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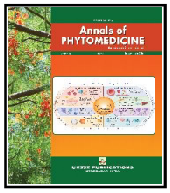

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Phytochemical constituents and pharmacological properties of *Cordyceps militaris* (L.) Fr. : A comprehensive review of its bioactive compounds and therapeutic potential

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Abstract

Cordyceps militaris (L.) Fr. is an entomopathogenic medicinal fungus that has attracted considerable scientific and commercial attention owing to its rich phytochemical profile and wide-ranging pharmacological properties. This review compiles and critically evaluates existing literature on its taxonomy, morphological characteristics, nutritional composition, and key bioactive constituents, such as cordycepin, polysaccharides, carotenoids, ergosterol, and sulfur-containing non-protein amino acids like ergothioneine. Special focus is given to the biosynthetic pathway of cordycepin, with recent studies elucidating the role of the cns1-cns4 gene cluster and its regulatory framework. The pharmacological properties of *C. militaris* notably their immunomodulatory, antioxidant, antitumor, anti-inflammatory, hypoglycemic, neuroprotective, and cardioprotective activities, supported by insights into their underlying molecular mechanisms. Furthermore, its effects on major physiological systems; namely, the endocrine, nervous, musculoskeletal, and cardiovascular systems are systematically discussed. Despite its significant therapeutic promise, the large-scale utilization of *C. militaris* is constrained by challenges such as strain instability, susceptibility to contamination, lack of standardized cultivation protocols, and gaps in the understanding of its metabolic networks. In summary, *C. militaris* serves as a potent reservoir of bioactive compounds with substantial potential for application in nutraceutical and pharmaceutical sectors, necessitating further research aimed at improving production efficiency and expanding its industrial applicability.

1. Introduction

Mushrooms have long been recognized as dietary components and traditional therapeutic agents. Of the more than 14,000 identified species, approximately 2,000 are regarded as edible, among which medicinal mushrooms are particularly valued for their health-promoting properties (Sabaratnam *et al*., 2013). The genus *Cordyceps*, classified under the phylum Ascomycota, class Sordariomycetes, order Hypocreales, and family Clavicipitaceae, is notable for its distinctive biology. Members of this genus are entomopathogenic fungi that parasitize insects and other arthropods (Kang *et al*., 2017). Historical records indicate that interest in *Cordyceps* dates back to the 17th century, reflecting its long-standing importance in both biological and medicinal contexts (Shrestha *et al*., 2014). Over time, medicinal mushrooms have played a crucial role in traditional healthcare systems, with *Cordyceps* gaining prominence for its wide-ranging therapeutic potential. The genus is highly diverse, encompassing more than 750 species with considerable variation in morphology, host specificity, ecological adaptation, and geographic distribution (Kim *et al*., 2010; Sung *et al*., 2011). These fungi are predominantly found in humid, temperate regions, particularly in high-altitude areas such as Tibet and parts of China, where environmental conditions favor their growth (Sung *et al*., 2007). Commonly known as “winter worm, summer grass,” *Cordyceps* exhibits a unique life cycle in which it infects an insect host and subsequently produces a grass-like fruiting body. Traditionally, it has been utilized in countries such as China, Korea, and Japan as both a functional food and a medicinal resource, primarily to enhance immunity, improve stamina, and promote overall vitality, often compared with *Panax* species. Despite the extensive diversity within the genus, only a limited number of species are widely exploited for medicinal purposes, including *Ophiocordyceps sinensis*, *C. militaris*, *C. ophioglossoides*, *C. sobolifera*, *C. liangshanensis*, and *C. cicadicola* (Hong *et al*., 2010). Among these, *C. militaris* has gained particular attention due to its amenability to artificial cultivation and its capacity to produce pharmacologically significant compounds such as cordycepin. Notably, the bioactive profile and efficacy of *C. militaris* are considered comparable to those of *O. sinensis*, making it a sustainable alternative to wild-harvested species (Liu *et al*., 2015). Increasing global demand for *Cordyceps* as a nutraceutical and pharmaceutical resource, coupled with overexploitation and declining natural availability, has accelerated the development of controlled

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cultivation strategies (Phull *et al*., 2022). Habitat degradation and overharvesting have led to the inclusion of certain species in the IUCN Red List (Smith *et al*., 2022), underscoring the need for conservation and sustainable production approaches. Species of *Cordyceps* infect insects across several orders, including Lepidoptera, Coleoptera, Hymenoptera, Diptera, and Hemiptera, with approximately 60% of documented species associated with Lepidopteran and Coleopteran hosts (Shrestha *et al*., 2016). *C. militaris*, in particular, is capable of infecting larvae from more than 60 Lepidopteran species (Wang *et al*., 2011). Its life cycle occurs within soft-bodied insect larvae, which provide a nutrient-rich environment dominated by proteins and lipids, facilitating fungal growth and fruiting body development. *C. militaris* is rich in biologically active compounds, including cordycepin, adenosine, polysaccharides, cordycepic acid, fatty acids, amino acids, vitamins, ergosterol, and myriocin (Quy *et al*., 2019). These constituents contribute to a wide range of biological activities, supporting applications in pharmaceuticals, nutraceuticals, and cosmeceuticals. More broadly, the genus *Cordyceps* has been reported to contain over 200 metabolites, including nucleosides, sterols, cyclic peptides, flavonoids, dihydrobenzofurans, bioxanthracenes, polyketides, terpenoids, alkaloids, and phenolic compounds. These metabolites exhibit diverse bioactivities such as immunomodulatory, antioxidant, antitumor, cytotoxic, anti-inflammatory, antiallergic, antidiabetic, analgesic, anti-HIV, antibacterial, antimalarial, and antifungal effects (Olatunji *et al*., 2018). Recent advances in molecular biology and metabolic engineering have further elucidated the biosynthetic pathways and regulatory mechanisms underlying key bioactive compounds, particularly cordycepin, enhancing the prospects for strain improvement and industrial-scale production (Wang *et al.,* 2024). In this context, the present review focuses on the phytochemical diversity of *C. militaris* and its associated pharmacological properties, highlighting its potential as a promising source of bioactive compounds for therapeutic applications and drug development.

2. Historical development and taxonomic classification of *C. militaris*

The term *Cordyceps* is derived from Latin, where “cord” signifies a club and “ceps” denotes a head, describing the characteristic morphology of the fungus, in which a club-shaped fruiting body (stroma) emerges from the mummified remains of an infected insect (Holliday and Cleaver, 2008). The species *C. militaris* was first described by Carl Linnaeus in 1753 as *Clavaria militaris*, based on its distinct bright orange, club-like stromata. Subsequently, in 1818, Elias Magnus Fries reassigned it to the genus *Cordyceps*, thereby establishing its present taxonomic classification (Sung *et al*., 2007). During the 19th and early 20th centuries, investigations on this species were largely confined to its morphological features, developmental cycle, host associations, and geographical distribution across regions such as Asia, Europe, and North America. Unlike *Ophiocordyceps sinensis*, which is restricted to specific ecological niches and host organisms, *C. militaris* demonstrates greater ecological flexibility, infecting a broad range of lepidopteran larvae and pupae under varied environmental conditions (Kobayasi, 1941; Sung *et al*., 2007). The medicinal significance of *C. militaris* gained prominence in the mid-20th century with the discovery of cordycepin (32 -deoxyadenosine), a bioactive nucleoside known for its antimicrobial, antitumor, and immunomodulatory properties (Cunningham *et al*., 1950; Tuli *et al*., 2014). From the latter half of the 20th century, advancements in fungal biotechnology enabled its successful cultivation under controlled conditions using insect-based substrates, cereal media, and submerged fermentation systems. These developments have contributed to reducing reliance on wild sources while supporting sustainable production practices (Zhang *et al*., 2012; Liu *et al*., 2015). More recently, the application of genomic and metabolomic tools, including whole-genome sequencing, has enhanced our understanding of the biosynthetic pathways responsible for secondary metabolite production, as well as the adaptive strategies of *C. militaris*. Consequently, this species is now widely recognized as an important model organism among medicinal entomopathogenic fungi (Zheng *et al*., 2011; Shrestha *et al*., 2016).

3. Morphological characteristics of *Cordyceps* species

Species of *Cordyceps* have garnered significant attention in mycological studies owing to their unique capacity to develop fruiting bodies directly from infected insect hosts. Morphologically, these fungi are composed of two main structures: the endosclerotium, which develops internally within the host, and the stroma, the external reproductive structure that protrudes from the host body. Taxonomic identification primarily relies on microscopic characteristics of the fruiting bodies, including the morphology and organization of perithecia, asci, and ascospores (Xiong *et al*., 2010). Under natural conditions, *C. militaris* is typically characterized by stromata exhibiting bright orange to yellow coloration, a prominent feature used for species identification (Wu *et al*., 2024). The key morphological differences between *C. sinensis* and *C. militaris* are summarized in Table 1.

