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***Cordyceps sinensis* (Berk) Sacc. a pioneer medicinal mushroom, pharmacological properties, and their applications: An advanced review**

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Abstract

The healthy life of humans is always questioned due to their improper food habits, and lack of information about ancestors' diet and medicinal values. Keeping this background these reports remind us of one of the flagship medicinal mushrooms *C. sinensis*. It is a high altitude-loving precious mushroom used in folk medicine for healing cough, cold, wheezing disorders, nutritional enhancement, skin care, diarrhea, fatigue, headache, and importance issues in East Asian countries. Commonly, this mushroom has completed its lifespan as an insect ghost moth. Host population and climatic factors influenced the growth and development of *C. sinensis*. Majorly, this mushroom produces some significant pharmacological properties such as nucleosides, nucleotide derivatives, cordycepin, cordycepic acids, polysaccharides, fatty acids, amino acids, cyclic peptides, and carotenoids were used in huge quantitatively. In modern medicine, the supreme performance of clinical therapeutics for diabetes, neuro-regulation, analgesic, antiepileptic, antimicrobial, derma cure, antihyperlipidemic, hypoglycemia, aphrodisiac, autism, vitiligo, and Alzheimer's disease reported by using *C. sinensis*. Remarkably, these mushroom species have undergone several mutations, and their potential has been exploited due to unethical human practices. Mitigating these issues related to *C. sinensis* is crucial for its continued benefit to human health, especially in the context of future pandemics.

1. Introduction

From human evolution to novel inventions, quality-promoting developments have significantly contributed to human welfare and longevity. This development, from the Stone Age to the present, has relied on the use of natural resources as food sources (Alt *et al.*, 2022). The advancements in microbiological studies have greatly contributed to human day-to-day life for better health, directly or indirectly. Among these, various microbes such as fungi, bacteria, actinomycetes, yeasts, and algae have been utilized in numerous sectors including agriculture, pharmaceutical industries, industrial purposes, and ecological biosafety (Ghosh *et al.*, 2021). Mushrooms, in particular, are among the most promising, having been used as food, medicines, and cosmetics from ancient times to the present. More than 2000 species of mushrooms exist in nature, but only 25 species are commercially cultivated for food and additional purposes (Chatterjee *et al.*, 2021). Generally, both cultivated and wild species like *Albatrellus*, *Agaricus*, *Antrodia*, *Cordyceps*, *Calvatia*, *Clitocybe*, *Fomes*, *Flammulina*, *Fungia*, *Glomus*, *Ganoderma*, *Inonotus*, *Inocybe*, *Pleurotus*, *Phellinus*, *Russula*, *Suillus*, *Schizophyllum*, *Tremella*, *Trametes*, and *Xerocomus*, *etc.*, are used in various ways

to support human health (Azeem *et al.*, 2020). These different species of medicinal mushrooms are gaining more attention due to their pharmacological properties. This is because they are found in highly diversified natural habitats in the wild and are not easily obtained. Furthermore, they receive significant attention due to their diverse production of novel anticancer, neuroregulatory, immunomodulatory, anti-inflammatory, digestive, skin health-regulating, and nutritional substances/supplements (Wei *et al.*, 2021). These specialized characteristics are often obtained in extremely small quantities, necessitating a focus on their production, standardization, and commercialization (Hee-Young *et al.*, 2020). These therapeutic fungi are also highly valuable and biopotential, posing no significant risk to people compared to certain bacteria, algae, or plant species (Slusarczyk *et al.*, 2021). Among various mushroom species, *Hericium erinaceus* (lion's mane mushroom), *Ganoderma lingzhi* (the Reishi mushroom), *Cordyceps* spp. (the caterpillar mushroom), *Inonotus obliquus* (the Chaga mushroom), *Trametes versicolor* (the Turkey tail mushroom), *Lentinula edodes* (the shiitake mushroom), and *Grifola frondosa* (the maitake mushroom) have contributed significantly (Lindequist *et al.*, 2014).

