

***Cordyceps militaris*: “A promising nutraceutical formulation through traditional fermentation aligned with IKS framework.”**

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Abstract

Cordyceps militaris is a valuable medicinal mushroom packed with nutrients. It contains high-quality proteins, essential amino acids, bioactive polysaccharides, and cordycepin (3'-deoxyadenosine), a compound known for its immune-boosting, antioxidant, and anti-inflammatory effects. Edible bacteria, including *Lactobacillus*, *Bacillus*, and filamentous fungi, have been part of traditional Indian diets for a long time. They help with digestibility, nutrient availability, and the creation of beneficial compounds in fermented foods like ambali, dhokla, and kanji. Adding *C. militaris* to fermented food helps improve the release and availability of polysaccharides and cordycepin due to microbial fermentation. This approach aligns with Ayurvedic Rasayana principles, which highlight the use of natural, bioactive foods to support metabolic balance, immune strength, and rejuvenation. When solid-state or submerged fermentation uses locally available substrates like millets and legumes, it ensures the efficient use of resources, reduces waste, and promotes environmental sustainability. Overall, *C. militaris* appears to be a promising functional food and nutraceutical based on the Indian Knowledge System.

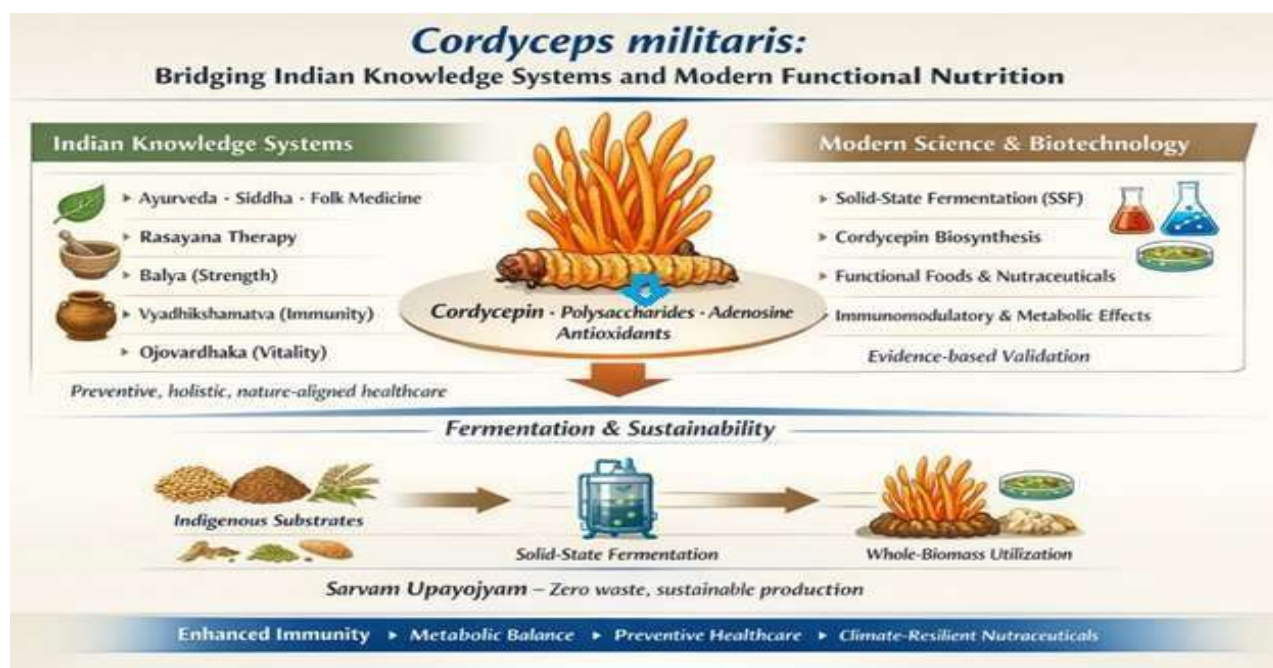
Keywords: Bioaccessibility, Immunomodulatory, cordycepin, nutraceutical, Indian knowledge system