Table 1: Morphological features of *C. sinensis* and *C. militaris*

Feature	*C. sinensis*	*C. militaris*
Color	Dark brown to black	Bright orange or reddish
Host	High-altitude caterpillars (Thitarodes)	Low-altitude moth larvae/pupae
Fruiting body shape	Slender, clavate	Club-shaped, often thicker
Spore structure	Filiform ascospores in perithecia	Asci with filiform ascospores
Size	5-15 cm (fruiting body)	1-5 cm (fruiting body)
Cultivation	Difficult (natural only)	Easily cultivable on artificial media

4. Nutritional composition of *C. militaris*

C. militaris is widely acknowledged for its complex and nutritionally valuable composition. It is a rich source of essential amino acids and vital vitamins, including fat-soluble vitamins such as K and E, as well as water-soluble B-complex vitamins, notably B_1, B_2, and B_{12}. The carbohydrate profile comprises simple sugars such as monosaccharides and disaccharides, along with oligosaccharides and

structurally diverse polysaccharides. In addition, the fungus contains important biochemical constituents, including proteins, sterols, and nucleosides, and is enriched with a broad range of trace elements. These include sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), iron (Fe), copper (Cu), vanadium (V), phosphorus (Pi), selenium (Se), nickel (Ni), strontium (Sr), silicon (Si), titanium (Ti), chromium (Cr), gallium (Ga), zinc (Zn), and zirconium (Zr), which collectively contribute to its nutritional and therapeutic value (Zhou *et al*., 2009). Comprehensive details regarding its nutrient composition are provided in Table 2.

Table 2: Nutrient profile of *C. militaris* (Source: Mala *et al*., 2024)

Component	Content (on dry weight basis)
Protein (%)	39.15 (g/100 g)
Vitamin A	32.7 (mg/100 g)
Vitamin B_1	12.4 (mg/100 g)
Vitamin B_3	40.6 (mg/100 g)
Vitamin B_6	58.7 (mg/100 g)
Vitamin B_{12}	69.3 (µg/100 g)
Zinc (Zn)	127.1 (mg/kg)
Copper (Cu)	27.7 (mg/kg)
Selenium (Se)	0.35 (mg/kg)
Cordycepin (%)	1.24 (g/100 g)
Cordycepic acid (%)	10.79 (g/100 g)
Polysaccharides (%)	28 (g/100 g)
SOD (Units/mg protein)	51

5. Major bioactive compounds and their properties

C. militaris is characterized by a wide range of bioactive constituents that play a crucial role in its pharmacological efficacy. These include cordycepin, ergosterol, carotenoids, D-mannitol, proteins, essential amino acids, volatile compounds, vitamins, minerals, nucleosides, and sterols, along with several other functionally active metabolites. In addition, the presence of diverse carbohydrate fractions such as mono-, oligo-, and polysaccharides further enhances its nutritional and therapeutic properties (Das *et al*., 2010). Among these constituents, cordycepin (32-deoxyadenosine) is considered one of the most significant bioactive compounds. The ability of *C. militaris* to produce relatively high levels of cordycepin largely contributes to its medicinal importance and commercial value (Zheng *et al*., 2015). Owing to its biological significance, cordycepin is widely employed as a standard marker for quality assessment of *C. militaris* based products (Yang *et al*., 2020). Polysaccharides constitute another important class of compounds, typically accounting for approximately 3-8% of the dry biomass (Wu *et al*., 2024). D-mannitol, a characteristic metabolite of this species, is also present in varying concentrations depending on strain variability and cultivation conditions, with reported levels ranging from about 20 to 190 mg/g of dry weight (Liang *et al*., 2014). Furthermore, *C. militaris* produces fibrinolytic enzymes capable of degrading fibrin, the key protein involved in blood clot formation. These enzymes exhibit strong fibrin-binding affinity and fibrinolytic activity, suggesting potential applications in the management of cardiovascular disorders (Choi *et al*., 2011). Carotenoids represent another important group of metabolites in *C. militaris* and are generally present at higher concentrations compared to many other edible mushrooms. Identified compounds include lutein, zeaxanthin, and cordyxanthin pigments (Wang *et al*., 2018). In addition to imparting the characteristic coloration of the fruiting bodies, these carotenoids exhibit significant biological activities, including antioxidant and anti-inflammatory effects, as well as protective roles in skin health (Baswan *et al*., 2021; Kabir *et al*., 2022; Young and Lowe, 2018). Certain carotenoids, such as lutein and β-carotene, have also been associated with anti-aging effects through the modulation of oxidative stress and regulation of cellular pathways involving insulin-like growth factor (IGF-1), reactive oxygen species (ROS), and histone acetylation (Chou *et al*., 2024). Overall, the broad spectrum of bioactive compounds identified in *C. militaris* highlights its substantial medicinal potential and versatility in therapeutic applications. The major metabolites and their corresponding biological functions are summarized in Table 3, while Figure 1 presents the chemical structures of bioactive compounds isolated from *Cordyceps* species.

Table 3: *C. militaris* derived metabolites and their associated biological activities

Metabolites	Biological activities	References
Cordycepin	Exhibits anti-inflammatory, antioxidant, antitumor, antidiabetic, and anti-bacterial properties; also shows immunomodulatory, antithrombotic, hypo-lipidemic, analgesic, neuroprotective effects, and inhibits platelet aggregation	Elkhateeb *et al*., 2019; Hueng *et al*., 2017; Bawadekji *et al*., 2016; Liu *et al*., 2015
Cordycepic acid	Demonstrates potential activity against lung cancer	Wang *et al*., 2021
Adenosine	Plays a role in regulating energy balance, modulating organ function and central nervous system activity; involved in controlling cardiac rhythm, synaptic transmission recovery, and tumor immunity	Liu *et al*., 2023
Ergosterol	Shows anti-inflammatory, antioxidant, anticancer, and antitumor activities; also exhibits diuretic effects and inhibits bladder carcinogenesis	Dupont *et al*., 2012; Li *et al*., 2015; Yasukawa *et al*., 1994; Yazawa *et al*., 2020
Pentostatin	Used therapeutically in the management of certain types of leukemia	Else *et al*., 2011
Polysaccharides	Possess immunomodulatory, antioxidant, antiageing, antitumor, and anti-inflammatory properties	Phull *et al*., 2022
Mannoglucan	Exhibits cytotoxic activity	Wu *et al*., 2007
Cordyglucans	Demonstrate antitumor potential	Liu *et al*., 2015
Cordysinocan	Promotes cellular proliferation	Cheung *et al*., 2009
Cordymin	Shows antidiabetic activity	Qi *et al*., 2013