Of these, *Cordyceps* spp. has been credited with playing a significant role in drug discoveries, undergoing pre- and post-clinical studies for various human pharmacological activities such as antioxidant (Shweta *et al.*, 2023), antihyperlipidemic (Wang *et al.*, 2015a), antiviral (Zhang *et al.*, 2022), antiageing (Zhu *et al.*, 2020), antidepressant (Singh *et al.*, 2014), antifatigue (Geng *et al.*, 2017), hypocholesterolemic (Yin

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et al., 2017), hypotensive (Ching-Ping *et al.*, 2016), cardiovascular relaxation (Wang *et al.*, 2022), cardiac functions (Wang *et al.*, 2015b), and aphrodisiac effects (Nguyen *et al.*, 2021b). Numerous bioactive substances (or structural molecules), including nucleosides (Bach *et al.*, 2022), sterols (Yoneyama *et al.*, 2022), polysaccharides (Elkhateeb *et al.*, 2019), proteins and associated amino acids (Sethy *et al.*, 2016), fatty and organic acids (Das *et al.*, 2021), metals (Bhetwal *et al.*, 2021), and vitamins (Dang *et al.*, 2018), have been shown to modulate the aforementioned chemo-physiological functions. Among the species of *Cordyceps*, *C. sinensis* yields valuable and highly potential output and has been widely utilized through scientific approaches by the pharmaceutical industries for human welfare (Abdul-Rehman *et al.*, 2022). Given the increasing interest in *Cordyceps* for both mycology and medicine, further research is necessary to provide a comprehensive overview of the potential of these mushrooms (Nguyen *et al.*, 2025). Therefore, this paper extensively reviews the topic. This review summarizes the origin of *C. sinensis*, its economic potential, nature and distribution, growth habitat, pharmacological properties, and their potential usage, as described below.

2. Origin

This fungal species, entomopathogenic by nature, has survived in the wild since the Cretaceous period (Gibson *et al.*, 2014). During their infection and growth in insects, these fungi promptly release a wide range of secondary metabolites (Chakraborty *et al.*, 2014). Miles Berkeley first gave it the scientific name *Sphaeria sinensis* in 1843, and Andrea Saccardo later reclassified it as *Cordyceps* spp. in 1878 (Nikoh, 2000). While previously known as *Ophiocordyceps sinensis*, it is now also referred to as *C. sinensis*, as well as common names such as “caterpillar fungus,” “Yarsha Gambo,” “Keera jhar,” and “Keera ghas.” It is one of approximately 700 species within the families Clavicipitaceae, Ascomycota, Pyrenomycetes, and Hypocreales. The name *Cordyceps* is derived from the Latin word “ceps” (head) and the Greek word “Kordyle” (club) (Olatunji *et al.*, 2018).

2.1 Economic potential

Compared to other therapeutic mushroom species, *Cordyceps* spp. are particularly sensitive to their specific ecosystems for growth.

Therefore, collecting the required amounts of this fungus in the wild is challenging (Hardeep *et al.*, 2014). However, in countries like Nepal, China, Bhutan, the Himalayan regions of Tibet, and the northeastern provinces of India, individuals between the ages of 15 and 65 are involved in harvesting this fungus for domestic uses, such as raw food and traditional medicinal purposes (Hopping *et al.*, 2018). Prices have increased in the international market, driven by supply, demand, and market levels. The global market size for *Cordyceps*-based medications is predicted to be between \$5 billion and \$11 billion. In China, this fungus is sold for between \$35,000 and \$60,000 per kilogram under the brand name “soft gold” (Shrestha, 2012).