Figure 1: Graphical abstract

Introduction

India's traditional knowledge systems create a framework for sustainability, nutrition, and health. Years of careful observation led to the development of these systems (Gadgil & Vartak, 2016). Folk medicine, Ayurveda, and Siddha highlight the importance of balance between nature and humans (Gadgil & Vartak, 2016; Sharma, 2022). They advocate for natural remedies, food, and lifestyle choices for health (Sharma, 2022). Classical texts mainly discuss plants, but cultures in the Himalayas and woodlands also use fungi and mushrooms (Patil, Verma, Jamdagni, et al., 2024). These fungi are used to boost vitality and energy (Patil, Verma, Jamdagni, et al., 2024). Cordyceps species are unique among mushrooms due to their significant bioactivities and links to both fungi and insects (Paterson, 2008; Li, et al., 2011). Traditionally, Cordyceps sinensis has been used in medicine (Patil, Verma, Jamdagni, et al., 2024). However, Cordyceps militaris has gained popularity because of overharvesting and environmental issues (Paterson, 2008). It serves as a sustainable alternative (Li, et al., 2011). Its benefits have been confirmed by recent advancements in biotechnology (Chen, et al., 2024; Kim, et al., 2019). India's traditional knowledge systems represent a solid basis for health, nutrition, and sustainability (Gadgil & Vartak, 2016). In Ayurveda, Rasayana therapy encompasses rejuvenation practices that enhance immunity, vitality, and longevity (Sharma, 2022). Rasayana substances are seen as nourishing, immune-boosting, and supportive (Sharma, 2022). Modern functional foods and nutraceuticals resemble this concept, offering health benefits beyond basic nutrition (Kaur & Kaur, 2020). Traditional Indian diets include fermentation in foods like idli, dosa, kanji, and fermented cereals (Kaur & Kaur, 2020). These methods enhance digestibility, nutrient availability, and therapeutic value (Kaur & Kaur, 2020). Solid-state fermentation is now common in mushroom cultivation. It mirrors these traditional methods by utilizing low-cost materials and natural microbial processes (Exploring the Potential of Cordyceps militaris Cultivation on Agricultural Waste, 2022; Comparative Analysis of Cordyceps militaris Growth on Pearl Millet, 2025). Cordyceps militaris generates bioactive compounds. These compounds include cordycepin, adenosine, polysaccharides, and antioxidants (Chen, et al., 2024; Kim, et al., 2019). They provide health benefits and display anti-inflammatory, antioxidant, anti-diabetic, and anti-cancer effects (Chen, et al., 2024; Kim, et al., 2019; Wei, et al., 2021). From an Ayurvedic viewpoint, these activities correspond to: Balya (strength promoting), Ojovardhaka (boosting vitality and immunity), Rasayana (rejuvenating effects)

Thus, *Cordyceps militaris* can be regarded as a Rasayana nutraceutical, supported by modern scientific proof (Chen, et al., 2024; Sharma, 2022; Kim, et al., 2019). Indian traditional systems emphasize sustainability. Cultivating *Cordyceps militaris* on cereal grains such as rice, finger millet, and wheat bran reflects this principle (Exploring the Potential of *Cordyceps militaris* Cultivation on Agricultural Waste, 2022; Comparative Analysis of *Cordyceps militaris* Growth on Pearl Millet, 2025; Pradhan, et al., 2021). Millets are climate-smart crops that bolster sustainability and nutrition security (Pradhan, et al., 2021). This review explores the current literature on *Cordyceps militaris* and discusses its health benefits, cultivation strategies, and sustainability. The goal is to connect traditional concepts with modern scientific validation (Gadgil & Vartak,



2016; Sharma, 2022; Kim, et al., 2019).

