as precursors of vitamin D_2, thereby contributing to various physiological benefits. Moreover, bioactive peptides in G. lucidum have been shown to exhibit notable antimicrobial properties and hepatoprotective effects, reinforcing the multifaceted therapeutic potential of this medicinal mushroom.

e. The Influence of Extraction Methods on Bioactive Composition

A growing body of research demonstrates that extraction methods play a decisive role in shaping the composition and concentration of bioactive compounds in Ganoderma lucidum. Findings by (23), (24), and (22) consistently highlight that hot water extraction tends to increase polysaccharide yield due to the high solubility of these macromolecules in aqueous media. In contrast, ultrasonic-assisted extraction (UAE) enhances cell wall disruption, thereby facilitating greater release of both polysaccharides and phenolic compounds. Microwave-assisted extraction (MAE) has been reported to promote the rapid liberation of triterpenoids and phenolics through fast volumetric heating. Furthermore, fermentation-based processes can elevate antioxidant constituents via microbial enzymatic biotransformation, which modifies precursor molecules into more bioactive forms.

2. Pharmacological and Anti-Inflammatory Activities

a. Antioxidant and Anti-inflammatory Activity

Several studies indicate that Ganoderma lucidum (GL) possesses very strong antioxidant potential. (17) found that GL polysaccharides are capable of scavenging various reactive oxygen species (ROS) while simultaneously enhancing radical stability and reducing capacity. These findings are consistent with the report by (26), which confirms that GL's antioxidant activity works by inhibiting ROS formation and increasing endogenous antioxidant enzymes. Additionally, studies by (24) and (27) indicate that the fermentation process of GL can significantly enhance antioxidant activity, particularly in HepG2 cells, by increasing the expression of protective proteins and reducing oxidative stress markers. Overall, the evidence confirms that GL polysaccharides play a significant role as relevant antioxidant and anti-inflammatory agents in the prevention of degenerative diseases.

b. Anticancer and Antiproliferative Activity

Anticancer activity is one of the most widely reported pharmacological aspects of GL. (16) and (27) reported that the bioactive compound GL can induce apoptosis of skin cancer cells through upregulation of caspases and downregulation of cell proliferation. (28) and (29) demonstrated the antiproliferative effects of GL on cervical and breast cancer cells, primarily through inhibition of the cell cycle phase and modulation of the PI3K/Akt pathway. (30) reinforced these findings by showing that GL extract can inhibit tumor angiogenesis and suppress VEGF expression in prostate cancer models. Meanwhile, (31) identified that GL is also effective against gastrointestinal cancer, with mechanisms including enhanced immunomodulation, NK cell activation, and inhibition of metastasis formation. These findings suggest that GL has broad potential as a multipath way anticancer agent, not only inhibiting proliferation but also targeting more complex tumorigenesis processes.

c. Hepatoprotective and Anti-Fibrotic Activity

Some studies support the hepatoprotective benefits of GL against various types of liver injury. (32) reported that GL polysaccharides can protect hepatocytes from carbon tetrachloride (CCl_4)-induced damage by increasing antioxidant activity and reducing lipid peroxidation. (33) showed that GL can suppress the progression of liver fibrosis by reducing the expression of TGF-β and collagen, and by normalizing liver function biomarkers. GL works by enhancing cellular detoxification mechanisms, reducing inflammatory cytokines such as IL-6 and TNF-α, and improving liver histological structure. Overall, the data confirms that GL has strong hepatoprotective properties, making it a potential candidate for development as a supportive therapeutic agent for chronic liver disorders

d. Neuroprotective and Anti-Alzheimer's Activities

The neuroprotective potential of G. lucidum has also been widely reported. (34) found that GL was able to reduce neuronal oxidative stress by increasing superoxide dismutase activity and decreasing malondialdehyde. (35) and (36) reported that GL polysaccharides can inhibit β-amyloid aggregation, which is one of the main mechanisms in the pathogenesis of Alzheimer's disease. Additionally, (37) demonstrated that GL extract can enhance neuronal viability, reduce apoptosis, and improve memory function in neurodegenerative animal models. Collectively, these studies suggest that GL has the potential to be developed as an adjunctive therapy candidate for Alzheimer's disease and other neurodegenerative disorders.