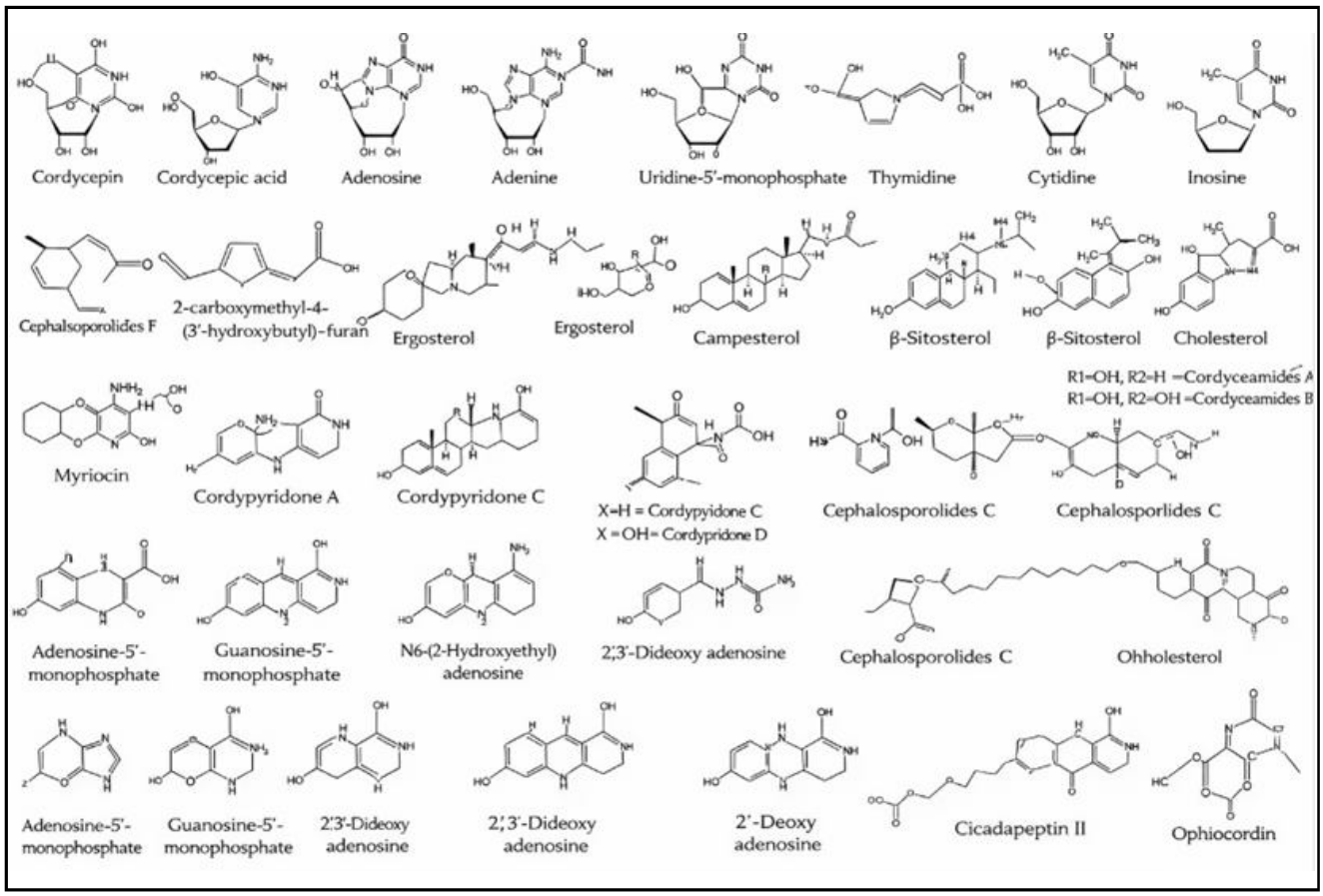

Figure 1: Chemical structures of bioactive metabolites from *Cordyceps* species (Source: Das *et al*., 2021).

5.1 Cordycepin biosynthesis pathway

The biosynthetic pathway of cordycepin in *C. militaris* was initially investigated using radiolabeled precursor studies, which demonstrated that cordycepin is synthesized directly from adenosine without cleavage of the adenine-ribose linkage. The pathway was proposed to involve a reductive mechanism analogous to ribonucleotide reduction, implicating the role of a modified ribonucleotide reductase, particularly under conditions where DNA synthesis is suppressed. Pathway analysis based on KEGG indicates that cordycepin biosynthesis is integrated with the de novo purine metabolic pathway. In this process, glucose is first converted to ribose-5-phosphate via the pentose phosphate pathway, followed by the sequential formation of phosphoribosyl pyrophosphate (PRPP), inosine monophosphate (IMP), and adenosine monophosphate (AMP). Intermediates such as 32-deoxyadenosine monophosphate (32-dAMP) and adenosine have been identified as probable precursors in the biosynthetic route. Despite extensive investigation, the precise genetic determinants of cordycepin biosynthesis remained unresolved until the identification of the cns1-cns4 gene cluster (Xia *et al*., 2017). These genes encode distinct enzymes with specialized functions: Cns3 catalyzes the phosphorylation of adenosine to form 32-AMP; Cns2 subsequently converts this intermediate into 22-C-32 -deoxyadenosine; and Cns1 facilitates the final oxidation-reduction step leading to the formation of cordycepin. In addition, Cns4 acts as an ATP-binding cassette (ABC) transporter, contributing to the export of metabolites. An important feature of this pathway is the co-production of pentostatin, which protects cordycepin from enzymatic deamination through a protector-protégé mechanism, thereby enhancing its stability. The coordinated expression and interaction of these genes, particularly between Cns1 and Cns2, are critical for effective cordycepin biosynthesis, as disruption of either gene results in complete loss of production (Kunhorm *et al*., 2019). The schematic representation of the cordycepin biosynthetic pathway is presented in Figure 2.

5.2 D-Mannitol

D-mannitol, a key metabolite of *C. militaris*, is a polyhydric alcohol also known as cordycepic acid. It functions as a carbon storage compound and plays a role in maintaining osmotic balance and intracellular transport within the fungus. Because of its osmotic properties, it has also found applications in medicine, particularly as a diuretic and for reducing edema. In addition to mannitol, *C. militaris* produces diverse polysaccharides that occur either inside the cells (IPS) or are secreted externally (EPS). Their structural complexity depends on factors such as monosaccharide composition, linkage type, and branching patterns. The primary sugars present include mannose, glucose, and galactose, while others like arabinose, rhamnose, and xylose occur in smaller proportions. Studies show that both natural and cultivated strains differ in their polysaccharide profiles, influenced by growth conditions and extraction techniques (Zhang *et al*., 2019). Various polysaccharide fractions such as CMN1, LCMPs-II, and SeCSP-I differ in molecular weight, sugar

composition, and glycosidic linkages, contributing to their structural diversity (Bi *et al*., 2018). These structural features are critical in determining their biological functions. Functionally, *C. militaris* polysaccharides exhibit multiple pharmacological properties, including immune enhancement, antioxidant, anti-inflammatory, and metabolic regulatory effects. They stimulate immune responses by activating macrophages and increasing cytokine production (*e.g*., IL-1β, IFN-γ, TNF-α), while also enhancing the activity of lymphocytes and natural killer cells. Additionally, they show anticancer potential by inhibiting tumor growth and inducing programmed cell death through cell cycle arrest and regulation of key enzymes involved in cancer progression (Zhang *et al*., 2019).

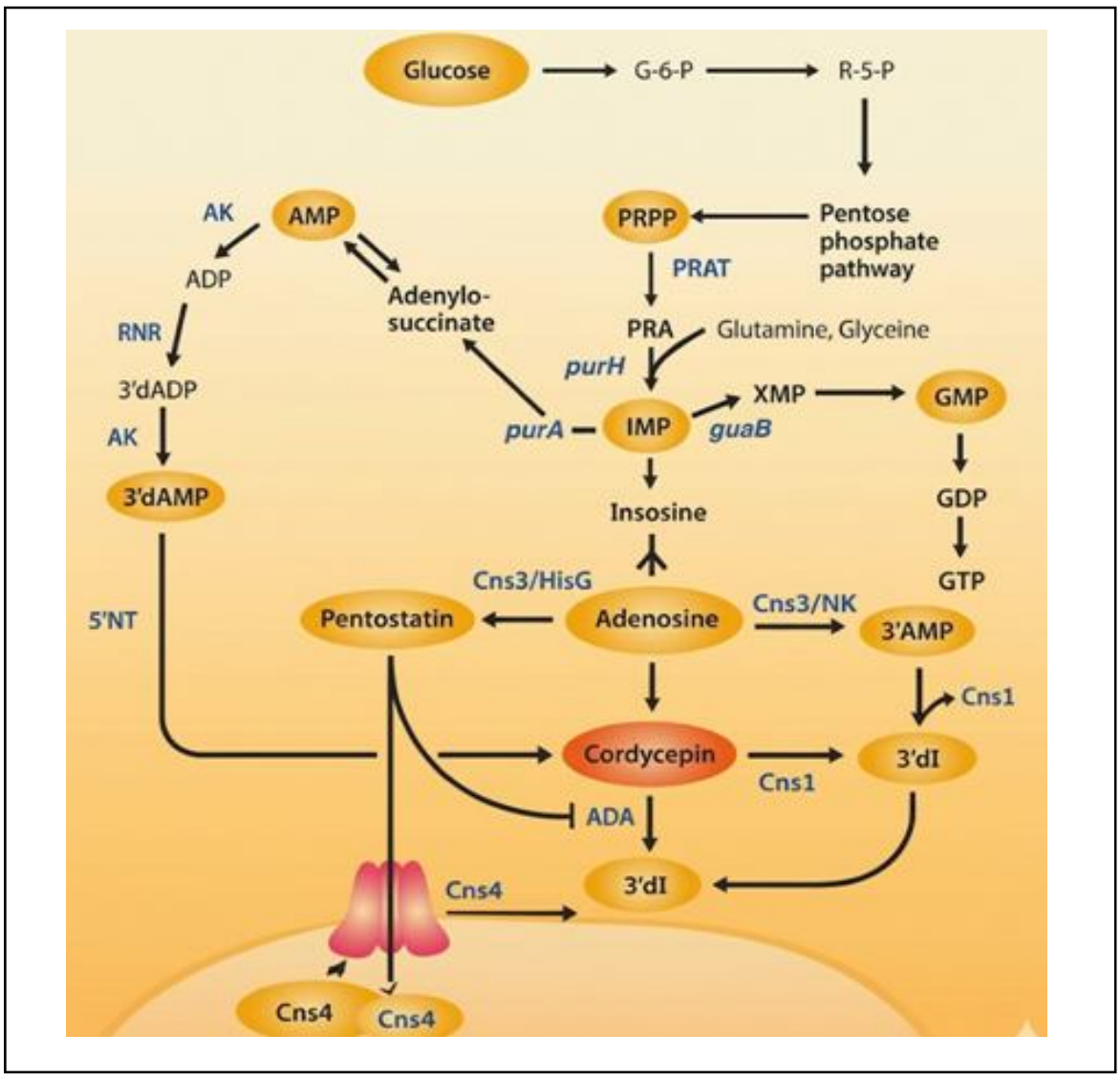

Figure 2: Cordycepin biosynthetic pathway (Source: Kunhorm *et al*., 2019).