Fermentation has been vital in Indian food and medicine for centuries, as noted by Sharma et al. (2011). Ancient Ayurvedic texts mention Sandhana Kalpana, a fermentation method that enhances the bioavailability, shelf life, and healing power of natural ingredients. Common items like idli, dosa, kanji, and fermented rice illustrate how well Indians understood microbial processes long ago (Tamang et al., 2016). India's traditional knowledge emphasizes sustainability, simple processing, and maximizing every natural resource (Patwardhan, 2014). These ideas align with modern solid-state fermentation (SSF) techniques, where microbes thrive on solid materials

with minimal free water—efficiently producing valuable compounds with little waste (Soccol et al., 2017). In essence, modern SSF can be seen as a high-tech recognition of India's ancient fermentation expertise.

Table1: Traditional Indian Fermented foods

Region	State	Traditional Fermented Food	Primary Substrate	Type of Fermentation	Nutritional Significance	Reference
North India	Hima-chal Pra-desh	Siddu, Chhang	Wheat, barley, millet	Yeast and lactic fermentation	Energy-rich; supports cold-climate adaptation	Thakur&Sharma 2018.
South India	Karnataka	Ragi dosa, Ambali	Finger millet	Lactic acid fermentation	Rich in dietary fiber and minerals	Shobana et al., 2013
	Andhra Pra-desh	Ambali	Finger millet (ragi)	Lactic acid fermentation	Traditional probiotic drink	Ghosh et al., 2015
	Telangana	Sajja Ambali	Pearl millet	Lactic acid fermentation	Rich in dietary fiber and minerals	Saleh et al., 2013
East India	Assam	Khorisa, Haanz	Bamboo shoot, rice	Mixed microbial fermentation	Source of vitamins; ethnic food tradition	Tamanget al., 2009
West India	Gujarat	Dhokla, Khandvi, Handvo	Rice, Bengal gram	Mixed lactic and yeast fermentation	Improved mineral bio-availability	Tamang 2015

Central India	Chhattisgarh	BoreBaasi	Rice	Natural lacto-fermentation	Climate- resilient traditional food practice	Tamang 2020
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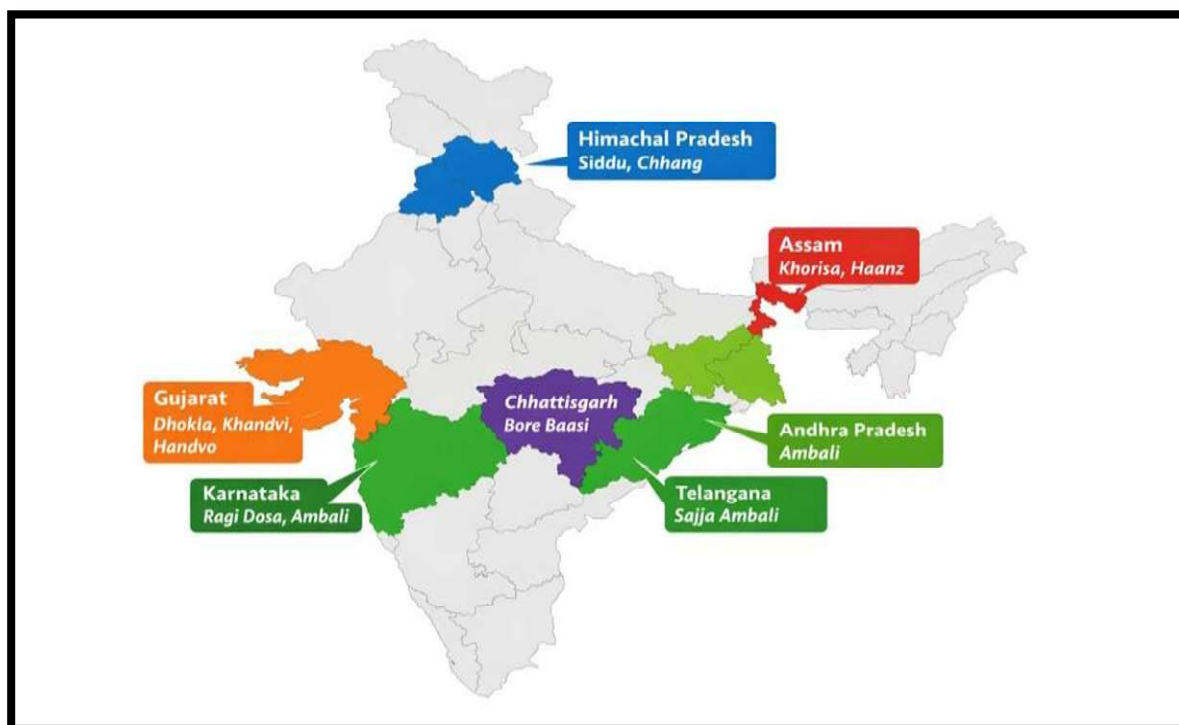