e. Antimicrobial and Antiviral Activity

The antimicrobial activity of GL has been shown to be very broad. (38) showed that the ethanolic extract of GL has significant inhibitory activity against Gram-positive bacteria such as Staphylococcus aureus and Gramnegative bacteria such as Escherichia coli. (39) also reported that the methanolic fraction of GL was able to inhibit the growth of pathogenic fungi through a cell membrane damage mechanism. Additionally, (40) developed silver nanoparticles based on GL extract, which showed higher antimicrobial potential, including against antibiotic-resistant bacterial strains. Overall, these findings suggest that GL not only possesses natural antimicrobial effects but can also be enhanced through nanotechnology to achieve greater effectiveness

3. Development of Ganoderma Lucidum Extraction Methods
   a. Conventional Extraction (Hot Water, Soxhlet, Reflux)

      Conventional methods are still the most frequently used techniques in GL research, particularly hot-water extraction (HWE). Studies by (41) and (1) show that HWE is effective in extracting water-soluble polysaccharides, which are the dominant bioactive fraction. This technique utilizes high temperatures to break down the fungal cell walls, allowing the polysaccharides to dissolve into the solvent. Soxhlet and reflux are used to extract nonpolar components such as triterpenoids, as reported by (42) and (39). However, this method has limitations such as long extraction duration, the use of large amounts of solvent, and the risk of thermal degradation of polysaccharides sensitive to high temperatures. Nevertheless, conventional methods remain relevant as a benchmark in comparative studies.

   b. Microwave-Assisted Extraction (MAE)

      MAE is becoming an increasingly popular modern method due to its ability to significantly shorten extraction time without compromising the quality of bioactive compounds. (42) showed that MAE yielded higher oil yields from GL spores compared to Soxhlet and increased the antioxidant activity of the extract. Microwave energy allows for even volumetric heating, accelerating solvent penetration and the release of cellular components. The advantages of MAE include energy efficiency, shorter extraction duration, and minimal thermal degradation when parameters are optimally set. However, the application of MAE on an industrial scale still requires optimization regarding heating consistency and appropriate reactor design.

   c. Fermentation (Enzymatic and Microbial)

      Fermentation techniques are a new approach aimed at increasing the bioavailability and biological activity of GL components through modification of polysaccharide structures. (24); (43); and (44) reported that fermentation using Lactiplantibacillus plantarum alters the structure of GL polysaccharides, thereby increasing their antioxidant activity and bioavailability. Enzymatic fermentation using enzymes such as cellulase, pectinase, or β-glucanase serves to degrade cell walls, making bioactive compounds easier to extract. This approach offers advantages such as milder reaction conditions, no need for high temperatures, and the ability to increase polysaccharide yield. However, the fermentation process has drawbacks including high enzyme costs, potential for microbial contamination, and the need for strict control of fermentation conditions.

   d. Green Chemistry and Nanotechnology-Based Extraction

      Green extraction approaches are increasingly being applied, in line with the demand to reduce the use of organic solvents and improve process sustainability. (38) reported that GL extract can be used for the synthesis of silver nanoparticles through an environmentally friendly process, resulting in a product with higher antimicrobial activity compared to conventional extracts. Other modern techniques included in this category are supercritical fluid extraction (SFE), subcritical water extraction (SWE), and the use of biodegradable ethanol or glycol-based green solvents. The advantages of this approach include the high purity of the extract, minimal harmful residues, and the potential for nanoformulations that enhance stability and biological effectiveness. The main challenges include equipment complexity and high investment costs.

e. Spectroscopic Methods for Extraction Evaluation (HSI and NIR)

Although not a direct extraction method, spectroscopy techniques such as hyperspectral imaging (HSI) and near-infrared spectroscopy (NIR) are increasingly used as supporting tools to evaluate the extraction process and the quality of raw materials. Studies by (34) and (45) show that HSI and NIR are capable of rapidly, non-destructively, and accurately predicting the polysaccharide content of GL. This approach is highly relevant in the context of process analytical technology (PAT), as it allows for real-time adjustment of process parameters to ensure the consistency of extract quality. Its limitations lie in the need for a complex calibration curve and the relatively high initial investment in equipment.

f. Purification and Isolation of Bioactive Compounds

After the extraction process, a purification step is required to obtain bioactive compounds with pharmaceutical purity. Various methods such as ethanol precipitation, ultrafiltration, dialysis, and column chromatography are reported in the studies by (1), (46), and (20). Ethanol precipitation is the most common technique for separating polysaccharides from protein contaminants and small molecules, while ion exchange chromatography can separate polysaccharides based on charge. For lipophilic compounds like triterpenoids, purification using preparative chromatography or HPLC is often performed to achieve high purity. The purification stage is very important because the structure and purity of polysaccharides directly affect their biological activity, especially their immunomodulatory, anti-inflammatory, and antitumor activities.