5.3 Ergothioneine

The total amino acid content in the fruiting bodies of *C. militaris* has been reported to be approximately 57.39 mg/g on a dry weight basis. Alongside standard proteinogenic amino acids, these fruiting bodies also contain non-protein amino acids such as γ-aminobutyric acid (GABA) and ergothioneine. GABA is synthesized from glutamic acid in humans and acts as a major inhibitory neurotransmitter in the central nervous system. It influences several brain regions, including the cerebellum, hippocampus, hypothalamus, striatum, and spinal cord. By interacting with GABA receptor subtypes A, B, and C, it regulates sleep patterns, learning, memory, and emotional states such as stress and anxiety. Additionally, GABA exhibits anticonvulsant and muscle-relaxant properties. However, findings on oral GABA supplementation remain variable. Some studies report limited bioavailability due to poor intestinal absorption, restricted penetration across the blood-brain barrier, and rapid metabolic degradation, while others suggest that oral intake may still exert measurable physiological effects (Hepsomali *et al*., 2020). Quantitative analyses indicate that GABA concentrations in *C. militaris* range from 68.6 to 180.1 mg/kg in mycelial biomass and approximately 756.30 µg/g in fruiting bodies on a dry weight basis. Ergothioneine, a sulfur-containing derivative

of histidine, represents another important non-protein amino acid present in *C. militaris*. It is synthesized by certain fungi and microorganisms but cannot be produced endogenously in humans, making dietary intake essential. Edible mushrooms are recognized as rich sources of ergothioneine, with reported concentrations varying across species-for example, *Agaricus bisporus* (~0.55 mg/g), *Lentinula edodes* (~1.98 mg/g), *Pleurotus ostreatus* (~2.59 mg/g), and *Grifola frondosa* (~1.13 mg/g) on a dry weight basis (Muszynska *et al*., 2017). In *C. militaris*, ergothioneine content has been reported at approximately 782.3 mg/kg in fruiting bodies and about 130.6 mg/kg in mycelium, with some studies indicating levels near 409.8 µg/g in dry fruiting bodies. In humans, ergothioneine is actively transported *via* the OCTN1 transporter and preferentially accumulates in tissues such as erythrocytes, liver, spleen, and ocular tissues. It exhibits potent antioxidant, cytoprotective, and radioprotective properties (Borodina *et al*., 2020). Clinical evidence suggests that supplementation with ergothioneine (5-25 mg/day) may help reduce oxidative stress markers, particularly under conditions associated with elevated oxidative load, such as inflammation or intense physical activity (Cheah *et al*., 2017). Furthermore, endogenous ergothioneine levels tend to decline with age, and reduced levels in older individuals, particularly those above 60 years, have been associated with the progression of neurodegenerative disorders.

5.4 Polysaccharides

Polysaccharides are among the major bioactive components of *C. militaris*, found in its fruiting bodies, mycelium, and fermentation broth, and are often used as markers of quality in functional mushroom products (Zhang *et al*., 2019). They exist as intracellular (IPS) and extracellular (EPS) forms and are known for a wide range of biological activities, particularly immune regulation, antioxidant defense, anti-inflammatory action, and anticancer potential. These compounds significantly enhance immune responses. For example, PCLM stimulates macrophage activity by increasing nitric oxide (NO), superoxide dismutase (SOD), and TNF-α levels, while also improving phagocytosis. Other polysaccharides such as CMP-W1, CMP-S1, CMP40, and CMP50 promote lymphocyte proliferation and strengthen overall immune function. In addition, several fractions including W-CBP50II, CBP-1, and P70-1 exhibit strong antioxidant properties by effectively scavenging free radicals (Phull *et al*., 2022). Polysaccharides from *C. militaris* also show notable anticancer activity. They inhibit the growth of various cancer cell lines such as HepG2, HeLa, K562, HT29, and A549, and have demonstrated tumor-suppressing effects in experimental models. Beyond this, some polysaccharides possess antiviral, cytoprotective, and antiageing effects, mainly through regulating oxidative stress and maintaining mitochondrial function. Their biological activity is closely linked to structural features, including monosaccharide composition and glycosidic linkages. Polysaccharides rich in glucose and galactose can interact with Toll-like receptor 2 (TLR2), thereby enhancing immune signalling. Moreover, α-and β-glycosidic bonds are associated with increased nitric oxide production in macrophages. Certain compounds, such as CMPB90-1, further influence immune responses by promoting macrophage polarization toward the M1 type, emphasizing their therapeutic potential (Phull *et al*., 2022). The extraction technique plays a crucial role in determining the yield, structural features, and biological activity of polysaccharides. Conventional methods such as hot water extraction followed by ethanol precipitation are widely used to isolate high molecular weight polysaccharides with notable immunomodulatory effects. In contrast, advanced approaches like enzymatic or ultrasound-assisted extraction can improve extraction efficiency and alter the physicochemical and functional properties of the polysaccharides, which may, in turn, influence their pharmacological performance (Zhang *et al*., 2019; Phull *et al*., 2022).

5.5 Carotenoids

Carotenoids, especially xanthophyll-type compounds, are important pigments found in the fruiting bodies of *C. militaris*, giving them their characteristic yellow-orange color. Major carotenoids identified include β-carotene, lycopene, lutein, and zeaxanthin. Among these, lutein and zeaxanthin are also naturally present in the human retina, where they support vision and color perception. Beyond eye health, carotenoids are linked to improved cognitive function, reduced stress levels, and enhanced antioxidant status following dietary intake (Stringham *et al*., 2018). Dietary sources rich in carotenoids, such as tomato and carrot products, have been associated with better immune responses, particularly in individuals with low baseline intake. However, the role of β-carotene remains controversial. While some evidence suggests anticancer benefits, high-dose intake (20-30 mg/day) has been associated with increased risks of certain cancers, including lung and stomach cancer. Lycopene, on the other hand, shows more consistent benefits, such as improving vascular function in cardiovascular patients and reducing the risk of metabolic syndrome. It also exhibits anticancer potential by inhibiting tumor growth and inducing apoptosis, particularly in prostate cancer cells (Senkus *et al*., 2019; Mirahmadi *et al*., 2020). Quantitative studies of *C. militaris* reveal variable carotenoid content depending on extraction methods. Reported levels include â-carotene (0.328 mg/g) and lycopene (0.277 mg/g), while lower concentrations are found in aqueous extracts (Joshi *et al*., 2019; Choi *et al*., 2020). Compared to other edible mushrooms, *C. militaris* generally contains higher carotenoid levels. In addition to common carotenoids, *C. militaris* produces unique compounds known as cordyxanthins (I-IV). These differ structurally from typical carotenoids by having fewer methyl groups and more hydroxyl groups, which increases their water solubility. A distinctive feature is observed in cordyxanthin II, which contains an unusual combination of one six-membered and one five-membered ring, unlike the typical dual six-membered ring structure. This structural uniqueness may contribute to their specific biological properties and potential applications The method of extraction is a key factor influencing both the yield and composition of carotenoids. The use of organic solvents such as ethanol, acetone, or hexane typically leads to greater carotenoid recovery than aqueous extraction, which can enhance their antioxidant potential and associated biological effects. As a result, differences in extraction approaches may substantially affect the pharmacological efficacy of carotenoid-rich extracts (Joshi *et al*., 2019; Choi *et al*., 2020).

6. Mechanism of action of pharmacological activities of *Cordyceps* sp.

This Table 4 summarizes the underlying mechanisms through which *Cordyceps* exerts its pharmacological effects. It highlights the key molecular pathways and signaling processes involved in mediating its diverse biological activities (Das *et al*., 2021).