Figure 2: Traditional fermented foods geographical representation in India

Cordyceps militaris in Historical and Modern Contexts:

Cordyceps militaris in traditional and modern contexts shows that entomopathogenic and medicinal fungi have been a part of Indian ethnomedicine and forest healing practices, even though Cordyceps sinensis is more commonly documented in Traditional Chinese Medicine (Harsh et al., 1996; Kala, 2010). In ancient Indian traditions, fungi were recognized as Rasayana agents that enhance longevity, immunity, and energy. Recent research shows that C. militaris is a rich source of cordycepin (3'-deoxyadenosine), which has anticancer, immunomodulatory, anti-inflammatory, and antioxidant properties (Kim et al., 2006; Paterson, 2008; Das et al., 2010). As the demand for cordycepin grows, there is more focus on sustainable farming practices that respect cultural and ecological framework.

NutritionalCompositionProfile

Macronutrient content : The fruiting bodies of *C. militaris* contain significant amounts of fiber, proteins, and carbohydrates when measured on a dry weight basis. Research on in vitro cultured fruiting bodies showed that carbohydrates make up roughly 60 percent of the dry mass. The protein content is about 23 percent of the dry mass, while crude fiber is approximately 11 percent. This provides a solid basis for energy and structure. The amounts of crude protein and carbohydrates can vary depending on the growth medium and method. However, overall values indicate that the macronutrients are suitable for functional foods (Pavleen et al., 2024).

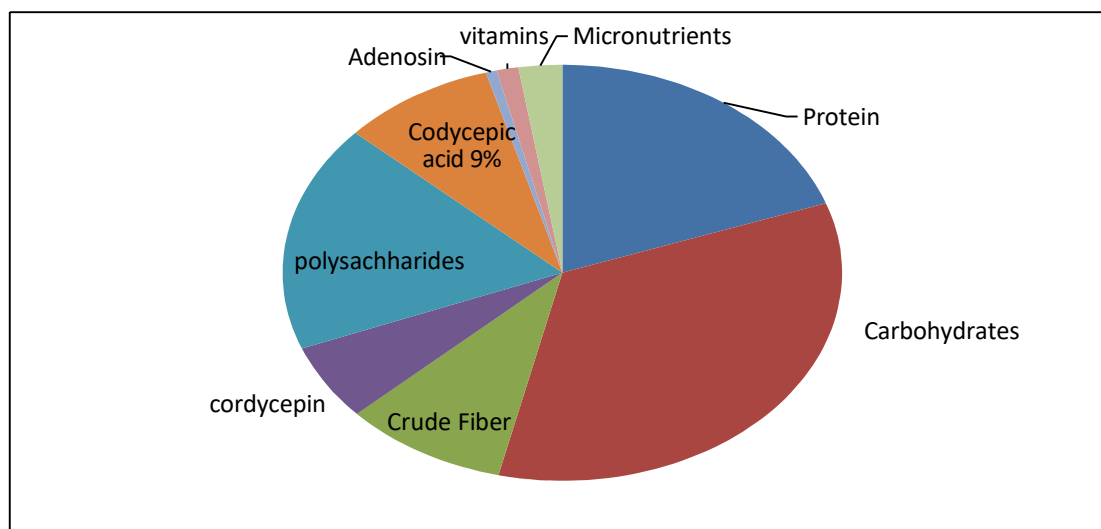


Figure3: Nutritional Composition of *Cordyceps militaris*

Micronutrient Content: *C. militaris* fruiting bodies are also sources of important micronutrients such as zinc (Zn) and copper (Cu) and trace elements such as selenium (Se), and minerals important for cellular and metabolic processes .Further, vitamins, particularly the B-complex (B1, B3, B6, and B12) are present in differing but nutritionally large quantities, contributing to metabolic and enzymatic activities (Mala et al., 2024).

