Antibacterial Efficacy of

Aqueous and Ethanolic *Ganoderma lucidum*

Exploring the Potential of
Medicinal Mushroom Extracts

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Antibacterial Efficacy of Aqueous and Ethanolic Ganoderma lucidum

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Abstract

Mother natural goods serve as both a rich supply of pharmacologically active scaffolds for the development of novel drugs and the cornerstone of global health care. The rapid and unchecked development of antimicrobial resistance (AMR), systemic toxicity, and adverse effects of conventional synthetic medications are the causes of the health crisis in contemporary medicine. In order to combat opportunistic fungal diseases and resistant bacteria, it is imperative to find novel biocompatible treatments. Although terrestrial medicinal plants have historically been the focus of bioprospecting, macrofungal, or mushrooms, provide a very potential but mostly unexplored bio-resource. G. lucidum is an Eastern traditional medicine, but in order to satisfy the requirements of contemporary medicines, its precise molecular and secondary metabolite profiles must be thoroughly scientifically confirmed.

This work set out to rigorously extract, identify, and qualitatively characterize the unique profile of bioactive secondary metabolites found in G. lucidum. In order to determine its therapeutic potential as a safe, effective, and synergistic broad spectrum antimicrobial drug, the current investigation additionally concentrated on evaluating its in vitro antibacterial properties against a panel of clinically relevant pathogenic strains.

In this study, G. lucidum basidiocarps were completely dried, ground into a powder, and then extracted using the Soxhlet extraction method using essentially two solvents: ethanol and distilled water. The primary types of metabolites were qualitatively tested for in the resulting crude extracts. The typical bacterial strains Staphylococcus aureus, Escherichia coli, and Bacillus cereus were subjected to the antimicrobial activity in vitro using the paper disc method in order to precisely identify the zones of inhibition (ZOI).

Additionally, the Minimum Inhibitory Concentration (MIC) was taken into consideration for bacterial strains. To establish quantitative efficacy, the concentrations were calculated using the microdilution method.

The targeted extract has a very rich and varied profile of secondary metabolites, according to preliminary phytochemical screening. This allowed for the verification of the presence of triterpenoids, polysaccharides, polyphenols, and flavonoids. The extracts of G. lucidum displayed a strong concentration-dependent inhibitory impact on both Gram-positive and Gram-negative bacterial strains, according to the antimicrobial bioassays.

Keywords:

Ganoderma lucidum, Antimicrobial Activity, Antibacterial Activity, Secondary Metabolites, Phytochemical Screening, Bioactive Compounds, Minimum Inhibitory Concentration (MIC), Broad-Spectrum Antimicrobial Agent

1. Introduction

Antler Reshi Mushroom

Many modern medications are derived from natural sources, usually based on their traditional uses. It has been estimated that roughly 80% of people worldwide rely on herbal medicines to meet their primary healthcare needs. Most of such dependence is in the remote and rural areas of the developing countries where millions of people continue to rely on medicinal plants for their health. Besides that, it is said that more than 65% of the world's population use medicinal plants as their principal mode of treatment. That's why, these figures indicate the tremendous worth and significance of these natural resources in healing and sustaining human health (1). The fact that people like herbal remedies shows that the old ways work well. This is how a lot of modern medicines have been developed as well (2).

The current antibiotics may be toxic and the overuse of antibiotics has caused bacteria to become resistant. So still, people search for new antibiotics, plants with a history of medicinal use, and microorganisms, have been discovered to carry a wide variety of biologically active compounds capable of providing therapeutic benefits, for example tannins alkaloids and flavonoids. And, terpenoids and phenols are categorized as among the harmful bacteria fighting agents. Investigation in plants and microbes is uncovering their potential for generating new antibiotics. It is significant because drug-resistant infections are an escalating problem even though human nature is still the source of a great many chemical health solutions (3). Sources that have been ignored for a long time might mean new drugs.