2.2 Nature and distribution

Approximately 700 different species of entomopathogenic fungi, including *C. sinensis*, parasitize the *Elaphomyces* genus in temperate and subarctic forest ecosystems (Baral *et al.*, 2015; Shrestha *et al.*, 2016). Furthermore, various *Cordyceps* species, such as *C. sinensis*, *C. ophioglossoides*, *C. militaris*, *C. gracilis*, *C. sobolifera*, *C. subsessilis*, *C. gunnii*, *C. tuberculata*, *C. scarabaeicola*, *C. minuta*, *C. myrmecophila*, *C. canadensis*, *C. nutans*, *C. agriota*, *C. nigrella*, *C. pruinosa*, and *C. tricentrata*, have demonstrated high entomopathogenic activity against insect orders including Arachnida, Coleoptera, Hemiptera, Hymenoptera, Isoptera, and Lepidoptera (Zha *et al.*, 2019). Specifically, *C. sinensis* primarily parasitizes larvae of the “swift” or “ghost moth” and is predominantly found in deep forests and meadows of the Himalayan regions in India, Tibet, Nepal, and China, typically at altitudes around 5000 m above mean sea level (Grehan and Ismavel, 2017). Its distribution extends throughout Europe and American nations, as well as Asian countries such as Bhutan, Japan, Korea, Thailand, and Vietnam (Rakhee *et al.*, 2021). In India, it can be found in the highest-elevation sub-alpine areas, including Kumaun and the Garhwal Himalayas (Pradhan *et al.*, 2019). The geographical and climatic conditions, including altitude (m), low temperature (°C), high precipitation (mm), relative humidity (%), oxygen levels, CO₂ levels, and sunshine exposure, significantly influence the composition of biometabolites (both qualitatively and quantitatively) in *Cordyceps* spp. (Guo *et al.*, 2015; Huang and Ohga, 2018). Figure 1 shows the global distribution of *C. sinensis*.



Figure 1: Geographical distribution of *Cordyceps sinensis* (Berk.) Sacc.

2.3 Growth habitat

In early spring, the mycelium of the fungus (*C. sinensis*) develops from the larva of *Hepialus armoricanus*, covering the whole body and forming a club-shaped cap consisting of stroma and endosclerotium (Elkhateeb and Daba, 2020). Initially, caterpillars are yellow, but they later turn brown to black during the formation of the fungal stroma. Typically, this fungus undergoes three stages: infection, parasitism, and saprophytic growth. The fungus grows on the body of the host juvenile larva below the ground surface. When

mature, it emerges above the ground, having consumed approximately 90% of the larva's body (Toledo *et al.*, 2013). During this period, the host larva becomes hard, rough, and mummified, forming a sclerotial structure. The sexual fruiting body generates from the larva's head and connects to the sclerotia below the ground upon completion of its lifespan. Subsequently, the sclerotial body hardens, becomes dormant, and ruptures the entire larval body after winter (Guo *et al.*, 2017). Figure 2 shows the multipotential of the caterpillar mushroom, *C. sinensis*.



Figure 2: Naturally collected wild *Cordyceps sinensis* (Berk.) Sacc. from north-eastern Himalayan regions.

An anamorph stage of *C. sinensis* is called *Hirsutella sinensis*, although the development of its fruiting body remains unknown. Through genealogical approaches, its identity has been confirmed via 539 bp amplification by ITS markers (Zhang *et al.*, 2010), and a genome size of 102.72 Mb has been obtained (Jin *et al.*, 2020). Additionally, functional genes, including transcriptional factors of the zinc cluster gene (ZnCys6) (Zhang *et al.*, 2019), the MAPK 1 gene (Ujita *et al.*, 2006), the FKS 1 gene (Park *et al.*, 2005), the Copper, Zinc superoxide dismutase (Cu, Zn SOD 1) genes (Zhang *et al.*, 2008), and serine protease genes (*csp1* and *csp2*) (Liu *et al.*, 2017), were utilized for further confirmation.