Cordycepin (3'-Deoxyadenosine)

Cordycepin is likely the most notable bioactive nucleoside found in *C. militaris*. Its concentration depends on the cultivation conditions and varies significantly. Research indicates that well-cultivated samples can show cordycepin levels over 300 mg per 100 g dry weight, indicating strong biological potential. This compound is linked to anti-inflammatory, immune-boosting, and metabolic regulatory effects, further enhancing its role in functional food development beyond

basic nutrition (Karol et al., 2025). In addition to cordycepin and polysaccharides, *C. militaris* is also rich in compounds like adenosine, ergothioneine, and cordycepic acid, which contribute to its antioxidant and physiological properties. The combination of polysaccharides and cordycepin in *C. militaris* offers synergistic effects, supporting its use in more powerful health formulations (Park, 2025).

Fermented Foods: Role of Edible Microbes

Traditional Indian fermented foods include a wide variety of products due to the activities of helpful microbes. These foods depend on microbes such as lactic acid bacteria (LAB) including *Lactobacillus*, *Leuconostoc* and *Pediococcus* and also yeasts and molds such as *Aspergillus*, *Penicillium*. Microbial activity in products such as curd, dosa and idli batter and fermented beverages such as kanji improves food preservation, flavor and health benefits. (Sathish et al., 2013)

