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MEDICINAL POTENTIAL OF INONOTUS OBLIQUUS *(CHAGA MUSHROOM): A COMPREHENSIVE REVIEW OF BIOACTIVE COMPOUNDS AND THERAPEUTIC APPLICATIONS*

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ABSTRACT

Inonotus obliquus (Chaga mushroom) is a medicinal fungus extensively utilized in traditional systems of medicine across Europe and Asia, particularly in Russia, China, and Northern Europe. In recent years, growing scientific interest has led to extensive investigations into its pharmacological potential, validating many of its traditional uses. This bioactive fungus is known for a wide range of therapeutic properties, including potent antioxidant, anti-inflammatory, anticancer, antidiabetic, antiviral, immunomodulatory, and hepatoprotective effects. These diverse biological activities are primarily attributed to its rich and complex phytochemical composition, which includes polysaccharides (especially β-glucans), triterpenoids (such as betulin and betulinic acid), polyphenols, flavonoids, sterols, and melanin pigments. The antioxidant activity of I. obliquus plays a central role in its therapeutic efficacy by scavenging free radicals, reducing oxidative stress, and preventing cellular damage. Its anticancer potential is linked to mechanisms such as induction of apoptosis, inhibition of tumor cell proliferation, and modulation of signaling pathways. Additionally, its antidiabetic effects are associated with improved glucose metabolism and insulin sensitivity. The fungus also exhibits significant antiviral activity and supports liver health through hepatoprotective mechanisms. This review comprehensively summarizes the current understanding of the phytochemistry, pharmacological activities, and medicinal applications of Inonotus obliquus. It also explores underlying mechanisms of action and highlights its emerging role as a

functional food and nutraceutical. Furthermore, the review emphasizes existing research gaps and suggests future directions for clinical studies to fully establish its therapeutic potential and safety profile.

KEYWORDS: *Inonotus obliquus*, Chaga mushroom, bioactive compounds, antioxidant, anticancer, immunomodulation.

1. INTRODUCTION

Inonotus obliquus is a parasitic fungus primarily found on birch trees in cold climates of the Northern Hemisphere. It has been used since the 16th century in traditional medicine to treat gastrointestinal disorders, cancer, and metabolic diseases (Ern *et al*., 2023). The fungus forms a black, charcoal-like mass and contains a complex mixture of biologically active compounds. Modern research has demonstrated its pharmacological importance, especially in chronic disease management (Peng & Shahidi, 2020).

Table: Phytochemical Composition of *Inonotus obliquus* (Chaga Mushroom).

Phytochemical Class	Major Compounds Identified	Chemical Nature	Key Biological Functions	References
Polysaccharides	β-glucans, heteropolysaccharides	Complex carbohydrates	Immunomodulatory, anticancer, antidiabetic, antioxidant	(Zhang *et al*., 2026; Wang *et al*., 2021)
Triterpenoids	Inotodiol, betulin, betulinic acid, trametenolic acid	Lanostane-type triterpenes	Anticancer, anti-inflammatory, antiviral	(Zhao *et al*., 2015; Kim *et al*., 2020)
Polyphenols	Hispidin, hispolon, phenolic acids	Aromatic compounds	Strong antioxidant, anti-inflammatory	(Hwang *et al*., 2015)
Melanin Complex	Melanin pigments	High molecular weight pigment	Radioprotective, antioxidant, immune-enhancing	(Babitskaya *et al*., 2002; Wang *et al*., 2021)
Sterols	Ergosterol, ergosterol peroxide	Steroid compounds	Anti-inflammatory, anticancer	(Wasser, 2010; Zheng *et al*., 2010)
Phenolic Acids	p-coumaric acid, ferulic acid, chlorogenic acid	Organic acids	Antioxidant, antimicrobial	(Nowak *et al*., 2022)
Flavonoids	Quercetin-like compounds (trace levels)	Polyphenolic compounds	Free radical scavenging	(Nowak *et al*., 2022)
Proteins &	Essential amino acids	Nitrogen-	Nutritional,	(Wang *et*

Amino Acids		containing compounds	metabolic support	*al*., 2021)
Minerals & Vitamins	Potassium, selenium, vitamin D	Micronutrients	Antioxidant, metabolic functions	(Zhang *et al*., 2026)
Other Bioactives	Lignin derivatives, polysaccharide-protein complexes	Mixed compounds	Synergistic therapeutic effects	(Wang *et al*., 2021)

2. Medicinal Values and Detailed Pharmacological Activities

2.1 Antioxidant Activity

The antioxidant potential of *Inonotus obliquus* is one of its most extensively studied properties. Oxidative stress occurs due to an imbalance between reactive oxygen species (ROS) and the body's antioxidant defense system, leading to cellular damage, aging, and chronic diseases.