4. Applications of Ganoderma Lucidum Products Based on Extraction Findings

a. Pharmaceutical Industry & Clinical Therapy

Various recent studies indicate increased utilization of Ganoderma lucidum (GL) in the pharmaceutical and clinical therapy sectors. (47) reported that the polysaccharide and triterpenoid fractions of GL have significant immunomodulatory activity, making them potentially useful as an adjunct therapy to chemotherapy. These bioactive compounds are capable of enhancing immune response, reducing inflammation, and decreasing the toxicity of cytotoxic drugs. Additionally, (48) reinforced previous findings that GL also has a hepatoprotective effect through mechanisms of inhibiting oxidative stress and increasing hepatic detoxification enzyme activity. In the context of therapy for degenerative diseases, GL polysaccharides exhibit neuroprotective activity through the modulation of antioxidant and anti-apoptotic pathways. This finding makes GL a potential candidate for complementary therapy in neurodegenerative diseases such as Alzheimer's and Parkinson's. The use of GL as a complementary herbal therapy for gastrointestinal cancer is also beginning to receive clinical attention, particularly due to its antiproliferative activity and its ability to enhance the efficacy of the body's immune response against cancer cells. Thus, these studies indicate that GL holds a strategic position in the development of safer and more effective herbal-based therapies.

b. Food and Beverage Industry

In the food sector, Ganoderma lucidum is increasingly used as a raw material for functional foods. (49) reported that GL flour can be integrated into whole wheat bread products without significantly reducing organoleptic quality. Conversely, the addition of GL can enhance the nutritional value of the product by increasing fibre content, antioxidant activity, and the chemical stability of bread. These improvements in functional properties demonstrate the significant potential of GL in developing high-value-added functional foods, particularly for products aimed at consumers who require antioxidant intake or immune system support. The food and beverage industry continues to explore the use of GL in powder form, liquid extracts, and microcapsules as a nutraceutical additive.

c. Utilisation in the Cosmetics and Personal Care Industry

Ganoderma lucidum extract also finds widespread application in the beauty industry. (50) and (51) showed that the bioactive components of GL have strong antioxidant and anti-aging activity, primarily through their ability to neutralise free radicals and prevent collagen damage. Additionally, GL extract has a skin-brightening effect by inhibiting tyrosinase and anti-inflammatory activity that can help soothe irritation and repair the skin barrier. The increasing interest of the global cosmetics industry in natural herbal ingredients is further driving the utilisation of GL in various formulations such as serums, anti-aging creams, essences, face masks, and sun care products. Its relative safety and bioactive effectiveness make GL one of the leading ingredients in modern natural-based cosmetics.

d. Applications in Environmental and Biotechnology

Besides the health and beauty fields, Ganoderma also has potential in environmental and biotechnology applications. (52) reported that the laccase enzyme produced by Ganoderma multipileum is capable of degrading chromium (Cr) compounds, making this fungus suitable for use as a bioremediation agent in environments contaminated with heavy metals. This degradation mechanism shows good efficiency and can be an environmentally friendly alternative compared to more chemical-based conventional methods. Meanwhile, (53) revealed that the mechanical structure of GL fruiting bodies has biomechanical characteristics that can inspire the development of bioengineered materials. The cellular structure of GL exhibits good compressive strength, flexibility, and a unique fibrous pattern, making it a potential model for material engineering in biodesign, biomaterials, and sustainable architectural applications.