Table 4: Mechanisms underlying the pharmacological activities of *Cordyceps* species

Pharmacological activity	Mechanism of action
Immunomodulatory and anti-inflammatory	Enhances immune defense by activating natural killer (NK) cells and macrophages, improving phagocytosis. Regulates cytokines such as IL-6, TNF-α, IFN-γ, and IL-1β, and promotes hematopoietic factors like GM-CSF. Increases nitric oxide (NO) production and iNOS expression, while also modulating transcription factors. Additionally, it can suppress excessive inflammation by blocking NF-κB, Akt, JNK, and p38 signaling pathways, thereby reducing inflammatory mediators.
Antioxidant and antiageing	Protects cells from oxidative damage by reducing lipid peroxidation and malondialdehyde (MDA) levels. Enhances antioxidant enzymes such as SOD, catalase, and GPx across tissues (liver, brain, blood). Improves enzyme balance, lowers oxidative stress markers, and supports overall cellular health, contributing to antiageing effects.
Hypoglycemic activity	Improves glucose metabolism by stimulating enzymes like glucokinase, hexokinase, and G6PD. Enhances insulin sensitivity and glucose uptake *via* GLUT2 regulation and AMPK activation. Also reduces gluconeogenesis and inhibits PTP1B, helping maintain better blood glucose control.
Hypocholesterolemic, hypotensive and vasorelaxant	Supports cardiovascular health by promoting nitric oxide release and improving blood vessel relaxation. Reduces LDL oxidation and lipid accumulation, while improving lipid profile (HDL, LDL/VLDL). Inhibits vascular smooth muscle proliferation and enhances lipid metabolism through enzyme activation, contributing to better heart and liver function.
Antifatigue and antidepressant	Boosts energy metabolism by improving mitochondrial efficiency and increasing ATP production. Enhances endurance, reduces fatigue markers (lactate, urea), and increases glycogen storage. Activates pathways like AMPK, PGC-1, and NRF2, while lowering oxidative stress and improving antioxidant defenses.
Aphrodisiac potential	Supports steroid hormone production by activating signaling pathways such as cAMP-PKA and PKC. Increases expression of StAR protein and key steroidogenic enzymes (CYP11A1, 3β-HSD, CYP17A1). Also modulates hormonal balance and related signaling pathways involved in reproductive function.

Footnote: GM-CSF - Granulocyte-Macrophage Colony-Stimulating Factor, NO -Nitric Oxide , iNOS - Inducible Nitric Oxide Synthase, NF-κB - Nuclear Factor kappa-light-chain-enhancer of activated B cells.

7. Effect of *C. militaris* on the endocrine system

Research in animal models suggests that *C. militaris* can affect endocrine function, particularly by increasing testosterone levels. Its key compound, cordycepin, has been shown to stimulate steroid hormone production, leading to higher testosterone and progesterone levels. Studies in rats report improved testicular function, enhanced sperm formation, and better sperm motility, along with beneficial changes such as increased calcium levels and reduced urea and creatinine (Kopalli *et al*., 2019). Similar improvements in reproductive parameters have also been observed in livestock, where supplementation improved semen quality in infertile boars. Further evidence indicates that cordycepin-rich extracts may help regulate androgen activity and suppress abnormal prostate cell growth in experimental models (Kusama *et al*., 2021). However, human evidence is still lacking. For instance, supplementation with *C. sinensis* in healthy men did not significantly alter testosterone levels, and no direct clinical trials have yet examined the role of *C. militaris*. A recent randomized controlled clinical trial demonstrated that *C. militaris* supplementation in healthy adults can modulate immune responses and inflammatory biomarkers, confirming its biological activity in humans, although endocrine outcomes were not specifically assessed (Ontawong *et al*., 2024). Given its higher cordycepin content, its hormonal effects remain promising but require more rigorous human studies for confirmation (Jedrejko *et al*., 2021).

7.1 Effect on the locomotor system

Experimental evidence indicates that *C. militaris* may help in the management of osteoporosis by targeting bone resorption processes. Laboratory studies show that it suppresses the formation of osteoclasts by downregulating key genes involved in their development. Its major compound, cordycepin, also exhibits anti-inflammatory effects in joint cells by lowering the production of inflammatory mediators such as prostaglandin E, (PGE,) and nitric oxide, while inhibiting NF-κB activation triggered by IL-1β (Ashraf

et al., 2019). In animal models, cordycepin reduces inflammation-related bone loss and limits bone degradation. Both cordycepin and *C. militaris* extracts act by blocking the RANKL signaling pathway, which is essential for osteoclast formation. This is accompanied by decreased expression of osteoclast-related markers such as TRAP, cathepsin K, MMP-9, and NFATc1, along with inhibition of p38 and NF-κB signaling. Additionally, studies in osteoarthritis models suggest that cordycepin can reduce joint inflammation and pain, highlighting its potential role in bone and joint health (Ashraf *et al*., 2019).

7.2 Effect on the nervous system

Cordycepin, a major compound of *C. militaris*, has shown notable neuroprotective effects in experimental studies, mainly due to its anti-inflammatory and antioxidant properties (He *et al*., 2019). Animal studies indicate that *C. militaris* can improve memory and learning, particularly by reversing scopolamine-induced cognitive impairment and showing benefits in models of dementia and brain ischemia (Kim *et al*., 2019). A polypeptide derived from the fungus has also been linked to better memory performance, reduced acetylcholinesterase (AChE) activity, and enhanced GABA-related neurotransmission, along with increased antioxidant enzyme activity (SOD) and reduced lipid peroxidation (MDA). In Alzheimer's disease models, *C. militaris* improved cognitive function in behavioral tests such as maze navigation and object recognition (He *et al*., 2019). It has also demonstrated protective effects against chemotherapy-induced brain damage by reducing oxidative stress, increasing brain energy levels (ATP), and inhibiting AChE activity (Veenan *et al*., 2020). Although, some early human observations suggest possible effects on mood and emotional regulation, there is currently no strong clinical evidence confirming its role in treating depression (Jedrejko *et al*., 2021).

7.3 Effect on the cardiovascular system

Cordycepin from *C. militaris* shows strong potential in protecting cardiovascular health, particularly against atherosclerosis. Animal studies demonstrate that it effectively lowers triglycerides, total cholesterol, LDL, and VLDL levels, mainly through activation of AMPK and regulation of lipid-metabolizing enzymes (Huang *et al*., 2018). It also limits fat accumulation by suppressing adipocyte differentiation *via* pathways such as C/EBPβ, PPARγ, and mTORC1, while enhancing AMPK signaling. In addition to its lipid-lowering effects, cordycepin exhibits antiplatelet activity by inhibiting platelet aggregation. This is achieved through increased cAMP and cGMP levels, reduced intracellular calcium, and decreased thromboxane A, synthesis. It also interferes with fibrinogen binding to platelet receptors and modulates signaling pathways involved in clot formation (Choi *et al*., 2020). Furthermore, polysaccharides from *C. militaris* contribute to hypolipidemic and protective effects in high-fat diet models, while specific fractions such as CMN1 show resistance to hypoxia. Cardioprotective benefits have also been observed in ischemic heart models, suggesting that *C. militaris* and its bioactive compounds may support overall cardiovascular function (Huang *et al*., 2018).

8. Value-added products and nutraceutical applications

Products made from *C. militaris* are commonly marketed as nutraceuticals and are consumed either in their natural form or as processed products such as extracts, fermented powders, and tinctures (Olatunji *et al*., 2018; Kontogiannatos *et al*., 2021). In China, around 36 health-related products based on this fungus have received official approval. Commercial formulations, including mycelium-based powders and capsules, are also available and promoted for their potential health-supporting properties (Phull *et al*., 2022). These products are widely used across Southeast Asia, especially in countries like China, Taiwan, and Hong Kong (Li *et al*., 2015). The fruiting bodies are often included in traditional dishes such as soups, stews with chicken or duck, and herbal teas. Regarding safety, intake of the fruiting bodies is generally considered safe when consumed below 2.5 g per kg of body weight (Bawadekji *et al*., 2016). A detailed overview of various value-added products and their functional benefits is provided in Table 5.