Chaga exhibits strong antioxidant activity primarily due to its phenolic compounds, flavonoids, polysaccharides, and melanin complex, which act through multiple complementary mechanisms. It effectively scavenges free radicals by neutralizing reactive oxygen species (ROS) such as superoxide anions, hydroxyl radicals, and hydrogen peroxide, thereby reducing oxidative stress and cellular damage. In addition, it demonstrates metal-chelating properties by binding transition metals like Fe^{2+} and Cu^{2+}, which helps prevent the generation of additional reactive oxygen species through metal-catalyzed reactions. Furthermore, Chaga enhances the body's endogenous antioxidant defence system by increasing the activity of key antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase, contributing to overall cellular protection and maintenance of redox balance. Melanin present in Chaga also contributes to radioprotective and antioxidant effects by absorbing harmful radiation and reducing oxidative damage. These combined effects protect cellular components such as DNA, proteins, and lipids (Hwang *et al*., 2015; Zhang *et al*., 2011).

2.2 Anticancer Activity

Inonotus obliquus has demonstrated promising anticancer effects in both in vitro and in vivo studies. Its bioactive compounds, particularly polysaccharides and triterpenoids (betulinic acid), act through several pathways: Chaga exhibits anticancer activity through multiple coordinated mechanisms, including the induction of apoptosis by activating programmed cell death via mitochondrial pathways involving caspase activation, and the arrest of the cell cycle, which halts cancer cell proliferation at critical phases such as G0/G1 or G2/M. It also

inhibits metastasis by suppressing tumor cell invasion and migration, while its anti-angiogenic effects prevent the formation of new blood vessels necessary for tumor growth and progression. Additionally, Chaga modulates key cellular signaling pathways, including NF-κB, which is involved in inflammation and cancer progression, and the PI3K/Akt pathway, which plays a crucial role in cell survival and proliferation. These actions collectively reduce tumor growth and enhance immune-mediated tumor destruction (Niu *et al*., 2011; Wasser, 2010).

2.3 Anti-inflammatory Activity

Chronic inflammation is associated with diseases like arthritis, cardiovascular disorders, and cancer. Chaga exerts anti-inflammatory effects by regulating immune responses. Chaga exhibits anti-inflammatory activity through multiple mechanisms, including the inhibition of pro-inflammatory mediators by reducing the production of nitric oxide (NO), prostaglandins, and cytokines such as TNF-α, IL-1β, and IL-6, while also suppressing inflammatory enzymes by downregulating the expression of cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS). Furthermore, it modulates key signaling pathways by inhibiting the activation of NF-κB and mitogen-activated protein kinase (MAPK) pathways, thereby contributing to the reduction of inflammation and associated cellular damage. Polysaccharides and polyphenols are the major contributors. These compounds help in reducing tissue damage caused by excessive inflammation (Sun *et al*., 2008; Youn *et al*., 2009).

2.4 Antidiabetic Activity

Chaga shows significant potential in managing diabetes mellitus, particularly type 2 diabetes. Chaga exhibits antidiabetic activity through multiple mechanisms, including the reduction of blood glucose levels by enhancing insulin sensitivity, along with the improvement of glucose metabolism through the promotion of glucose uptake in peripheral tissues. It also inhibits carbohydrate-digesting enzymes by suppressing the activity of α-amylase and α-glucosidase, thereby reducing postprandial glucose spikes, while additionally protecting pancreatic β-cells by minimizing oxidative stress-induced damage and preserving their functional integrity. Polysaccharides play a key role in regulating blood glucose levels and improving metabolic functions (Pan *et al*., 2013).