2.4 Ethnopharmacy

In the early periods, *C. sinensis* and its raw products were used in traditional medicine, consumed as capsules, powder, paste, pellets, syrup, or raw drinks (or mixed with water, milk, or liquor) to remedy diseases such as cough, cold, pulmonary disorders, and to provide nutritional enhancement, skin care, and relief from diarrhea, fatigue, headache, and impotence disorders, often through trial-and-error approaches (Choda, 2017). These practices are predominantly followed in China, Nepal, India, Bhutan, Bangladesh, Indonesia, Korea, Malaysia, Myanmar, Singapore, and Japan (Das *et al.*, 2021). Contemporary ethnopharmacological research has revealed a diverse range of bioactive compounds in *Cordyceps* spp., including cordycepin, polysaccharides, adenosine, and sterols. These components exhibit a variety of pharmacological effects, such as immunomodulation, antioxidant properties, anti-inflammatory actions, antitumor effects, and antimicrobial capabilities. Scientific investigations validate numerous traditional assertions, showcasing

Cordyceps' potential as a natural supplement for improving physical performance, addressing metabolic disorders, and bolstering immune health (Fogarasi *et al.*, 2024).

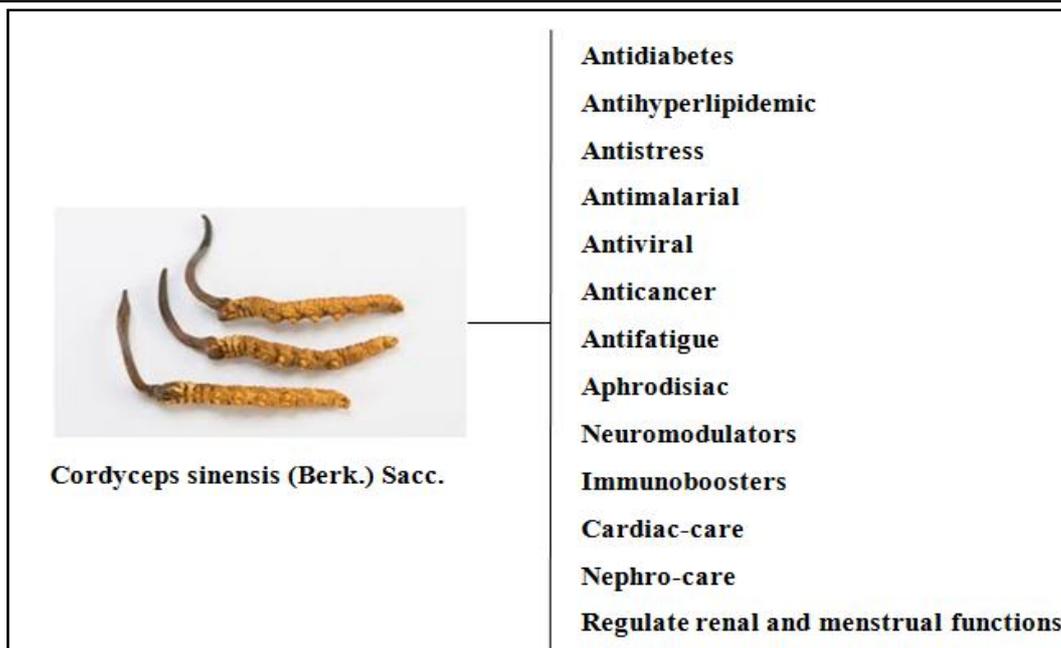
When used in different forms like raw food, powder, capsules, soup, or tonic, *Cordyceps* is believed to improve physical performance and endurance (vitality and energy), and it is used to treat asthma, bronchitis, and coughs. Additionally, it is thought to promote detoxification and organ function (kidney and liver health), act as a modulator of the immune system to increase disease resistance (immune boosters and regulators), improve reproductive function and libido (reproductive health), and is prized as a tonic that extends life and vitality (antiageing) (Krishna *et al.*, 2025). Ultimately, the ethnopharmacology of *Cordyceps* illustrates a complex interplay of traditional knowledge, cultural practices, and increasing validation from scientific research. Its historical and current applications highlight its importance as a medicinal resource, offering potential for future therapeutic advancements rooted in both traditional insights and contemporary studies (Hyde *et al.*, 2024). Following this, we discuss their pharmaceutical compounds and benefits below.