The results of the review of all the journals used indicate that Ganoderma lucidum (GL) is consistently described as a medicinal mushroom with potent bioactive compounds, particularly triterpenoids, polysaccharides, and phenolics. Generally, previous studies highlight three main issues: variations in extraction methods, differences in pharmacological effectiveness, and challenges in standardizing extracts. First, various journals emphasize that the extraction method is a key factor determining the quality of active compounds in GL. (3) showed that polar solvents such as ethanol and hot water are able to produce polysaccharides and triterpenoids with higher yields. Meanwhile, (17) highlight that process parameters such as temperature, particle size, and heating duration can alter the stability and quantity of bioactive compounds extracted. This indicates that the choice of extraction technique must be tailored to specific target bioactive components.

Second, all journals provide a consistent picture of GL's extremely broad pharmacological activity. (15) reported that GL has a hepatoprotective effect through increased antioxidant capacity and reduced oxidative stress. On the other hand, (16) explained its significant antimicrobial activity, particularly against Gram-positive bacteria. These findings are consistent with the report by (17), which identified antitumor, antifungal, and antioxidant activities in various types of GL extracts. Therefore, it can be understood that the pharmacological effectiveness of GL is highly influenced by the composition of the extracts produced by each extraction technique.

Third, although all journals strongly highlight the therapeutic potential of GL, there are significant challenges related to extract standardization. (21) noted that variations in the origin of raw materials, processing methods, and differences in mushroom cultivation conditions lead to non-uniform levels of active compounds. This difference makes the research results not always consistent and difficult to replicate. Therefore, future research directions need to consider standardizing the extraction process to ensure the quality of GL extracts.

Additionally, most of the literature reviewed is still descriptive, without presenting a quantitative comparison of the effectiveness of each extraction method. This makes it difficult to determine the best method for producing specific compounds such as triterpenoids or polysaccharides. More systematic experimental research is needed to evaluate the relationship between extraction methods, the stability of bioactive components, and their pharmacological efficiency. Overall, the literature review indicates that Ganoderma lucidum has a very broad and relevant pharmacological potential for development as a raw material for herbal or pharmaceutical products.

CONCLUTION

A review of various scientific publications on Ganoderma lucidum indicates that this mushroom has a very broad pharmacological potential, primarily due to its content of triterpenoids, polysaccharides, and phenolic compounds. The effectiveness of these compounds is highly influenced by the extraction method used. Techniques such as hot water extraction, ethanol extraction, ultrasound-assisted extraction, and microwaveassisted extraction have been proven capable of producing different bioactive components in terms of both yield and biological activity strength. Therefore, the choice of extraction method needs to be tailored to the type of active compound being targeted. The results of the literature synthesis also show that G. lucidum has biological activity including antioxidant, antimicrobial, hepatoprotective, immunomodulatory, and antitumor properties. However, the considerable variation in research results indicates challenges in standardising extracts. Differences in raw material sources, cultivation conditions, processing techniques, and extraction parameters lead to non-uniform bioactive composition, resulting in inconsistent effectiveness across studies. Thus, it can be concluded that Ganoderma lucidum is a strong candidate for development as a pharmaceutical raw material and herbal health product.

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REFERENCES

1. Zhong Y, Tan P, Lin H, Zhang D, Chen X, Pang J, et al. A Review of Ganoderma lucidum Polysaccharide: Preparations, Structures, Physicochemical Properties and Application. Foods. 2024 Aug 24;13(17):2665.

2. Raza SHA, Zhong R, Li X, Pant SD, Shen X, BinMowyna MN, et al. *Ganoderma lucidum* triterpenoids investigating their role in medicinal applications and genomic protection. Journal of Pharmacy and Pharmacology. 2024 Dec 2;76(12):1535–51.

3. Ahmad R, Riaz M, Khan A, Aljamea A, Algheryafi M, Sewaket D, et al. *Ganoderma lucidum* (Reishi) an edible mushroom; a comprehensive and critical review of its nutritional, cosmeceutical, mycochemical, pharmacological, clinical, and toxicological properties. Phytotherapy Research. 2021 Nov;35(11):6030–62.

4. Galappaththi MCA, Patabendige NM, Premarathne BM, Hapuarachchi KK, Tibpromma S, Dai DQ, et al. A Review of Ganoderma Triterpenoids and Their Bioactivities. Biomolecules. 2022 Dec 22;13(1):24.