2.5 Immunomodulatory Activity

Chaga is known for its ability to enhance and regulate immune responses. Chaga exhibits immunomodulatory activity through multiple coordinated mechanisms, including the activation of macrophages, which enhances phagocytosis and promotes effective pathogen destruction, as well as the stimulation of natural killer (NK) cells, thereby improving the body's defence against tumors and infections. It also regulates cytokine production by increasing levels of IL-2 and IFN-γ while maintaining a balanced immune response, contributing to overall immune system enhancement and homeostasis. β-glucans present in Chaga are primarily responsible for immunomodulatory effects. They act as biological response modifiers, strengthening host defence systems (Kim *et al*., 2005).

2.6 Hepatoprotective Activity

The liver is highly susceptible to oxidative stress and toxic damage. Chaga provides hepatoprotection through: Chaga exhibits hepatoprotective activity through multiple mechanisms, including the reduction of lipid peroxidation, which helps prevent damage to liver cell membranes, along with the enhancement of detoxification enzymes that support normal liver metabolism and function. It also provides protection against toxins by reducing liver damage caused by harmful chemicals and drugs, thereby contributing to overall liver health and resilience. These effects are mainly due to antioxidants and triterpenoids, which help maintain liver function and integrity (Zhu *et al*., 2016).

2.7 Antiviral Activity

Chaga exhibits antiviral activity through multiple mechanisms, including the inhibition of viral replication by interfering with viral entry and subsequent multiplication within host cells, along with the enhancement of host immunity by boosting the immune response against viral infections. It also blocks viral enzymes, thereby preventing viral protein synthesis and limiting the progression of infection. This makes it useful in managing viral infections, including respiratory viruses (Zhao *et al*., 2014).

2.8 Antibacterial Activity

Chaga extracts have demonstrated broad-spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria through multiple complementary mechanisms. They disrupt bacterial cell wall and membrane integrity, leading to leakage of intracellular contents and eventual cell death, while also altering membrane permeability and interfering with essential transport processes. In addition, Chaga inhibits key microbial enzymes involved in

metabolism and energy production, thereby impairing bacterial growth and replication. The extracts further prevent the formation of biofilms by inhibiting bacterial adhesion and quorum sensing, which are critical for microbial communication and colony establishment, making pathogens more susceptible to host defenses and antimicrobial agents. Moreover, its rich phenolic and polysaccharide content contributes to oxidative stress within bacterial cells, enhancing antimicrobial efficacy and reducing the likelihood of resistance development. Phenolic compounds and triterpenes contribute significantly to antimicrobial effects (Ma *et al*., 2013).

2.9 Anti-obesity Activity

Chaga plays a significant role in regulating body weight and lipid metabolism through multiple interconnected mechanisms, including the reduction of lipid accumulation by decreasing fat storage in adipose tissue and inhibiting adipogenesis, while also regulating the expression of key genes involved in lipid metabolism such as those controlling fatty acid synthesis and breakdown. In addition, it improves the balance of gut microbiota by promoting beneficial microbial populations and suppressing harmful bacteria, which contributes to better energy homeostasis, enhanced nutrient metabolism, and reduced inflammation associated with obesity. These effects help in preventing obesity and related metabolic disorders (Wang *et al*., 2017).

2.10 Anti-fatigue Activity

Chaga improves physical performance and reduces fatigue through several coordinated mechanisms, including the enhancement of energy metabolism by increasing glycogen storage in muscles and the liver, which provides a sustained energy supply during physical activity, along with the reduction of lactic acid accumulation, thereby delaying muscle fatigue and improving endurance. Additionally, its strong antioxidant properties help reduce exercise-induced oxidative stress by neutralizing free radicals, protecting muscle tissues from damage, and supporting faster recovery after exertion. This makes it beneficial for improving endurance and recovery (Liu *et al*., 2019).

2.11 Renoprotective Activity

Chaga protects kidney tissues from damage caused by toxins and oxidative stress through multiple mechanisms, including the reduction of oxidative stress in renal tissues by scavenging free radicals and enhancing antioxidant defences, along with its anti-inflammatory effects that help suppress inflammatory responses in the kidneys. It also

prevents cellular apoptosis in kidney cells by stabilizing mitochondrial function and regulating apoptotic pathways, thereby preserving renal structure and function and reducing the risk of toxin-induced kidney injury. Triterpenoids play a major role in protecting kidney function (Chen *et al*., 2018).

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