Currently scientists are quite focused on fungi when looking for substances to fight diseases. Plants used to be the main source of powerful agents against harmful microbes, but now people are starting to look elsewhere (4). In countries like India, the number of deadly fungal infections is going up all the time. And, these fungi are becoming resistant to medicines that previously were effective. So, exploring unknown active chemicals in mushrooms and molds may open paths toward stronger remedies for stubborn infections and future medicine development (5), (6)

This approach has to be immensely powerful and could allow for some rather exciting breakthroughs to be made. The study of fungi may even allow for the discovery of new ways to treat illness that currently no medicine can combat.

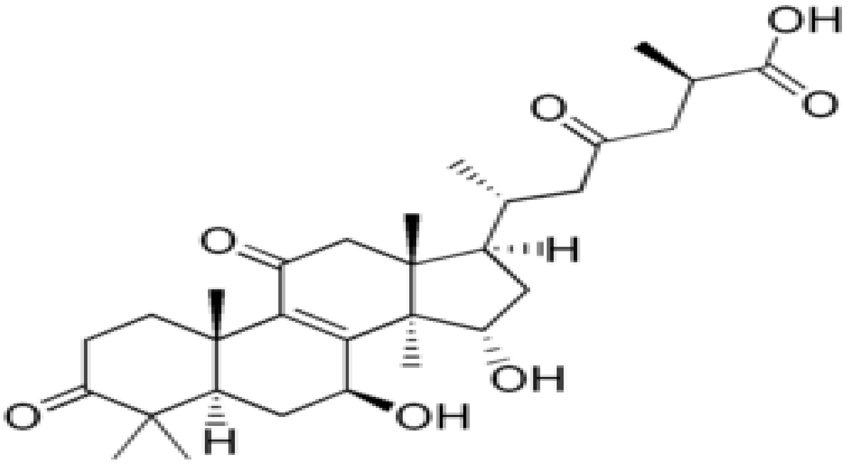
The scientific name Ganoderma lucidum combines the genus Ganoderma, from the Greek word’s genos (meaning brightness or sheen) and derma (skin), translating to "shining skin," with lucidum, derived from the Latin lucidus, meaning "bright" or "clear"(7) commonly referred to as reishi, varnished conk, lacquered bracket, or lingzhi, this mushroom typically appears in shades of purple-brown. It features a fan-shaped cap with a glossy surface, a long stalk, and brown spores, and is sometimes associated with six distinct colors. It primarily grows on decaying stumps of plum or oak trees (8). Native to China, Japan, and parts of North America, it is widely cultivated across Asia and has limited presence in Europe and certain northern regions of India, where it thrives on decomposing hardwoods (9).

While a study explored methods for cultivating G. lucidum using various waste materials and side-streams, the species generally performs poorly on softwoods compared to hardwoods like aspen. This is likely due to toxic compounds in softwoods that inhibit fungal growth, including many Ganoderma species. However, recent research shows that G. lucidum can still break down Pinus sylvestris wood, effectively delignifying it while preserving carbohydrate content—suggesting new potential for using softwoods in its cultivation (10).

The fruiting bodies can reach up to 35 centimetres (14 inches) in diameter. They almost always have a stipe, colored tawny to russet, typically about 1.5 times the cap's diameter. The internal context tissue—located between the cap crust and the start of the pores—is corky in texture, ranges from pink-buff to cinnamon-buff, displays concentric growth rings, and lacks resinous or melanoid deposits. The hymenium has 4 to 5 pores per millimetre (11). Chlamydospores are not present. Basidiospores measure 8.2–12.1 µm in length (average 10.7 µm) and 4.8–8.9 µm in width (average 7.1 µm), with a spore shape index of 66.2 (12).

For thousands of years, Ganoderma lucidum has been used in traditional Eastern medicine to support general health and aid recovery from illness. Modern science is now examining this ancient remedy more closely and confirming that it possesses notable therapeutic properties. The mushroom contains unique bioactive compounds capable of influencing physiological processes in the human body.

Ganoderic acid A, a compound isolated from Lingzi mushroom (Ganoderma lucidum)



Modern scientific studies and therapeutic trials have confirmed the ancient knowledge of G. lucidum in Asian nations, and the scientific foundation has been supplied. According to recent research, G. lucidum contains a number of compounds, such as triterpenes (ganoderic acids), which share molecular similarities with steroid hormones (13). Additionally, it contains phytochemicals such mannitol, polysaccharides (like beta-glucan), coumarin, and alkaloids that are present in the fungal material (Wu et al., 2023, p. 568). Ganoderol, ganoderenic acid, ganoderiol, ganodermanontriol, lucidadiol, and ganodermadiol were the sterols that were extracted from the mushroom (14).