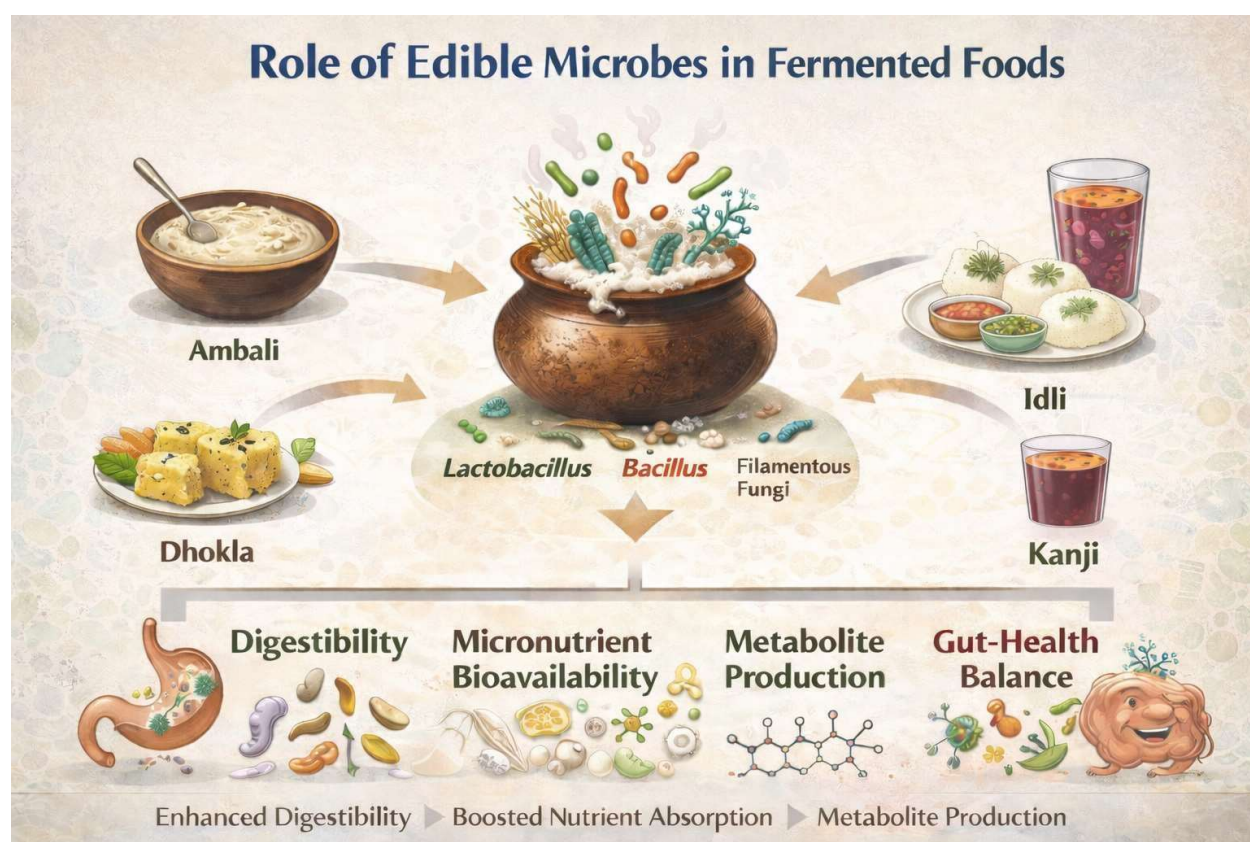


Figure 4: Microbes function in Indian fermented foods and their effects on gut health

Table2:Nutritional Significance and Food Applications of Edible Microbes

Edible microbe	Protein content (%)	Key nutritional components	Application	Food use	Example	Refer ence
<i>Saccharomyces cerevisiae</i>	45–55	Vitamin complex, BCAAs	Baking brewing	Alcoholic beverages & leavened foods	Beer, wine, kefir, bread	Bekat orouet al., 2006
<i>Aspergillus</i> spp.	18–23	Protein, Vitamin C, essential aminoacids	Koji fermentation	Cereal & legume fermentation	Soy sauce, ricevinegar	Machi da et al., 2008
<i>Penicillium</i> spp.	34.8	Vitamin B, ergosterol, aminoacids	Cheese ripening	Dairy fermentation	Camembert, Gorgonzola, Roquefort	Foxet al., 2017
<i>Candida milleri</i> (<i>Kazachstania humilis</i>)	45–60	Vitamin B, fiber, low lipid content	Fermented foods	Cereal & beverage fermentation	Kombucha, sourdough	Deet al., 2016
<i>Fusarium venenatum</i>	40–50	Essential aminoacids, riboflavin, Zn, Se	Single cell protein	Meat analogue production	Mycoprotein	Finnig an et al., 2019
<i>Rhizopus oligosporus</i>	40–50	Fiber, minerals, improved digestibility	Soy fermentation	Legume fermentation	Tempeh	Nout & Kiers 2005
<i>Neurospora</i> spp.	45–55	Protein, carbohydrates, fiber, Fe, Zn	Starter culture	Soy & cereal fermentation	Oncom, miso-like products	Ray & Joshi 2014

<i>Spirulina</i> (<i>Arthrospira</i>)	60–70	Essential amino acids, antioxidants, bioactives	Nutraceutical & mixed fermentation	Functional foods	Probiotic formulations	Becker 2007
<i>Lactobacillus</i> spp.(LAB)	38	Amino acids, vitamin B-complex, minerals	Dairy & vegetable fermentation	Probiotic foods	Yogurt, sauerkraut	Holzappel & Wood, 2014

Indian Knowledge Systems and the Art of Fermentation

Sharma et al. (2011) reported that fermentation has been a significant phenomenon in Indian cuisine and medicinal traditions since ages. Classical Ayurvedic literature states that Sandhana Kalpana is a fermentation process to increase the bioavailability, stability and therapeutic activity of natural products. The examples of the Indigenous knowledge on microbial transformations are the traditional foods such as idli, dosa, kanji and fermented rice wholes (Tamang et al., 2016). The Indian Knowledge Systems is based on the fundamental beliefs of sustainability, minimal processing and complete utilization of natural resources (Patwardhan 2014). The principles are in full agreement with the modern Solid-State Fermentation (SSF) technology, which involves microbial growth without free flowing water, enabling maximum metabolites production. (2020). According to Thomas & Kumar (2019), SSF mimics the natural growth of fungi with low water and energy utilization. Thus, SSF can be viewed as a scientific extension of traditional Indian fermentation wisdom.