3. Pharmacological properties and uses

Naturally, the compounds produced by *C. sinensis* are biologically and chemically diverse, influenced by their maturity, ecological conditions, and time of harvest (Shashidhar *et al.*, 2013). *C. sinensis* contains unique bioactive compounds beneficial for human health, including nucleosides, nucleobases, nucleotides, sugars, sterols, fatty acids, proteins, amino acids, cyclic polypeptides, and carotenoids (Chen *et al.*, 2013). These compounds are described in Table 1 and Figure 3 below.

Table 1: Pharmacological properties and applications of *Cordyceps* species in human health

S. No.	Preliminary compounds	Biofunctional compounds	Therapeutics	Mushroom spp.	References
1.	Nucleosides and nucleobases	Adenosine, N-acetylgalactosamine, cordycepin, beauveriolides, beauvericin, tenellin, militarinones, fumosorinone, farinosones, pentostatin, oosporein, cordycepin triphosphate, deoxyguanine and guanine.	Cardiovascular tissues bumping ability, digestive regulators, anti-inflammatory, anticancer, anxiety, antidepressive, anticonvulsant, analgesic, immunomodulators and neurostimulators.	<i>C. sinensis</i> , <i>C. militaris</i> , <i>C. cicadae</i>	Liu <i>et al.</i> , 2015; Tescarollo <i>et al.</i> , 2020; Ng and Wang, 2005; Chen <i>et al.</i> , 2018
2.	Sugars	Polysaccharides, APS, CPS1 and CPS2 cordycepic acid.	Antiaging, antitumor, glycemic regulation, derma properties, internal organ healing. Chronic urinal disorders, fatty liver, WBC counts and maintenance.	<i>C. sinensis</i> , <i>C. militaris</i>	Yalin <i>et al.</i> , 2006; Bhambri <i>et al.</i> , 2022; Yuan <i>et al.</i> , 2022; Shi <i>et al.</i> , 2022
3.	Sterols and fatty acids	Ergosterol, linoleic acid and oleic acid.	Prostatic cancer, liver fibrosis and hyperlipidemia.	<i>C. sinensis</i>	Chen <i>et al.</i> , 2013
4.	Proteins	L-tryptophan, cadaverine, flazin, perloyrine, putrescine, and spermidine.	The strengthening of cardio-tissues regulates serum levels in the blood.	<i>C. sinensis</i>	Kumar <i>et al.</i> , 2021; Mishra and Uphadyay <i>et al.</i> , 2011
5.	Amino acids and cyclic peptides	Phe-Pro, Gly-Pro, Thr-Leu and Val-Pro, Cordymin.	Antimicrobial, antidiabetic, inhibitors for aflatoxins synthesis.	<i>C. sinensis</i>	Wong <i>et al.</i> , 2011; Vestergaard <i>et al.</i> , 2009; Quian <i>et al.</i> , 2012
6.	Carotenoids	β -carotene, lutein, lycopene and zeaxanthin.	Retain eye vision.	<i>C. sinensis</i>	Stringham <i>et al.</i> , 2018

**Figure 3: Multifaceted benefits of *Cordyceps sinensis* (Berk.) Sacc. for human well-being.**

3.1 Nucleosides and nucleobases

Nucleosides are among the significant compounds of *Cordyceps* spp., including adenine, adenosine, N-acetylgalactosamine, cytosine, guanine, guanosine, hypoxanthine, thymine, and uracil, which are mostly extracted from the mycelium of the fungi (Liu *et al.*, 2015). Interestingly, nucleobases, namely purine and pyrimidine, act as notable indicators for nutritional values in *Cordyceps* spp. These

base compounds have been investigated for their neuroregulatory and modulatory roles in human physiological disorders like epilepsy and Parkinson's disease (Tescarollo *et al.*, 2020). Furthermore, various deoxyribonucleoside-based compounds such as adenosine, 2'-deoxyadenosine, 2',3'-dideoxyadenosine, beauveriolides, beauvericin, hydroxyethyl-adenosine, 3'-deoxyadenosine (cordycepin), N6-(2-hydroxyethyl)-adenosine, tenellin,