G. lucidum has a variety of pharmacological effects, including anti-tumour, immunomodulation, antioxidants, antimicrobial, anti-diabetes, cardioprotective, anti-inflammatory, anti-androgenic, antimutagenic, and neuroprotective (15).

Due to its abundance of bioactive compounds and diverse range of pharmacological effects, G. lucidum has recently been identified as a widely studied and product-developed medicinal fungus. In the current review, we looked closely at G. lucidum's chemistry and quality control, bioactivity and its mechanism, preclinical and clinical trials, safety toxicity, and evaluation of side effects. Ganoderma lucidum as a dietary supplement because of its rich nutritional value

- A significant amount of water-soluble proteins (19.5 g/100 g) and 18 different types of amino acids are present in G. lucidum. The most prevalent amino acid, leucine, has potent hypoglycaemic and antioxidant properties (16), (17).

- According to (18), G. lucidum has 3.5 g of dietary fibre per 100 g of mushrooms (d/w).

- G. lucidum has notable concentrations of trace elements like Cu, Mg, and Fe as well as important minerals like phosphorus and sulfur (17).

- A wide range of vitamins, such as riboflavin, niacin, thiamine, B1, B2, B6, -carotene C, D, and E, are found in G. lucidum (16).

- The nutritional profile of G. lucidum makes this fungus extremely nutrient-rich, which positively reflects its health-promoting qualities.

Lingzi is traditionally prepared as a hot water extract in folk medicine due to its naturally bitter taste (19). Thin slices or powder of Lingzi—whether fresh or dried—are boiled and then simmered for about two hours under a covered lid. The resulting liquid is dark and distinctly bitter, with red varieties generally being more bitter than black ones. This extraction process may be repeated to achieve a higher concentration.

The preparation is believed to have calming effects and may help alleviate symptoms of the flu and respiratory issues (20). In traditional use, G. lucidum has been employed to address dizziness, sleep disorders, and irregular heartbeats. Known as reishi in Japan, it has earned names such as the mushroom of immortality, a symbol of spiritual strength, and a sacred herb across various cultures. It is often associated with health benefits including rejuvenation, increased stamina, and support for cardiovascular function. Traditionally, it has also been used in managing chronic conditions like liver disease, nephritis, hypertension, arthritis, migraines, bronchitis, asthma, cancer, and diabetes.

The antimicrobial properties of G. lucidum are largely attributed to its diverse triterpenoid content, such as ganoderic acids and ganoderal, which effectively inhibit microbial growth (7), (21). In addition to triterpenoids, the polysaccharides found in this fungus are recognized as major bioactive components with strong antimicrobial activity against a range of pathogenic microbes (22).

When combined with fatty acids and peptides, these compounds contribute to a broad-spectrum defense system, making them a key focus in contemporary pharmacological studies. Other bioactive metabolites present—such as lectins, proteins, and adenosine—further highlight the fungus's potential as a natural source of therapeutic agents (23).

2. Material and method

2.1 Sample Preparation

Fruiting body of G. lucidum is collected from Polaris shrooms Hathibadkala Dehradun Uttarakhand India

2.1.1 Ethanolic extract

The bioactive secondary metabolites were isolated using Soxhlet extraction (24) of the medicinal mushroom Ganoderma lucidum with ethanol as extraction solvents. This solvent is popular because they are good at extracting a lot of different phytochemicals with different polarities (25). Ethanol is a good solvent for extracting phenolic compounds, flavonoids and triterpenoids.

Step 1 – Sample Collection and Preparation

The fresh basidiocarps of Ganoderma lucidum were collected and cleaned properly to remove the dirt and other contaminants. The samples of mushroom were dried in shade for 7-10 days till completely dry. The dried material was then ground to a fine powder in a clean mechanical grinder. The powdered sample was kept in air tight containers in cool and dry place until further use.