Solid-State Fermentation as a Sustainable Approach

Using agro-residues and traditional grains reduces waste and improves bioactive compound production, making the process both economically and environmentally sustainable (Rodhe AV et al., 2025). Indian medicine prioritizes prevention over cure. The immunomodulatory and adaptogenic properties of *C. militaris* suggest its potential role in preventive healthcare, lifestyle disorders, and recovery after illness (Patwardhan et al., 2015). Its relevance gained further attention during the COVID-19 pandemic, reinforcing traditional views on strengthening immunity through natural supplements (Patwardhan et al., 2020). Thomas and Kumar (2019) noted that

SSF mimics natural fungal growth and needs minimal water and energy inputs. This fits with the Indian principle of Prakriti-anukoola, which emphasizes nature-aligned practices.

Cultivation of *Cordyceps militaris* by integrating with Traditional Fermentation

The current review focuses on *Cordyceps militaris*, a medicinal mushroom backed by scientific research. Its benefits closely align with traditional Indian health concepts such as Rasayana, Balya, and Vyadhikshamatva. The mushroom's rich content of cordycepin, polysaccharides, and antioxidants helps boost immunity, rejuvenate the body, and support metabolic balance, which fits well with Ayurveda's preventive healthcare philosophy (Patwardhan et al., 2015). Including *C. militaris* in functional foods, supplements, and integrative medicine can effectively translate traditional knowledge into contemporary health solutions. Sustainable cultivation methods, such as solid-state fermentation using local cereal substrates like brown rice and millets, reflect India's traditional fermentation practices and ecological values. Future research should emphasize standardization, clinical validation, and policy integration within AYUSH and Indian Knowledge System initiatives to strengthen the role of *C. militaris* as a symbol of tradition-driven, sustainable innovation in health and nutrition. The Indian Knowledge System is grounded in Ayurveda, Siddha, and traditional food sciences, where health comes from a balance between diet, metabolism, and the environment. Fermentation (Sandhana Kalpana) is a key idea in classical Ayurvedic texts; it improves the availability, shelf life, and therapeutic effects of natural products (Sharma 2011). Traditional fermented foods like ambali, kanji, idli, and dhokla showcase microbial transformation as a natural tool (Tamang et al., 2016). Solid-state fermentation, while a modern term, conceptually matches these local practices. Growing fungi on cereal substrates connects with the Indian custom of using grains for both nourishment and medicine, emphasizing the importance of SSF as a technology aligned with Indian Knowledge Systems (Vimala et al., 2025).

Indigenous Substrates and IKS-Aligned Sustainability

Brown rice (Shashtika Shali in Ayurveda) is known for being nourishing and digestible. Finger millet (Ragi) is appreciated for its strength-boosting and metabolic advantages. Wheat bran, which has traditionally been used for animal feed and fermentation, represents circular resource use (Sharma, P. V. 2011 & Devi et al., 2014). This suggests that rice, finger millet, and wheat bran are effective substrates for cultivating *C. militaris* through solid-state fermentation. These

substrates are not only cost-effective but are also deeply rooted in Indian agricultural and nutritional traditions (Singh et al., 2012). The notable biological efficiency and cordycepin yield from brown rice (Vimala et al., 2025) align with the Ayurvedic belief that the quality of the substrate influences therapeutic effectiveness (Dravya Guna Siddhanta).