Table 5: Value-added products of *C. militaris* and their functional benefits (Source: Elkhateeb *et al*., 2019)

Product name	Functional benefits	Company name
Cordyceps (Mushroom extract)	Supports respiratory and renal health	Organika
Cordyceps	Enhances immune function and maintains vascular health	Moon juice
Ultra *Cordyceps* plus	Promotes lung function and supports liver health	Drbvitamins
Host defense *Cordyceps*	Aids kidney health and improves oxygen utilization	Host defense
Perfect *Cordyceps*	Strengthens immunity and supports sexual wellness	Perfect supplements
Paradise herbs Tibetan *Cordyceps*	Improves physical performance, endurance, and resistance	Paradise herbs
Solaray *Cordyceps*	Helps prevent throat infections and supports healthy cholesterol levels	Naturally healthy concepts
Oregon's wild harvest *Cordyceps*	Provides cardiovascular, respiratory, and immune system support	Oregon's wild harvest
Cordyceps CS-4	Enhances energy levels, boosts immunity, and supports cardiovascular function	Ireal herbs

9. Benefits of *Cordyceps*

Species of *Cordyceps* are widely recognized as valuable sources of bioactive compounds with strong therapeutic potential. These natural metabolites exhibit a wide range of biological effects and are increasingly being explored as candidates for future drug development (Olatunji *et al*., 2018). Laboratory studies have shown that *Cordyceps* extracts can inhibit the growth of several cancer cell lines, highlighting their possible role in anticancer strategies (Raethong *et al*., 2018). Beyond anticancer activity, *Cordyceps* and its derivatives support multiple body systems, including the liver, kidneys, heart, lungs, nervous system, reproductive system, and immune system. They display diverse pharmacological actions such as antioxidant, anti-inflammatory, antimicrobial, and immune-enhancing effects (Tuli *et*

al., 2014). Traditionally, these fungi have been used in Asian medicine to manage respiratory conditions like asthma and bronchitis, as well as to improve stamina and overall vitality. Clinical observations have also suggested benefits in conditions such as tuberculosis, leprosy, and certain leukemias (Elkhateeb and Daba, 2022). In addition, compounds like cordycepin show promising antiviral and anti-inflammatory properties, suggesting potential applications in managing systemic infections, including emerging diseases like COVID-19 (Chellapandi and Saranya, 2022). Apart from medical uses, *Cordyceps* has gained attention in green nanotechnology, where its extracts are used for eco-friendly synthesis of metal nanoparticles such as silver and gold. These nanoparticles demonstrate strong biological activities, including antibacterial, antifungal, insecticidal, and other biocontrol effects, making them useful in both medical and agricultural fields (Makhija *et al*., 2025).

10. Global market demand and commercial opportunities

The global production of Chinese cordyceps, mainly *Ophiocordyceps sinensis*, is relatively limited, estimated at around 83-182 tons annually. Among producing countries, China overwhelmingly dominates, contributing nearly 80-175 tons per year, which accounts for over 95% of the total global supply. In contrast, production in countries like Nepal (about 1-3 tons), India (around 1.7-2.8 tons), and Bhutan (approximately 0.5-1.5 tons) remains comparatively low. Despite difficulties in cultivation, harvesting, and processing, high-quality cordyceps commands extremely high prices in the global market, sometimes reaching up to USD 100,000 per kilogram, reflecting its strong and consistent demand (Holliday *et al*., 2017). In India, there is growing potential for cordyceps-based industries, particularly due to the availability of sericulture waste that can be utilized for cultivation. Currently, the global cordyceps market is experiencing a shift toward cultivated species such as *C. militaris*, driven by sustainability concerns, regulatory restrictions on wild harvesting, and increasing demand for standardized nutraceutical products, with significant growth observed in Asia-Pacific and emerging expansion in North American and European markets. A detailed list of companies involved in cordyceps product development in India is presented in the Table 6 (Jayaram *et al*., 2024).

Table 6: Indian companies involved in the development of *Cordyceps*-based products

S. No.	Company name	Location	Product details
1	Umbrella Agro Farming	Lonavala, Maharashtra	Produces *C. militaris* in dried form, *C. sinensis*, and capsule-based formulations
2	Himalayan Herbes	Dehradun, Uttarakhand	Offers Yarsagumba (Keeda Jadi) in dried, organic, and herbal forms
3	Pravansh Biosciences Private Limited	Gautam Budh Nagar, Uttar Pradesh	Supplies Kida Jadi
4	Nirup Traders	Mangalore, Karnataka	Deals in *Ophiocordyceps sinensis*
5	Samridhi Herbs	Rudrapur, Uttarakhand	Provides golden-yellow varieties of *C. sinensis*
6	Vana Shrubs Pvt. Ltd	Bardez, North Goa, Goa	Markets *C. militaris* products including capsule supplements, fresh mushrooms, and dried forms

11. Limitations and challenges

Although, *Cordyceps* species are widely regarded as safe, certain groups should exercise caution. Their use is generally not recommended for pregnant women or individuals with autoimmune conditions, bleeding disorders, or coagulation issues, as adverse effects have been reported in such cases (Goswami and Tah, 2018). From a production perspective, several challenges limit the large-scale cultivation of *C. militaris*. One major issue is strain degeneration, which reduces productivity over time and affects sustainability (Lou *et al*., 2019). Contamination during artificial cultivation is another critical concern, often arising from equipment failure, handling mistakes, or environmental exposure, leading to reduced yields or even complete loss of cultures (Chen *et al*., 2020). Improving commercially valuable traits in *C. militaris* remains difficult due to factors such as genetic instability, low biomass yield, limited production of bioactive compounds, and the long duration required for fruiting body development. In addition, incomplete understanding of optimal growth conditions and insufficient biochemical profiling further complicate optimization efforts (Wang *et al*., 2022; Zeng *et al*., 2024). Another key limitation is the lack of a standardized artificial medium capable of consistently supporting fruiting body formation, which continues to hinder reliable large-scale commercial production (Vardhan *et al*., 2025). Although, *Cordyceps* species are widely regarded as safe, certain groups should exercise caution. Their use is generally not recommended for pregnant women or individuals with autoimmune conditions, bleeding disorders, or coagulation issues, as adverse effects have been reported in such cases (Goswami and Tah, 2018). From a production perspective, several challenges limit the large-scale cultivation of *C. militaris*. One major issue is strain degeneration, which reduces productivity over time and affects sustainability (Lou *et al*., 2019). Contamination during artificial cultivation is another critical concern, often arising from equipment failure, handling mistakes, or environmental exposure, leading to reduced yields or even complete loss of cultures (Chen *et al*., 2020). Improving commercially valuable traits in *C. militaris* remains difficult due to factors such as genetic instability, low biomass yield, limited production of bioactive compounds, and the long duration required for fruiting body development. In addition, incomplete understanding of optimal growth conditions and insufficient biochemical profiling further complicate optimization efforts (Wang *et al*., 2022; Zeng *et al*., 2024). Another key limitation is the lack of a standardized artificial medium capable of consistently supporting fruiting body formation, which continues to hinder reliable large-scale commercial production (Vardhan *et al*., 2025). In addition to the limitations discussed, a more thorough assessment of the safety and toxicological aspects of *C. militaris* is still needed. Although, current findings generally indicate that it is safe for consumption, the available toxicological evidence is not sufficiently comprehensive. Some studies report that the fruiting bodies are well tolerated at doses below 2.5 g/kg body weight, with

no notable adverse effects observed (Bawadekji *et al*., 2016). Nevertheless, critical toxicological indicators, including median lethal dose (LD_{50}), long-term toxicity, and potential effects on liver function, have not been adequately investigated. Moreover, differences in extraction techniques and variations in bioactive constituents may affect its safety and toxicity profile (Goswami and Tah, 2018; Phull *et al*., 2022). Consequently, detailed and systematic toxicological studies, encompassing both acute and chronic exposure, are essential to confirm its safety for clinical use and nutraceutical applications.

12. Future prospects

Recent market analyses indicate that the global cordyceps sector is undergoing rapid expansion. The *C. militaris* market was valued at approximately USD 1.52 billion in 2025 and is projected to reach about USD 1.69 billion in 2026, with further growth expected to USD 3.9 billion by 2034, reflecting a compound annual growth rate (CAGR) of around 11.0%. Similarly, the broader cordyceps extract market reached approximately USD 1.35 billion in 2024 and is forecast to grow at a CAGR of about 10.9% through 2030. Given the trends in market size, the future development of *C. militaris* cultivation depends largely on overcoming current technical limitations in artificial production. Advances in biotechnology such as genetic engineering, genome editing, strain improvement, and tissue culture are opening new possibilities for developing high-yield and stable strains. At the same time, optimizing cultivation factors like substrate composition, temperature, humidity, and light is essential, as these directly influence growth, fruiting body formation, and overall product quality. Careful control of these parameters can improve consistency and enable large-scale production. In addition to cultivation improvements, there is strong potential in developing value-added products such as nutraceuticals, functional foods, and pharmaceutical formulations from *Cordyceps*. With continued research, technological progress, and well-planned commercialization, India has the potential to become a key player in the global medicinal mushroom industry.