Step 2 – Selection of Solvent

Ethanol was chosen as the extraction solvents because they can extract a broad spectrum of bioactive compounds (26). Ethanolic extracts are reported to have triterpenoids, polyphenols, flavonoids and other secondary metabolites while aqueous extracts are rich in polysaccharides and glycoproteins (27).

Step 3 – Soxhlet Extraction Method

Accurately weighed 10 g of dried mushroom powder and placed in a cellulose Soxhlet extraction thimble Then the thimble was put into the main chamber of the Soxhlet apparatus. A 500 mL round-bottom flask with about 200 mL of ethanol was attached to the apparatus and the extraction was performed for several cycles until the solvent became clear.

Step 4: Preparing the Final Extract

The solvent was removed by rotational evaporation or evaporation under low pressure after extraction. For additional phytochemical screening and antimicrobial investigation, the concentrated crude extracts were gathered, weighed, and kept in sterile, airtight containers at 4°C.

a) b)

2.2.2Aqueous Extract

Distilled water was used as the extraction solvent to extract water-soluble bioactive components from Ganoderma lucidum. Boiling is a simple and effective way to extract proteins, polysaccharides, glycoproteins, and other hydrophilic components that give the mushroom its therapeutic and antibacterial properties (21), (28).

Step 1 – Measurement and mixing

Weigh out 10 g of dry mushroom powder precisely from the prepared stock, then pour it into a 500 mL conical flask or beaker with 200 mL of distilled water. To help extract water-soluble bioactive chemicals, the mixture was heated and boiled at 80–100°C for 30–60 minutes while being stirred periodically.

Step 2 – Filtration

After that, it was heated to a boil and allowed to cool to room temperature. To eliminate solid residues and produce a clean filtrate, the extract was filtered using muslin cloth and Whatman No. 1 filter paper.

Step 3 - Concentration and Storage

Until the required volume or semi-solid crude extract was obtained, the filtrate was dried out in a water bath at 50–60 °C. For additional phytochemical analysis and antibacterial research, the concentrated aqueous extract was moved to sterile, airtight containers and kept at 4°C.

3. Phytochemical Analysis

Water and ethanol extracts of G. lucidum were screened for phenols, alkaloids, and terpenes using Soxhlet extraction techniques (29). While polysaccharides and other water-soluble components could be extracted using distilled water, secondary metabolites were detected using standard techniques (30).

i. Tannin test: one millilitre of the extract was used. Add three to five drops of a 10% lead acetate solution. Tannin was demonstrated by the development of a gelatinous precipitate.

ii. Saponin test: Take 1 millilitre of extract, add 1 millilitre of distilled water, and thoroughly mix. The development of a steady foam was used to identify saponins.

iii. Flavonoids test: one milliliter of extract was mixed with two milliliters of a 2% NaOH solution and three to four drops of diluted HCl. The color shifted to a bright yellow with the NaOH solution, and then it turned colorless. The presence of flavonoids was verified by the color shift.

iv. Terpenoids Test: 5–6 drops of chloroform were added to 1 milliliter of extract, which was then placed in a water bath for a few minutes. Concentrated sulfuric acid was then added in five to six drops. Terpenoids were proven to be present by the reddish-brown interface.

v. Phenolic groups test: One milliliter of the extract was used. A few drops of a 5% ferric chloride solution were added. The dark and bluish-black color verified the presence of phenolic chemicals.

vi. Test for reducing sugars: two drops of Fehling's solution were combined with roughly one milliliter of extract A and Fehling's solution B. The mixture was then placed in a water bath for a while. The presence of reducing sugar is indicated by the reddish-orange precipitate.

vii. Test for steroid: one milliliter of the extract was combined with one milliliter of concentrated sulfuric acid and one milliliter of chloroform. The presence of steroids was suggested by the emergence of upper red and lower yellow colors with green fluorescence.

viii. Test for alkaloids: add three to four drops of Dragendroff's reagent to approximately one milliliter of extract. The production of a reddish-brown precipitate indicated the presence of alkaloids.

ix. Test for carbonyl compounds: add four drops of 2, 4-Dinitrophenylhydrazine (DNPH) reagent to about one milliliter of the extract. The existence of carbonyl compounds is confirmed by the observation of yellow crystals.

