Journal of Advances in Biology & Biotechnology

Volume 27, Issue 5, Page 73-80, 2024; Article no.JABB.114869
ISSN: 2394-1081

Commercial Culture of *Cordyceps militaris* from Waste Products of Sericulture in India

P. R. Narzary [a*], D. Brahma [a], J. Sarma [b], I. Nath [a], P. L. Dutta [a] and N. R. Bora [a]

[a] *Department of Sericulture, Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam – 641 301, Tamil Nadu, India.*
[b] *ICAR-ATARI, Zone-VI, Guwahati 781 017, Assam, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JABB/2024/v27i5764

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114869

Review Article

Received: 17/01/2024
Accepted: 22/03/2024
Published: 27/03/2024

ABSTRACT

Cordyceps militaris, an entomopathogenic fungi belonging to Ascomycota group are currently in the limelight for its synthesis of Cordycepin, – an anti-cancer component. The host range of *Cordyceps* is extremely broad, with predominance on the orders Lepidoptera, Coleoptera, and Hymenoptera. Although this fungus is extremely rare in nature, its artificial culture is becoming more and more popular on the global market. However, the commercial culture of this fungus has been hampered by the difficulty in getting seeding material and the complex developmental technique. For ages, the silkworm (Order: Lepidoptera) has played a significant economic role in the food and silk industries of Asian nations. The waste product of the silkworm rearing process is the dead silkworm pupae, which are generated in large quantities after stifling of the cocoons for the purpose of producing raw silk. Waste from Sericulture in India has the potential to be used as a promising culture media for the growth of the *Cordyceps*-related sector, helping the silk farmers in their quest for future financial gain and the social advancement of the tribal society.

**Corresponding author: E-mail: pretty.narzry@gmail.com;*

Keywords: Cordyceps; cordycepin; artificial media; silkworm pupa; sericulture waste; Lepidoptera.

1. INTRODUCTION

Classification: A genus of Ascomycete fungi called *Cordyceps* mycelia grows on Lepidoptera larvae. Numerous insects in the orders Coleoptera, Hymenoptera, and Lepidoptera are hosts of the entomopathogen *Cordyceps* fungus [1,2]. *Cordyceps militaris* is one of the *Cordyceps* that is used in herbal medicine and as food. Cordycepin [3,4] and a polysaccharide component [5] are found in *C. militaris*, and these substances are thought to have anti-aging and cancer-treating properties [6,7]. According to Zhou et al. [8], cordycepin has the ability to activate the immune system and has an impact on the gut immune system in addition to innate and adaptive immunity. It is produced by *Cordyceps* both in its fruiting body and in its mycelium [9].

For centuries, Far East Asian countries like Korea, Japan, and China have utilised *Cordyceps* mushrooms, also known as "winter-worm summer-grass," as a food ingredient or traditional folk medicine to boost the immune system and restore energy, much like ginseng (*Panax* spp.). Only a few numbers are gathered for their therapeutic qualities, though. *OphioCordyceps sinensis* (previously *Cordyceps sinensis*), *C. militaris, C. ophioglossoides, C. sobolifera, C. liangshanensis,* and *C. cicadicola* are the species known as pharmaceutical *Cordyceps* mushrooms [10]. *OphioCordyceps sinensis* and *C. militaris* are generally the two species of *Cordyceps* mushrooms that are highly esteemed and used in traditional Asian medical treatment. While *C. militaris* is a global fungus that forms fruiting bodies on unconverted rice grain, *O. sinensis* is rather rare and difficult to cultivate in culture, despite being well-known and costly fungus [11].

Uses: *Cordyceps* has been used to treat a variety of illnesses, such as respiratory and pulmonary disorders, hyperlipidemia and hyposexuality, as well as liver, kidney, and cardiovascular disorders [12]. Additionally, immunological diseases and cancer are treated with it [13]. Cordycepin (3'-deoxyadenosine) and its derivatives, ergosterol, polysaccharides, a glycoprotein, and peptides containing α-aminoisobutyric acid are among the chemical components isolated from *Cordyceps* mycelia [1]. Important bioactive components such cordycepin, adenosine, and N6 - (2-hydroxyethyl) adenosine are also detected to be present.

Asia's most well-known traditional edible and medicinal mushroom is *Cordyceps militaris*. Its fruiting body resists influenza viruses [14], induces apoptosis in cancer cells [15], and has anti-tumor properties [16]. It also protects the liver and kidney. Techniques for producing *C. militaris* fruiting bodies on a large scale for commercial use are progressively being developed using artificial medium like rice [17] or insect source like silkworm pupae of the species *Bombyx mori* [18]. Nevertheless, *C. militaris* has a low yield in industrial settings because the regulation of fruiting body growth is a poorly understood process [19]. In light of this, it has become popular to study how the growth of fruiting bodies is regulated in *C. militaris*.

Active compounds: About 400 species of *Cordyceps* are present worldwide and are abundant and dominating in wet temperate and tropical woods [20]. With only a few observations on pupae and adults, *Cordyceps* primarily targets insect larvae. The fungus infiltrates the host tissue, gradually replacing it with its mycelium. The key active components that have been uncovered include nucleosides, polysaccharides, sterols, cordycepin, and cordycepic acid. In a variety of solvents, more than 20 pharmacologically bioactive chemicals have been identified, extracted, and applied to a range of medical conditions. In addition to their many medicinal uses in immune modulation, anti-oxidants, anti-tumor, anti-cancer, anti-metastatic, anti-inflammatory, anti-oxidative, antibiotics, hepatoprotective, nephroprotective, hypoglycemic, and hypocholesterolemic effects in humans, *Cordyceps* are also known to lengthen life and reduce fatigue [21].