5. Shen L, Pang S, Zhong M, Sun Y, Qayum A, Liu Y, et al. A comprehensive review of ultrasonic assisted extraction (UAE) for bioactive components: Principles, advantages, equipment, and combined technologies. Ultrasonics Sonochemistry. 2023 Dec;101:106646.

6. Zheng S, Zhang W, Liu S. Optimization of ultrasonic-assisted extraction of polysaccharides and triterpenoids from the medicinal mushroom Ganoderma lucidum and evaluation of their in vitro antioxidant capacities. Šiler BT, editor. PLoS ONE. 2020 Dec 31;15(12):e0244749.

7. Matsunaga Y, Machmudah S, . W, Kanda H, Sasaki M, Goto M. Subcritical Water Extraction and Direct Formation of Microparticulate Polysaccharides Powders from Ganoderma Lucidum. IJTech. 2014 Jan 1;5(1):40.

8. Alzorqi I, Sudheer S, Lu TJ, Manickam S. Ultrasonically extracted β-d-glucan from artificially cultivated mushroom, characteristic properties and antioxidant activity. Ultrasonics Sonochemistry. 2017 Mar;35:531–40.

9. Paterson RRM. Ganoderma – A therapeutic fungal biofactory. Phytochemistry. 2006 Sep;67(18):1985–2001.

10. Verma T, Verma R, Thawait R, Kumar A, Wamankar S, Kumar Nema R. Ganoderma Lucidum: A Comprehensive Review of its Health Benefits and Therapeutic Potential. IJAMRS. 2024 Dec 24;4(6):1251–7.

11. Baby S, Johnson AJ, Govindan B. Secondary metabolites from Ganoderma. Phytochemistry. 2015 Jun;114:66–101.

12. Wu S, Zhang S, Peng B, Tan D, Wu M, Wei J, et al. *Ganoderma lucidum* : a comprehensive review of phytochemistry, efficacy, safety and clinical study. Food Science and Human Wellness. 2024 Mar;13(2):568–96.

13. Bishop KS, Kao CHJ, Xu Y, Glucina MP, Paterson RRM, Ferguson LR. From 2000years of Ganoderma lucidum to recent developments in nutraceuticals. Phytochemistry. 2015 Jun;114:56–65.

14. Boh B, Berovic M, Zhang J, Zhi-Bin L. Ganoderma lucidum and its pharmaceutically active compounds. In: Biotechnology Annual Review [Internet]. Elsevier; 2007 [cited 2026 Feb 4]. p. 265–301. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1387265607130106

15. Ahmad MF, Ahmad FA, Zeyaullah Md, Alsayegh AA, Mahmood SE, AlShahrani AM, et al. Ganoderma lucidum: Novel Insight into Hepatoprotective Potential with Mechanisms of Action. Nutrients. 2023 Apr 13;15(8):1874.

16. Ahmad MF, Ahmad FA, Hasan N, Alsayegh AA, Hakami O, Bantun F, et al. Ganoderma lucidum: Multifaceted mechanisms to combat diabetes through polysaccharides and triterpenoids: A comprehensive review. International Journal of Biological Macromolecules. 2024 May;268:131644.

17. Cör Andrejč D, Knez Ž, Knez Marevci M. Antioxidant, antibacterial, antitumor, antifungal, antiviral, anti-inflammatory, and nevro-protective activity of Ganoderma lucidum: An overview. Front Pharmacol. 2022 Jul 22;13:934982.

18. Zhang H, Zhang J, Liu Y, Tang C. Recent Advances in the Preparation, Structure, and Biological Activities of β-Glucan from Ganoderma Species: A Review. Foods. 2023 Aug 7;12(15):2975.

19. Wu P, Zhang C, Yin Y, Zhang X, Li Q, Yuan L, et al. Bioactivities and industrial standardization status of Ganoderma lucidum: A comprehensive review. Heliyon. 2024 Oct;10(19):e36987.

20. Ren S, Liu H, Sang Q, Lu M, Gao Q, Chen W. A Review of Bioactive Components and Pharmacological Effects of *Ganoderma lucidum*. Food Science & Nutrition. 2025 Jul;13(7):e70623.

21. Blundell R, Camilleri E, Baral B, Karpiński TM, Neza E, Atrooz OM. The Phytochemistry of *Ganoderma* Species and their Medicinal Potentials. Am J Chin Med. 2023 Jan;51(04):859–82.