Whole-Biomass Utilization: An IKS Perspective

One significant finding of our work is that cordycepin is found in fruiting bodies, mycelium, and fermented substrates, allowing for complete use of the biomass (Dhar & Rawal 2008; Das et al., 2010; Vimala et al., 2025). This finding reflects the Indian philosophical idea of “Sarvam Upayojyam,” meaning nothing in nature is wasted. Traditional Indian systems promote minimal waste and maximum utility. Our results demonstrate that no part of the cultivation system is unproductive. Such integrated biomass recovery enhances economic viability and environmental sustainability, making the process suitable for rural and decentralized production.

Medicinal Importance of *Cordyceps militaris*:

Cordyceps militaris has long been a part of traditional Chinese medicine. It has been listed as an herbal drug in the Chinese Pharmacopoeia since 1964 and is used to enhance energy, treat fatigue, respiratory issues, and gastrointestinal disorders (Ontawong et al., 2024). Modern studies find that its therapeutic potential arises from various bioactive compounds like polysaccharides, cordycepin (3'-deoxyadenosine), adenosine, sterols, carotenoids, and peptides (Das et al., 2021). Water extracts and polysaccharide fractions of *Cordyceps militaris* improve thymic and splenic function, increase production of IFN- γ , IL-2, IL-12, and TNF- α , and promote antigen presentation by dendritic cells through MHC-I/II pathways. Ethanol extracts boost spleen cell growth and NK cell activity in immunocompromised mice (Thepmalee et al., 2024). An aqueous extract of *Cordyceps militaris* reduces OVA-induced asthma, lowers IgE levels, and inhibits cell degranulation (Ontawong et al., 2024). Cordycepin makes tumor cells more sensitive to NK-92-mediated killing, while polysaccharides induce ROS-mediated cell death and inhibit growth in diverse cancer cell lines (Li et al., 2022). The production of cordycepin is affected by genetics, nutrition, and environmental conditions. It disrupts RNA synthesis and cellular signaling pathways, contributing to its anticancer and immune-modulating properties. Together, these findings show how *Cordyceps militaris* connects ethnopharmacology with modern drug discovery, offering immune-boosting, anti-inflammatory, anticancer, and antiviral agents that are being developed as supplements and functional food ingredients. *Cordyceps militaris* is available globally in common

forms such as capsules and powders. It has been used in Chinese medicine for over 1,500 years to combat fatigue, kidney, and liver problems, and to boost overall vitality. The same fungus that forms the basis of long-standing “energy-boosting” tonics is now available in standardized capsules and powders that provide consistent doses of active compounds. This allows both traditional practitioners and modern consumers to access immune-supporting, anti-fatigue, and preventive health benefits in a practical, regulated way. From the Indian Knowledge System viewpoint, preparations rich in cordycepin can be seen as bioactive enhancers that support metabolic balance and disease resistance. The capability to increase cordycepin production through fermentation optimization supports the traditional belief that processing methods impact medicinal strength.

Conclusion:

Cordyceps militaris stands out as a scientifically validated medicinal mushroom with a bioactive profile that aligns closely with key principles of Indian Knowledge Systems, particularly Rasayana, Balya, and Vyadhikshamatva. Its richness in cordycepin, polysaccharides, adenosine, and essential micronutrients supports its recognized actions as an immune booster, antioxidant, anti-inflammatory agent, and metabolic regulator. These qualities justify its designation as a functional food and supplement relevant to preventive health. Cultivating it through solid-state fermentation using local substrates like brown rice and millets reflects traditional Indian fermentation methods (Sandhana Kalpana). This strategy improves active compound production while ensuring sustainability and ecological soundness. The presence of cordycepin in fruiting bodies, mycelium, and fermented substrate allows for full biomass utilization. Such comprehensive use aligns with Indian Knowledge System principles of minimizing waste and maximizing resource efficiency. Together, these features position *C. militaris* as a prime example that links traditional knowledge with modern biotechnology. Its integration into functional foods and nutraceuticals offers great potential for preventive healthcare. Future efforts should focus on standardization, clinical validation, and regulatory integration under AYUSH frameworks.

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