13. Conclusion

C. militaris has gained recognition as an important medicinal fungus with strong potential in both nutraceutical and pharmaceutical fields. Its bioactive compounds, particularly cordycepin and diverse polysaccharides, are responsible for a wide range of biological activities demonstrated in experimental studies. Recent progress in molecular research, including the identification of genes involved in cordycepin biosynthesis, has improved understanding of its metabolic pathways and created new opportunities for strain enhancement and metabolic engineering. Despite these advances, large-scale commercialization remains limited due to challenges such as genetic instability, inconsistent fruiting, contamination issues, and the absence of standardized cultivation methods. Overcoming these barriers will require integrated biotechnological approaches, including genome editing and improved cultivation strategies, to enhance productivity and quality. Furthermore, well-designed clinical studies are still needed to confirm its safety and therapeutic effectiveness in humans. With continued scientific and technological progress, *C. militaris* has strong potential to become a reliable source of bioactive compounds and play a significant role in future drug development and natural health products.

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Conflict of interest

There is no conflict of interest relevant to this article.

References

Ashraf, S.; Radhi, M.; Gowler, P.; Burston, J.J.; Gandhi, R.D.; Thorn, G.J. and De Moor, C.H. (2019). The polyadenylation inhibitor cordycepin reduces pain, inflammation and joint pathology in rodent models of osteoarthritis. Scientific Reports, **9(1)**:4696.

Baswan, S.M.; Klosner, A.E.; Weir, C.; Salter Venzon, D.; Gellenbeck, K.W.; Leverett, J. and Krutmann, J. (2021). Role of ingestible carotenoids in skin protection: A review of clinical evidence. Photodermatology, Photoimmunology and Photomedicine, **37(6)**:490-504.

Bawadekji, A.; Al Ali, K. and Al Ali, M. (2016). Bioactive compounds and medicinal value of *Cordyceps militaris*. Journal of North Basic and Applied Sciences, **1**:69-76.

Bi, S.; Jing, Y.; Zhou, Q.; Hu, X.; Zhu, J.; Guo, Z. and Yu, R. (2018). Structural elucidation and immunostimulatory activity of a polysaccharide from *Cordyceps militaris*. Food and Function, **9(1)**:279-293.

Borodina, I.; Kenny, L.C.; McCarthy, C.M.; Paramasivan, K.; Pretorius, E.; Roberts, T.J. and Kell, D.B. (2020). Biology of ergothioneine. Nutrition Research Reviews, **33(2)**:190-217.

Cheah, I.K.; Tang, R.M.; Yew, T.S.; Lim, K.H. and Halliwell, B. (2017). Ergothioneine administration in humans. Antioxidants and Redox Signaling, **26(5)**:193-206.

Chellapandi, P. and Saranya, S. (2022). Cordycepin for COVID-19. Coronaviruses, **3(1)**:3-8.

Cheung, J.K.; Li, J.; Cheung, A.W.; Zhu, Y.; Zheng, K.Y.; Bi, C.W. and Tsim, K.W. (2009). Immune activation by Cordysinocan. Journal of Ethnopharmacology, **124(1)**:61-68.

Choi, D.; Cha, W.S.; Park, N.; Kim, H.W.; Lee, J.H.; Park, J.S. and Park, S.S. (2011). Fibrinolytic enzyme from *Cordyceps militaris*. Bioresource Technology, **102(3)**:3279-3285.

Choi, E.J.; Park, B.; Lee, J. and Kim, J. (2020). Antiatopic dermatitis properties. Physical Activity and Nutrition, **24(4)**:7.

Choi, E.; Oh, J. and Sung, G.H. (2020). Antithrombotic effects. Mycobiology, **48(3)**:228-232.

Chou, Y.C.; Sung, T.H.; Hou, S.J.; Khumsupan, D.; Santoso, S.P.; Cheng, K.C. and Lin, S.P. (2024). Progress in *Cordyceps militaris*. Applied Sciences, **14(11)**:4610.

Cunningham, K.G.; Manson, W.I.; Spring, F.S. and Hutchinson, S.A. (1950). Cordycepin isolation. Nature, **166**:949.

Das, G.; Shin, H.S.; Leyva-Gómez, G.; Prado-Audelo, M.L.; Cortes, H.; Singh, Y.D. and Patra, J.K. (2021). Biological potentials of *Cordyceps*. Frontiers in Pharmacology, **11**:602364.

Das, S.K.; Masuda, M.; Sakurai, A. and Sakakibara, M. (2010). Medicinal uses of *Cordyceps militaris*. Fitoterapia, **81(8)**:961-968.

Dupont, S.; Lemetais, G.; Ferreira, T.; Cayot, P.; Gervais, P. and Beney, L. (2012). Ergosterol biosynthesis. Evolution, **66(9)**:2961-2968.

Elkhateeb, W.A. and Daba, G.M. (2022). Bioactive metabolites. Journal of Biomedical Research, **3(5)**:566-574.

Elkhateeb, W.A.; Daba, G.M.; Thomas, P.W. and Wen, T.C. (2019). Medicinal mushrooms. Egyptian Pharmaceutical Journal, **18(2)**:88-101.

Else, M.; Dearden, C.E.; Matutes, E.; Forconi, F.; Lauria, F.; Ahmad, H. and Catovsky, D. (2011). Leukemia treatment. Leukemia and Lymphoma, **52**:75-78.

Goswami, A. and Tah, J. (2018). Pharmacological activities. Journal of Pharmacognosy and Phytochemistry, **7(4)**:2341-2346.

He, M.T.; Lee, A.Y.; Kim, J.H.; Park, C.H.; Shin, Y.S. and Cho, E.J. (2019). Protective role of *Cordyceps militaris* in Alzheimer's disease. Food Science and Biotechnology, **28(3)**:865-872.

Hepsomali, P.; Groeger, J.A.; Nishihira, J. and Scholey, A. (2020). Effects of GABA on stress and sleep. Frontiers in Neuroscience, **14**:559962.

Holliday, J. (2017). *Cordyceps*: A highly coveted medicinal mushroom. In: Medicinal Plants and Fungi. Springer, pp. **59**-91.

Holliday, J. and Cleaver, M.P. (2008). Medicinal value of *Cordyceps*. International Journal of Medicinal Mushrooms, **10(3)**.

Hong, I.P.; Kang, P.D.; Kim, K.Y.; Nam, S.H.; Lee, M.Y.; Choi, Y.S. and Humber, R.A. (2010). Fruit body formation on silkworm. Mycobiology, **38(2)**:128-132.

Huang, Z.F.; Zhang, M.L.; Zhang, S.; Wang, Y.H. and Jiang, X.W. (2018). Polysaccharides and hypolipidemic effects. RSC Advances, **8**:41012-41022.

Hueng, D.Y.; Hsieh, C.H.; Cheng, Y.C.; Tsai, W.C. and Chen, Y. (2017). Cordycepin inhibits glioblastoma migration. Journal of Nutritional Biochemistry, **41**:109-116.

Jayaram, H.; Mahadevegowda, L.G. and Boregowda, M.H. (2024). Seri-entrepreneurship status. Current Agriculture Research Journal, **12(1)**.

Jêdrejko, K.J.; Lazur, J. and Muszyñska, B. (2021). Chemical constituents of *Cordyceps militaris*. Foods, **10(11)**:2634.

Joshi, M.; Sagar, A.; Kanwar, S.S. and Singh, S. (2019). Anticancer and antioxidant activities. Indian Journal of Experimental Biology, **57(1)**:15-20.

Kabir, M.T.; Rahman, M.H.; Shah, M.; Jamiruddin, M.R.; Basak, D.; Al-Harrasi, A. and Abdel-Daim, M.M. (2022). Carotenoids in neurodegenerative disorders. Biomedicine and Pharmacotherapy, **146**:112610.

Kang, N.; Lee, H.H.; Park, I. and Seo, Y.S. (2017). High cordycepin-producing strains. Mycobiology, **45(1)**:31-38.

Kim, H.G.; Song, H.; Yoon, D.H.; Song, B.W.; Park, S.M.; Sung, G.H. and Kim, T.W. (2010). Apoptosis induction in HeLa cells. Journal of Ethnopharmacology, **128(2)**:342-351.

Kim, Y.O.; Kim, H.J.; Abu-Taweel, G.M.; Oh, J. and Sung, G.H. (2019). Neuroprotective effects. Saudi Journal of Biological Sciences, **26(7)**:1352-1357.

Kobayasi, Y. (1941). The genus *Cordyceps*. Science Reports, **5**:53-260.

Kontogiannatos, D.; Koutrotsios, G.; Xekalaki, S. and Zervakis, G.I. (2021). Biomass and cordycepin production. Journal of Fungi, **7(11)**:986.