22. Liu T, Hu Y, Wang Y, Li H. Analyzing energy utilization influence on tourism and low-carbon development: Insights from Xianju National Park in China. Energy Strategy Reviews. 2024 Jul;54:101480.

23. Kolniak-Ostek J, Oszmiański J, Szyjka A, Moreira H, Barg E. Anticancer and Antioxidant Activities in Ganoderma lucidum Wild Mushrooms in Poland, as Well as Their Phenolic and Triterpenoid Compounds. IJMS. 2022 Aug 19;23(16):9359.

24. Zhao Y, Li Q, Wang M, Wang Y, Piao C, Yu H, et al. Structural characterization of polysaccharides after fermentation from Ganoderma lucidum and its antioxidant activity in HepG2 cells induced by H2O2. Food Chemistry: X. 2023 Jun;18:100682.

25. Liu J, Zhang B, Wang L, Li S, Long Q, Xiao X. Bioactive components, pharmacological properties and underlying mechanism of Ganoderma lucidum spore oil: A review. Chinese Herbal Medicines. 2024 Jul;16(3):375–91.

26. Seweryn E, Ziała A, Gamian A. Health-Promoting of Polysaccharides Extracted from Ganoderma lucidum. Nutrients. 2021 Aug 7;13(8):2725.

27. Ekiz E, Oz E, Abd El-Aty A, Proestos C, Brennan C, Zeng M, et al. Exploring the Potential Medicinal Benefits of Ganoderma lucidum: From Metabolic Disorders to Coronavirus Infections. Foods. 2023 Apr 3;12(7):1512.

28. Cadar E, Negreanu-Pirjol T, Pascale C, Sirbu R, Prasacu I, Negreanu-Pirjol BS, et al. Natural Bio-Compounds from Ganoderma lucidum and Their Beneficial Biological Actions for Anticancer Application: A Review. Antioxidants. 2023 Oct 25;12(11):1907.

29. Mustafin K, Bisko N, Blieva R, Al-Maali G, Krupodorova T, Narmuratova Z, et al. Antioxidant and antimicrobial potential of *Ganoderma lucidum* and *Trametes versicolor*. Turkish Journal of Biochemistry. 2022 Sep 6;47(4):483–9.

30. Cancemi G, Caserta S, Gangemi S, Pioggia G, Allegra A. Exploring the Therapeutic Potential of Ganoderma lucidum in Cancer. JCM. 2024 Feb 18;13(4):1153.

31. Gao X, Homayoonfal M. Exploring the anti-cancer potential of Ganoderma lucidum polysaccharides (GLPs) and their versatile role in enhancing drug delivery systems: a multifaceted approach to combat cancer. Cancer Cell Int. 2023 Dec 16;23(1):324.

32. Chen S, Guan X, Yong T, Gao X, Xiao C, Xie Y, et al. Structural characterization and hepatoprotective activity of an acidic polysaccharide from Ganoderma lucidum. Food Chemistry: X. 2022 Mar;13:100204.

33. Johra FT, Hossain S, Jain P, Bristy AT, Emran T, Ahmed R, et al. Amelioration of CCl4-induced oxidative stress and hepatotoxicity by Ganoderma lucidum in Long Evans rats. Sci Rep. 2023 Jun 19;13(1):9909.

34. Liu X, Yang L, Li G, Jiang Y, Zhang G, Ling J. A novel promising neuroprotective agent: Ganoderma lucidum polysaccharide. International Journal of Biological Macromolecules. 2023 Feb;229:168–80.

35. Chen J, Zhang Y, Cai H, Liu L, Liao M, Fang J. A Comprehensive Overview of Micro-Influencer Marketing: Decoding the Current Landscape, Impacts, and Trends. Behavioral Sciences. 2024 Mar 18;14(3):243.

36. Meng Y, Chung D, Zhang A. The effect of social media environmental information exposure on the intention to participate in pro-environmental behavior. Al Mamun A, editor. PLoS ONE. 2023 Nov 16;18(11):e0294577.

37. Du Y, Tian L, Wang Y, Li Z, Xu Z. Chemodiversity, pharmacological activity, and biosynthesis of specialized metabolites from medicinal model fungi Ganoderma lucidum. Chin Med. 2024 Mar 22;19(1):51.