3.1 Screening results

Table 1: Phytochemical test results (Ethanol and Aqueous extracts).

Bioactive test	In ethanol extract	In aqueous extract
Tannin test	+ve	+ve
Saponin test	-ve	+ve
Flavonoids test	-ve	-ve
Terpenoids test	-ve	-ve
Phenolic test	-ve	+ve
Reducing sugar test	+ve	+ve
Steroids test	-ve	-ve
Alkaloids test	+ve	+ve
Carbonyl test	-ve	-ve

(+ve: Present; -ve: Absent)

G. lucidum's phytochemical research identified a variety of bioactive substances (Table 1). Tannins were present in both the ethanol and aqueous extracts, but only the aqueous extract included saponins and phenolic chemicals. Both extracts included reducing sugars as well. Additionally, the research revealed that both extracts lacked flavonoids, terpenoids, steroids, and carbonyl compounds. Alkaloids were present in both extracts. These findings imply that G. lucidum is a valuable source of bioactive substances.

Recent research has shown G. lucidum's therapeutic qualities. According to (31), it may be used to treat viral infections like coronavirus and metabolic conditions like diabetes and obesity. (32), (33). examined its ability to prevent liver fibrosis caused by several infections. The pharmacological actions of G. lucidum spores and their advantages for cancer and metabolic disorders were further detailed in (34).

Ganoderma lucidum's phytochemical examination revealed a wide variety of bioactive substances, particularly in the aqueous extract. Tannins, saponins, phenolic compounds, reducing sugar, and alkaloids were shown to have potential therapeutic qualities, some of which are further studied in antimicrobial analysis.

4. Antimicrobial Activity

Ganoderma lucidum has a number of bioactive compounds with remarkable antibacterial capabilities. The antimicrobial compounds of Ganoderma species affect the fundamental structures and functions that all microorganisms share through a range of unique mechanisms of action (14), (35).

• Microbial cell wall disruption

The lipid components of bacterial and fungal cell membranes form inclusion complexes with ganoderic acids and other triterpenoids found in G. lucidum. Thus, the interaction of the lipid components results in non-lamellar structures, including membrane permeabilization and cell lysis (21). Ganoderma bioactive chemicals break down the microorganisms' cell walls. As a result, the cells are destroyed and their constituent parts flow out.

• Inhibition of nucleic acid synthesis

G. lucidum polysaccharides have been found to inhibit the synthesis of DNA and RNA by pathogenic microbes. By attaching themselves to nucleic acids or essential enzymes involved in transcription and replication, they prevent the bacteria from reproducing and developing. Inhibiting the synthesis of genetic material is necessary to prevent the hazardous microbes from proliferating and surviving (36), (37).

• Oxidative damage

G. lucidum's phenolic compounds have potent antioxidant qualities that support the maintenance of ROS levels within microbial cells. These substances can wreak havoc on cells by increasing oxidative stress beyond what the body can manage, particularly when microorganisms are present and the infections are eliminated (21). However, within host cells, Ganoderma antioxidants protect your cells from harm caused by free radicals, which aid in the defense against infections by eliminating excess reactive oxygen species. This helps prevent damage to tissues. This protective impact restores normal cellular functioning and expedites healing (38).

• Synergistic results

G. lucidum's bioactivities come from more than just individual bioactive compounds. Instead, phenolic compounds, proteins, peptides, polysaccharides, and triterpenoids interact to provide synergistic effects that have been improved to have greater therapeutic potential (39). Generally speaking, interactions between two or more things that have an effect greater than the sum of their individual effects are called "synergy."

4.1 Antibacterial analysis

The test is conducted against Staphylococcus aureus, Bacillus cereus and Escherichia coli bacteria which is collected from Rapture biotech lab Dehradun Uttarakhand India. The bugs were kept in a refrigerator at 4-8°C in sterile nutrient agar(40).
We grew the fresh batches on agar plates for use and it was easy to run our tests effectively.