militarinones, fumosorinone, farinosones, pentostatin, oosporein, cordycepin triphosphate, deoxyguanidine, and guanidine have been identified from these fungal species (Ng and Wang, 2005). The aforementioned adenosine is unique in that it requires more time during extraction and transduces signal molecules in intracardiovascular tissues, acting as a digestive enhancer, and exhibiting anti-inflammatory, anti-oncological, antianxiety, and antidepressive functionalities through specific GPCRs (Chen *et al.*, 2018).

3.2 Cordycepin

Cordycepin is primarily found in *C. militaris* and *C. sinensis*, albeit in low quantities, and is typically absent in artificially cultivated varieties. Structurally, it is a 32'-deoxyadenosine, and it is often associated with cordycepic acid (D-mannitol) (Tsai *et al.*, 2010). The absence of an oxygen molecule at the 3' position of the C' D-ribose sugar yields 32'-deoxyadenosine during extraction, typically using a mixture of acetonitrile and water at a ratio of 5:95 (v/v) (Chirivi *et al.*, 2017). This compound is commonly utilized for pain relief, as a physical immune enhancer, and for its antitumor, antidiabetic, antibacterial, antiviral, digestive regulatory, and neurostimulatory properties. It also finds use as a domestic pesticide for daily human welfare (Phull *et al.*, 2022).

3.3 Nucleotides/nucleotide derivatives

Naturally, three different nucleotides are present: adenosine-5'-monophosphate, guanosine-5'-monophosphate, and uridine-5'-monophosphate. These compounds consist of a base, phosphoric acid, and amphoteric molecules (Elkhateeb and Daba, 2022). Based on clinical diagnosis, these bioactive compounds are used for boosting the immune system, regulating lipid metabolism, improving gastrointestinal functions, acting as anti-inflammatory inhibitors in urethral pathways, enhancing blood circulation, and promoting neuroactivity (Liu *et al.*, 2015).

3.4 Sugars

These fungal species contain a diverse group of polysaccharides, typically comprising over 3% of their composition and usually found in the extracellular or intracellular fruiting bodies. These polysaccharides are fundamentally composed of various monosaccharides such as arabinose, glucose, galactose, fructose, mannitol, mannose, ribose, rhamnose, sorbose, and xylose (Liu *et al.*, 2016). Monosaccharides significantly contribute to fungal growth and maturity. Polysaccharides, such as astragalus polysaccharide, have been utilized for their antiageing properties, ability to inhibit tumor cell proliferation, regulation of blood glucose levels in type 1 and 2 diabetes, and involvement in lipid metabolism (Bhambri *et al.*, 2022). Furthermore, carbamoyl phosphate synthetase (CPS1 and CPS2) and cordycepic acid have shown efficacy against pneumoconiosis and possess analgesic properties for internal wounds in complex human health conditions (Yuan *et al.*, 2022). Additionally, hepatoprotective exopolysaccharides from *Cordyceps* spp. have been shown to cure chronic liver diseases caused by toxic substances like CCl₄ (carbon tetrachloride) (Nguyen *et al.*, 2021a).

3.5 Cordycepic acid

In *Cordyceps* spp., cordycepic acid, initially reported as an isomer of quinic acid, was later identified as D-mannitol due to observed changes in the formation of various dextrorotatory lactones, typically

present at 7-20% (Shi *et al.*, 2022). This compound plays a crucial role in the treatment of polyuria, liver fibrosis, osmoregulation, and the prevention of oxidative stress in blood circulation, as well as alleviating wheezing problems (Jerzy Edrejko *et al.*, 2021).