Kopalli, S.R.; Cha, K.M.; Lee, S.H.; Hwang, S.Y.; Lee, Y.J.; Koppula, S. and Kim, S.K. (2019). Cordycepin and testicular function. Nutrients, **11(4)**:906.

Kusama, K.; Miyagawa, M.; Ota, K.; Kuwabara, N.; Saeki, K.; Ohnishi, Y. and Tamura, K. (2020). Testosterone metabolism. Nutrients, **13(1)**:50.

Li, X.; Wu, Q.; Xie, Y.; Ding, Y.; Du, W.W.; Sdiri, M. and Yang, B.B. (2015). Ergosterol anticancer activity. Oncotarget, **6(19)**:17832.

Liang, Z.C.; Liang, C.H. and Wu, C.Y. (2014). Grain substrates for *Cordyceps*. International Journal of Medicinal Mushrooms, **16(6)**.

Liu, M.; Li, X.; Huai, M.; Yang, Y. and Dong, C. (2023). Current state of *Cordyceps militaris*. In: Fungi and Fungal Products, pp. **187**.

Liu, Y.; Wang, J.; Wang, W.; Zhang, H.; Zhang, X. and Han, C. (2015). Chemical constituents of *Cordyceps sinensis*. Evidence-Based Complementary Medicine, **2015**:575063.

Makhija, M.; Archana, T.S. and Kumar, D. (2026). Multifaceted biocidal activities of *Cordyceps militaris* and synthesis of green nanoparticles: a comprehensive review. Studies in Fungi, **11**:e001.

Mala, P.H.; Jayashree; Thrilekha, D.; Sithara, H.; Dukare, P.G. and Reddy, C.H. (2024). Silkworm as alternate host. International Journal of Advanced Biochemistry Research, **8**:695–699.

Mirahmadi, M.; Azimi-Hashemi, S.; Saburi, E.; Kamali, H.; Pishbin, M. and Hadizadeh, F. (2020). Lycopene in cancer. Biomedicine and Pharmacotherapy, **129**:110459.

Muszyñska, B.; Ka³a, K.; Rojowski, J.; Grzywacz, A. and Opoka, W. (2017). Composition and biological properties of *Agaricus bisporus* fruiting bodies - a review. Polish Journal of Food and Nutrition Sciences, **67(3)**:173-181.

Olatunji, O.J.; Tang, J.; Tola, A.; Auberon, F.; Oluwaniyi, O. and Ouyang, Z. (2018). Traditional uses and pharmacology. Fitoterapia, **129**:293-316.

Phull, A.R.; Ahmed, M. and Park, H.J. (2022). Anti-inflammatory mechanisms. Microorganisms, **10(2)**:405.

Qi, W.; Zhang, Y.; Yan, Y.B.; Lei, W.; Wu, Z.X.; Liu, N. and Fan, Y. (2013). Cordymin protective effect. Evidence-Based Complementary Medicine, **2013**:985636.

Raethong, N.; Laoteng, K. and Vongsangnak, W. (2018). Metabolic response to cordycepin. Scientific Reports, **8**:9250.

Sabaratnam, V.; Kah-Hui, W.; Naidu, M. and David, P.R. (2013). Mushrooms and neuronal health. Journal of Traditional Medicine, **3(1)**:62-68.

Senkus, K.E.; Tan, L. and Crowe-White, K.M. (2019). Lycopene and metabolic syndrome. Advances in Nutrition, **10(1)**:19-29.

Shrestha, B.; Tanaka, E.; Han, J.G.; Oh, J.; Han, S.K. and Lee, K.H. (2014). Chronicle of *Cordyceps*. Mycobiology, **42(2)**:93-99.

Shrestha, B.; Tanaka, E.; Hyun, M.W.; Han, J.G.; Kim, C.S.; Jo, J.W. and Sung, G.H. (2016). Hosts of *Cordyceps*. Journal of Mycology, **2016**:7648219.

Smith-Hall, C. and Bennike, R.B. (2022). Sustainability of harvesting. Biodiversity and Conservation, **31(2)**:729-733.

Stringham, N.T.; Holmes, P.V. and Stringham, J.M. (2018). Carotenoids and stress. Nutritional Neuroscience, **21(4)**:286-296.

Sung, G.H.; Hywel-Jones, N.L.; Sung, J.M.; Luangsa-Ard, J.J.; Shrestha, B. and Spatafora, J.W. (2007). Phylogenetic classification. Studies in Mycology, **57**:5-59.

Sung, G.H.; Shrestha, B.; Han, S.K. and Sung, J.M. (2011). Cultural characteristics. Mycobiology, **39(1)**:1-6.

Tuli, H.S.; Sandhu, S.S. and Sharma, A.K. (2014). Therapeutic potential of *Cordyceps*. 3 Biotech, **4(1)**:1-12.

Vardhan, S.; Parihar, A.; Anand, R.; Kushwaha, K. and Arora, S. (2025). Bioactive compounds and nanotechnology. Journal of Advances in Biology and Biotechnology, **28(11)**:1136-1154.

Veena, R.K.; Carmel, E.J.; Ramya, H.; Ajith, T.A.; Wasser, S.P. and Janardhanan, K.K. (2020). Oxidative stress attenuation. International Journal of Medicinal Mushrooms, **22(6)**:339-347.

Wang, F.; Liu, Q.; Zhang, J.; Liu, K.; Li, K.; Liu, G. and Dong, C. (2018). Transcriptome analysis. Frontiers in Microbiology, **9**:1237.

Wang, L.; Yan, H.; Zeng, B. and Hu, Z. (2022). Cordycepin synthesis. Bioengineering, **9(2)**:69.

Wang, X.L. and Yao, Y.J. (2011). Host insect species. ZooKeys, **127**:43.

Wang, Y.; Yang, Z.; Bao, D.; Li, B.; Yin, X.; Wu, Y. and Zou, G. (2021). Hypoxia adaptation. Frontiers in Microbiology, **12**:698436.

Wu, N.; Ge, X.; Yin, X.; Yang, L.; Chen, L.; Shao, R. and Xu, W. (2024). Polysaccharide biosynthesis. International Journal of Biological Macromolecules, **260**:129336.

Wu, Y.; Hu, N.; Pan, Y.; Zhou, L. and Zhou, X. (2007). Mannoglucan isolation. Carbohydrate Research, **342(6)**:870-875.

Xia, Y.; Luo, F.; Shang, Y.; Chen, P.; Lu, Y. and Wang, C. (2017). Cordycepin biosynthesis. Cell Chemical Biology, **24(12)**:1479-1489.

Xiong, C.; Xia, Y.; Zheng, P.; Shi, S. and Wang, C. (2010). Gene expression profiling. Mycology, **1(1)**:25-66.

Yang, L.; Li, G.; Chai, Z.; Gong, Q. and Guo, J. (2020). Synthesis of cordycepin. Fungal Genetics and Biology, **143**:103431.

Yasukawa, K.; Aoki, T.; Takido, M.; Ikekawa, T.; Saito, H. and Matsuzawa, T. (1994). Ergosterol anti-inflammatory effects. Phytotherapy Research, **8(1)**:10-13.

Yazawa, Y.; Ikarashi, N.; Hoshino, M.; Kikkawa, H.; Sakuma, F. and Sugiyama, K. (2020). Inhibitory effect of ergosterol on bladder carcinogenesis is due to androgen signaling inhibition by brassicasterol, a metabolite of ergosterol. Journal of Natural Medicines, **74(4)**, 680-688.

Young, A.J. and Lowe, G.L. (2018). Carotenoids antioxidant properties. Antioxidants, **7(2)**:28.

Zeng, J.; Zhou, Y.; Lyu, M.; Huang, X.; Xie, M.; Huang, M. and Wei, T. (2024). Metabolic engineering platform. Biotechnology Advances, **74**:108396.

Zhang, J.; Wen, C.; Duan, Y.; Zhang, H. and Ma, H. (2019). Polysaccharides review. International Journal of Biological Macromolecules, **132**:906-914.

Zhang, Y.; Li, E.; Wang, C.; Li, Y. and Liu, X. (2012). Ecology of *Ophiocordyceps sinensis*. Mycology, **3(1)**:2-10.

Zheng, P.; Xia, Y.; Xiao, G.; Xiong, C.; Hu, X.; Zhang, S. and Wang, C. (2011). Genome sequence. Genome Biology, **12(11)**:R116.

Zheng, Z.L.; Qiu, X.H. and Han, R.C. (2015). Genes in fruiting body formation. Mycobiology, **43(1)**:37-42.

Zhou, X.; Gong, Z.; Su, Y.; Lin, J. and Tang, K. (2009). Pharmacological functions. Journal of Pharmacy and Pharmacology, **61(3)**:279-291.

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