Paper Disc Assay (MIC) is accounted for the antibacterial test

The paper disc assay was used to test the activity of the mushroom extracts against the organisms (41). The aqueous and ethanol G. lucidum extracts were sterilized by Millipore filter membranes (0.45 mm) and reconstituted in the following concentration:

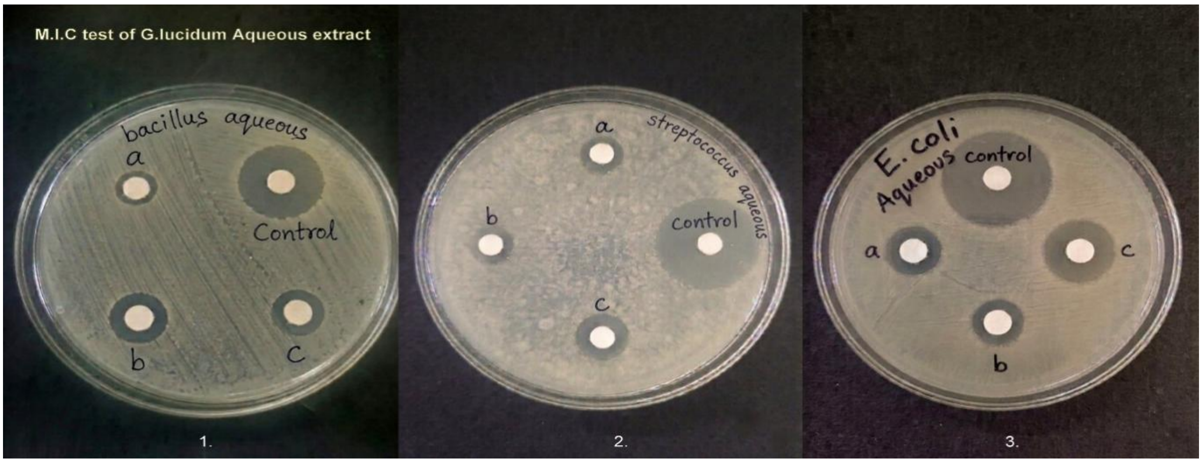
a).100 mg/500 µl. b). 200 mg/500 µl. c) 300 mg/500 µl.

The antibacterial activity was assessed by impregnating paper discs made from Whatman No. 1 filter paper with all the above different concentrations of both Aqueous and Ethanolic extracts and Ciprofloxin as standard at 1 mg/ml (42).

The fresh different bacterial cultures of above-mentioned strains with sterile water are prepared to obtain 24-hour-old bacterial cultures. The concentration of bacteria was measured by the UV/VIS spectrophotometer at600nm wavelength optical density to determine the concentration of 107 CFU/ml (43). Then, 0.5 ml of the bacterial suspension was plated on nutrient agar.

Then overnight treated paper discs of different extracts and concentration were then dried and zapped with a UV bulb to make them super sterile, the discs were placed on the agar plates that had been inoculated recently. All these plates were then incubated at 37°C for 3 days (44).

Finally, the measurements of the zones of inhibition of all plates around each disc with a clear ruler are recorded which is demonstrated in table no2 below.



(Aqueous extract)

(Ethanolic extract)

Table.2 inhibition zone of G. lucidum using Ethanol and Aqueous extracts

Bacterial Strain (Culture plate)	Concentration Of extracts (mg/ µl)	Aqueous extract Inhibition zone (mm)	Ethanolic extract Inhibition zone (mm)	Inhibition Zone By Standard
1.Bacillus cereus	a. 100 mg/500 µl	4.0 mm	0 mm	11mm
	b. 200 mg/500 µl	5.5 mm	0 mm	
	c. 300 mg/500 µl	6.0 mm	6.5 mm	
2.Streptococcus aures	a. 100 mg/500 µl	5.5 mm	0 mm	14.5 mm
	b. 200 mg/500 µl	5.5 mm	0 mm	
	c. 300 mg/500 µl	6.0 mm	8.0 mm	
3.Escherichia coli	a. 100 mg/500 µl	4.0 mm	0 mm	13 mm
	b. 200 mg/500 µl	4. 0mm	0 mm	
	c. 300 mg/500 µl	6.0 mm	7.5 mm	

Testing the two solvent extracts of Ganoderma lucidum against Staphylococcus aureus, Bacillus cereus and Escherichia coli are presented in Tables.2 . Although the ethanol extract was only active against all the organisms at the highest concentration of 300 mg/500 µl, the extract showed the strongest inhibition zone of 8.0 mm, against Staphylococcus aureus (45) .