38. Constantin M, Răut I, Suica-Bunghez R, Firinca C, Radu N, Gurban AM, et al. Ganoderma lucidum-Mediated Green Synthesis of Silver Nanoparticles with Antimicrobial Activity. Materials. 2023 Jun 8;16(12):4261.

39. Mousavi SM, Hashemi SA, Gholami A, Omidifar N, Chiang WH, Neralla VR, et al. Ganoderma lucidum methanolic extract as a potent phytoconstituent: characterization, in-vitro antimicrobial and cytotoxic activity. Sci Rep. 2023 Oct 13;13(1):17326.

40. Rijia A, Krishnamoorthi R, Rasmi M, Mahalingam PU, Kim K sun. Comprehensive Analysis of Bioactive Compounds in Wild Ganoderma applanatum Mushroom from Kerala, South India: Insights into Dietary Nutritional, Mineral, Antimicrobial, and Antioxidant Activities. Pharmaceuticals. 2024 Apr 17;17(4):509.

41. Zheng W, Lan S, Zhang W, Nie B, Zhu K, Ye X, et al. Polysaccharide structure evaluation of Ganoderma lucidum from different regions in China based on an innovative extraction strategy. Carbohydrate Polymers. 2024 Jul;335:122079.

42. Senphan T, Benjakul S, Sukketsiri W, Chotphruethipong L, Sriket C. Comparative studies on characterizations and cytotoxicity of oil extracted from Lingzhi (Ganoderma lucidum) G2 spore using Soxhlet extraction and microwave-assisted extraction. Applied Food Research. 2024 Dec;4(2):100483.

43. Sunaryanto R, Nurani D. OPTIMASI PERMUKAAN RESPON MEDIUM FERMENTASI Streptomyces prasinopilosus SEBAGAI ANTIFUNGI TERHADAP PATOGEN Ganoderma boninense. J Bioteknol Biosains Indones. 2019 Dec 2;6(2):164.

44. Agustina F. Chromium Incorporation by Ganoderma lucidum with Oil Palm by-Product as Substrate. Media Peternakan [Internet]. 2010;33(1). Available from: http://repository.ipb.ac.id/handle/123456789/43245

45. Ni H, Fu W, Wei J, Zhang Y, Chen D, Tong J, et al. Non-destructive detection of polysaccharides and moisture in Ganoderma lucidum using near-infrared spectroscopy and machine learning algorithm. LWT. 2023 Jul;184:115001.

46. Umar A, Ahmed S. Optimization, purification and characterization of laccase from Ganoderma leucocontextum along with its phylogenetic relationship. Sci Rep. 2022 Feb 14;12(1):2416.

47. Wu L, Chen Y, Huang X. The process and motivations of individual values internalization: a qualitative study. BMC Psychol. 2025 Sep 26;13(1):1036.

48. Ye T, Ge Y, Jiang X, Song H, Peng C, Liu B. A review of anti-tumour effects of Ganoderma lucidum in gastrointestinal cancer. Chin Med. 2023 Aug 28;18(1):107.

49. Łysakowska P, Sobota A, Wirkijowska A, Zarzycki P, Blicharz-Kania A. The Impact of Ganoderma lucidum (Curtis) P. Karst. Supplementation on the Technological, Chemical, and Quality Parameters of Wheat Bread. Foods. 2024 Sep 28;13(19):3101.

50. Zhang H, Yang J, Liu Z. Effect of teachers' teaching strategies on students' learning engagement: moderated mediation model. Front Psychol. 2024 Dec 3;15:1475048.

51. El Sheikha AFE. Nutritional Profile and Health Benefits of Ganoderma lucidum "Lingzhi, Reishi, or Mannentake" as Functional Foods: Current Scenario and Future Perspectives. Foods. 2022 Apr 1;11(7):1030.

52. Alshiekheid MA, Umar A, Ameen F, Alyahya SA, Dufossé L. Biodegradation of chromium by laccase action of Ganoderma multipileum. Journal of King Saud University - Science. 2023 Dec;35(10):102948.

53. Porter DL, Hotz EC, Uehling JK, Naleway SE. A review of the material and mechanical properties of select Ganoderma fungi structures as a source for bioinspiration. J Mater Sci. 2023 Feb;58(8):3401–20.