3.6 Sterols and fatty acids

Sterols, a subgroup of steroids, are primarily present in the cell wall membranes of most organisms, except edible mushrooms (Bacha *et al.*, 2019). Various sterol components have been identified in *C. sinensis*, including campesterol, daucosterol, ergosterol, ergosterol peroxide, β -sitosterol, and ergosterol-3-O- β -D-glucopyranoside (Shuai-Ling *et al.*, 2022). The levels of these sterols increase during the fruiting stage compared to the vegetative stage, attributed to energy consumption for growth and maturation. Additionally, several fatty acids, such as linoleic acid, palmitic acid, docosanoic acid, stearic acid, and oleic acid, have been reported from this genus. These fatty acids contribute to the early-stage healing of prostatic hypertrophy and exhibit anticancer and antihyperlipidemic properties (Gao *et al.*, 2011).

3.7 Proteins

Proteins derived from mushrooms are commonly considered highly nutritious due to their high caloric value and digestible fiber content (Venturella *et al.*, 2021). A species of *Cordyceps* typically contains various proteins, including L-tryptophan, cadaverine, flazin, peregriane, putrescine, and spermidine. These are often found as enzymes like deoxyribonuclease and serine protease, present in both intracellular and extracellular forms (Amir Ashraf *et al.*, 2020). When consumed raw, *Cordyceps* is believed to regulate the serum albumin ratio in the blood and maintain the contractile ability of cardiovascular tissues (Kumar *et al.*, 2021).

3.8 Amino acids and cyclic polypeptides

When infection occurs in juvenile larvae, the fungi typically produce glutamic and aspartic acids as food sources for energy conversion (Mishra and Upadhyay, 2011). Additionally, cyclic polypeptides such as cyclic Leu-Pro, Phe-Pro, Gly-Pro, Thr-Leu, and Val-Pro have been reported in all stages of fungal growth and development. Among these, cyclic Phe-Pro and Leu-Pro are known for their antimutagenic and antimicrobial properties, effective against vancomycin-resistant *Enterococcus* and yeasts, and for inhibiting aflatoxins (Rhee, 2004). An antifungal peptide named 'cordymin' has been identified as a lead compound from *C. sinensis*. This compound is highly effective against crop pathogens like *C. albicans*, *R. solani*, *C. arachidicola*, and *B. maydis* at concentrations ranging from 0.75 mM to 0.50 μ M, making it relevant for agricultural applications (Wong *et al.*, 2011). Furthermore, it is primarily recommended for regulating blood glucose levels (Vestergaard *et al.*, 2009) and for the prevention of diabetic osteopenia (Qian *et al.*, 2012).

3.9 Carotenoids

Carotenoids, specifically xanthophyll derivatives, have been obtained from the fruiting bodies of *Cordyceps* and are primarily responsible for the pigmentation and identification of mushroom species (Muszynska *et al.*, 2016). These include β -carotene, lutein, lycopene, and zeaxanthin. In humans, daytime vision is facilitated by clusters of cones in the eye's macula, a function that involves the presence of lutein and zeaxanthin (Bovier and Hammond, 2015). Scientific reports indicate that carotenoids significantly improve cognitive functions in children and youths (Yalin *et al.*, 2006; Stringham *et al.*, 2018).

4. Toxicology

C. sinensis has been traditionally used in various forms to address human physical ailments and maintain healthy immune and biological systems throughout life (Baral, 2017). Despite its broad utility and largely favorable safety profile, understanding the toxicological aspects of *C. sinensis* is crucial to ensure safe utilization and to identify any potential risks associated with its use (Ahuja *et al.*, 2023). Generally, approximately a thousand fungal species act as insect pathogens, exhibiting high diversity and primarily belonging to the families Clavicipitaceae (63.8%), Cordycipitaceae (6.9%), and Ophiocordycipitaceae (29.1%) (Joseph *et al.*, 2024). In human health,

excessive exposure to certain elements, whether physiological or psychological, can be detrimental (Mitra *et al.*, 2022). Consequently, the contemporary trend of promoting mushrooms as functional foods and medicinal products has, in some cases, led to adverse effects on both social and physical health (Bell *et al.*, 2022). Regular consumption of these mushrooms or their metabolites, whether through food or medicinal use, can lead to the gradual release of toxic substances that may be detrimental to human physiology. Indeed, numerous bioactive compounds can become toxic when ingested consistently over time (Ogidi and Adigwe, 2025). These toxic biocompounds are listed in Table 2 below.