Tables.2 show that the water extract was more potent than the ethanol extract because it was active at the lowest concentration of 100 mg/500 µl. This suggests that the extracts contain substances that are bactericidal. The widest zone of inhibition was obtained with the highest concentration of ethanol solvent extracts. The mean zone of inhibition of Staphylococcus aureus by the ethanol extract was comparable to that of the standard Ciprofloxin (46).

Both the extracts exhibited appreciable bactericidal activity but their zones of inhibition were less than the standard antibiotic, Ciprofloxacin which exhibited zones of inhibition ranging from 11mm to 14.5mm over the tested strains.

Staphylococcus aureus was the most susceptible to the two solvent extracts of G. lucidum at various concentrations tested. This activity strongly indicates that the water and ethanol extracts of G. lucidum could be very useful in treating gastroenteritis, food poisoning and other infections caused by these organisms. (47), (48), (49).

5. Conclusion

In this paper we report the systematic characterization of the phytochemical profile of Ganoderma lucidum and show its considerable antibacterial activity This way, supporting its traditional use as medicine. This study highlights macrofungal as a largely untapped resource for the development of safe biocompatible therapeutics in the face of rising antimicrobial resistance and the known toxicological constraints of synthetic drugs. Secondary Metabolites Diversity: Sequential Soxhlet extraction provided a broad spectrum of secondary metabolites.

The presence of tannins saponins phenolic compounds, reducing sugars and alkaloids was confirmed in the water extract. An efficient separation of functional metabolites including tannins, alkaloids and reducing sugars was also achieved in the ethanolic extract. Specific antibacterial effectiveness: Cell culture tests confirmed the killing ability of G. lucidum extracts made with alcohol and water not only against one but several types of bacteria including Gram positive bacteria (Bacillus cereus, Staphylococcus aureus) and Gram negative (Escherichia coli). The aqueous extract was more potent at lower concentrations (active at 100 mg/500 µl) and ethanolic extract showed the highest zone of inhibition at peak concentrations (8.0 mm) against S. aureus.

Mechanisms of Action: The antimicrobial activity observed is mainly attributed to the synergistic interactions of the isolated secondary metabolites. Compounds such as triterpenoids, phenols and polysaccharides actively damage microbial cell walls, inhibit essential synthesis of nucleic acids and induce specific oxidative stress in pathogenic cells while providing antioxidant protection to host tissues.

5.1 Broader Impact and Future Direction

The high sensitivity of clinical strains particularly Staphylococcus aureus towards these extracts, indicates the promising pharmacological value of locally harvested G. lucidum in the treatment of infectious diseases such as gastroenteritis and food poisoning. The existence of strong bioactive scaffolds, such as terpenes, phenolics, and alkaloids indicates that this fungal species is a powerful broad-spectrum antimicrobial agent.

The isolated secondary metabolites of G. lucidum are very promising candidates for new drug discovery in the future. Further in vivo studies, accurate quantitative isolation of active fractions (e.g. specific ganoderic acids) and investigations of their combined synergistic actions with existing clinical antibiotics are required to fully translate these natural fungal compounds into modern pharmaceutical interventions.

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About the Study

This study investigates the antibacterial efficacy of aqueous and ethanolic extracts of *Ganoderma lucidum*, a medicinal mushroom known for its bioactive compounds and therapeutic potential. The research aims to evaluate and compare the antimicrobial activity of these extracts against selected pathogenic bacteria.

Key Highlights

- Utilizes both aqueous and ethanolic extracts of Ganoderma lucidum
- Evaluates broad-spectrum antibacterial activity
- Scientifically analyzed for maximum reliability
- Supports the potential use of natural extracts in combating antibacterial resistance

Conclusion

The findings highlight the significant antibacterial potential of *Ganoderma lucidum* extracts, supporting their application in developing natural antimicrobial agents and contributing to future pharmaceutical innovations.

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