Table 2: Toxic bioactive compounds of *Cordyceps* spp. and their effects on human physiology with consecutive intake

S.No.	Producing <i>Cordyceps</i> spp.	Bioactive compounds	Toxic nature	References
1.	<i>C. bassiana</i>	Tenellin	Toxic towards erythrocytes	Hatton <i>et al.</i> , 2018; Chen <i>et al.</i> , 2020
2.	<i>C. militaris</i> and <i>C. cicadae</i>	N6 (2 hydroxyethyl) adenosine	Induction of oxidative stress	
3.	<i>C. militaris</i> , <i>C. bassiana</i> , <i>C. sinensis</i> , <i>C. farinose</i> , <i>C. cicadae</i>	Farinosones, Oosporein, Beauveriolides, Beauvericin, Cordycemadies, militarinones	Cell death	
4.	<i>C. militaris</i>	Pentostatin	Gastrointestinal, nausea, diarrhoea, renal and neuro-cells, pulmonary toxicity	
5.	<i>C. militaris</i>	Cordycepin	Gastrointestinal and bone marrow toxicity	

4.1 Future perspectives

Nature provides a vital foundation for human life when safeguarded; however, disturbances can lead to negative impacts at all levels. In this context, *C. sinensis* has held significant importance from the past to the present decades. The future of *C. sinensis*, an innovative medicinal mushroom, depends on enhancing our comprehension of its pharmacological mechanisms, standardizing its bioactive constituents, and progressing its clinical utilization. Although the fungus has exhibited a wide range of therapeutic effects including immunomodulatory, anticancer, anti-inflammatory, and antioxidant properties subsequent research should focus on clarifying specific molecular pathways through systems biology and omics technologies. As natural resources decline, it is crucial to develop sustainable cultivation and biotechnological production techniques to guarantee consistent quality and supply. Additionally, thorough clinical trials are essential to confirm its efficacy and safety in human subjects, especially as an adjunct therapy for chronic diseases. Advanced drug delivery systems, such as nanoformulations, may also improve their bioavailability and therapeutic targeting. To fully incorporate *C. sinensis* into contemporary medicine, comprehensive regulatory frameworks, strict quality control standards, and strong interdisciplinary collaboration are vital. Together, these initiatives will support the transition of *C. sinensis* from a traditional remedy to a scientifically validated therapeutic agent.

5. Conclusion

A healthy life is a primary goal for human beings. Based on this, natural mushrooms possess extensive potential and are widely

incorporated into diets for their nutraceutical value and beneficial compounds, such as high protein and fiber content, and low lipid levels. *C. sinensis* stands out among edible mushrooms due to their distinctive pharmacological properties and the high exploitation ratio of their biocompounds. Moreover, it helps prevent various genetic disorders, including atopic dermatitis, vitiligo, diabetes, obesity, epilepsy, Alzheimer's disease, and autism. These remarkable "life-saving" benefits stem from a diverse group of *Cordyceps* spp. widely distributed globally. These fungal species are predominantly gathered from Himalayan regions by tribal communities, often advocated through corporate pharmaceutical industries. Despite some species being cultured artificially *in vitro*, *C. sinensis* remains highly dependent on adaptation to temperate climates. This climatic factor significantly influences the grading of mushrooms and their products. Furthermore, the wild habitat of this mushroom is being disturbed by corporate collection efforts. To address these issues and conserve nature and the ecosystem, scientific approaches should be implemented in *in vitro* breeding programs for mushrooms and their species. When these efforts yield better outcomes, they will ensure a healthier life for coming generations, facilitated by nature.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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