Cordycepin: The primary active ingredient, cordycepin, was initially isolated from *Cordyceps militaris* [22,23,24,25]. It was later discovered to be present in *Cordyceps sinensis* and *Cordyceps kyushuensis* [26,27]. As a nucleoside analogue, cordycepin is a nucleic acid antibiotic that prevents cell cancer and helps normalise cancer cells by being a component of genetic material. Moreover, cordycepin's anti-cancer action can be enhanced by its incorporation into RNA molecules, which results in the early halting of RNA synthesis [28]. The anti-inflammatory impact of cordycepin on the generation of inflammatory mediators in lipopolysaccharide (LPS)-stimulated murine BV2 microglia was demonstrated by Jeong et al. (2010). The inhibition of the NF-κB, Akt, and MAPK signalling pathways is linked to its impact. According to Lee et al. [29], cordycepin exhibited dose-dependent anti-proliferative and apoptotic effects on cancer cell lines in vitro.

In addition to having strong antiviral efficacy against a variety of human viruses, cordycepin from medicinal fungi (*Cordyceps* spp.) and its nucleoside analogues that target viral RNA dependent RNA polymerase and human RNase L also have immunomodulatory and anti-inflammatory properties. The combined antiviral and anti-inflammatory qualities of cordycepin and its analogues suggest that they may be innovative treatments for the treatment of systemic COVID-19 infection [30].

Culture of *C. militaris* on dead silkworm larvae and pupae: It is discovered that the activity of cordycepin isolated from various *Cordyceps* mycelia sources varies greatly, and controlling the natural sources of *Cordyceps* mycelia is challenging. For this reason, the quality of *Cordyceps* mycelia cultivated on artificial diets ought to be more constant. The dead pupa and larvae of the silkworm, *B. mori* have been used in numerous researches as a growing substrate for a variety of fungi, such as *Cordyceps militaris*, *Isaria tenuipes*, and *Isaria farinose*, which produce *Cordyceps* mycelia. They were introduced as hosts, which are thought of as artificial diet food for the creation of *Cordyceps* mycelia with more uniform quality, in order to boost the value of dead silkworms and pupae. The dead pupa and larva of *B. mori* silkworms were also studied for their proximate composition as growth media.

2. UTILIZATION OF TASAR SILKWORM (*ANTHERAEA MYLITTA* DRURY) WASTE FOR THE CULTURE OF *CORDYCEPS*

In 2020, Jena and Baig carried up an experiment to test the suitability of Tasar silkworm (*Antheraea mylitta* Drury) excrement as a *Cordyceps* fruiting body in comparison to Muga (*Antheraea assamensis* Helfer) and Eri (*Samia ricini* Donovan) pupae. On silk waste, *Cordyceps militaris* DMRO 1163 was grown. It was discovered that 20–22 ºC and 80–85% RH were the appropriate temperatures and humidity. Furthermore, out of all the strains examined, rice has the highest biological efficiency percentage. In terms of biological efficiency percentage, rice is followed in descending order by wheat, ragi, barley, oats, and soybeans. Extract from *Cordyceps* has the ability to scavenge free radicals. After *Cordyceps* was subjected to phenolic and flavonoid profiling, the main phenolic components found were Gentistic acid, Coumaric acid, Ferulic acid, Cinnamic acid, and Gallic acid. Similarly, Naringenin, Catechin and Epicatechin were the major flavonoids observed in *Cordyceps* fruiting bodies (CTR&TI, 2022-23).

In the Table 1, it can be seen that the major phenolic components, *viz.*, Gentistic acid, Coumaric acid, Ferulic acid, Cinnamic and Gallic acid, which are the precursor for fruiting body of *Cordyceps*, are present in the highest amount in Tasar refuses. The highest Gentistic acid content 53.29 µg/gm and p- Coumaric acid content 39.84 µg/gm was found in Tasar pupae. Maximum t-Cinnamic acid content 115.18 µg/gm and Ferulic acid content 88.83 µg/gm was found in Tasar egg. Highest Gallic acid content 300.75 µg/gm and o-Coumaric acid content 1576.71 µg/gm was estimated in Tasar adult.

The three main flavonoids found in *Cordyceps* fruiting bodies were epicatechin, catechin, and naringenin. The maximum Epicatechin concentration and Catechin content were assessed in Tasar pupae, while the highest Naringenin level was discovered in Tasar adults. Tasar refuses appear to have the ability to act as a medium for *Cordyceps* fruiting bodies.

2.1 Reports on use of *Cordyceps militaris*

An investigation was conducted to check whether *B. mori* pupal powder was suitable for inducing the mycelial growth of *C. militaris* and its anamorph, *Paecilomyces tenuipes*, in culture media that included yolk and one of five types of Thai rice: plain rice, black rice, brown rice, glutinous rice, and rice bran [31]. For all *C. militaris* strains, the most successful mycelial growth recipe was found to be glutinous rice + pupal powder + yolk.

In an experiment done in 2002, Chen and Ichida developed methods for large-scale production of *Cordyceps militaris* (L.) stromata. *Bombyx mori* L., the silkworm, was infected, and the development of the stroma was studied. The fifth instar larvae and pupae of silkworms raised on a synthetic diet in a sterile indoor environment were injected hypodermically, sprayed, or dipped in *C. militaris*. Each of the three techniques had a different infection rate, with the hypodermic injection having the highest rate. Additionally, compared to the larvae, the pupae had a greater infection rate. The silkworm pupae had improved stromata development and growth. Several locations on the pupal body were injected with a conidial suspension. However, there was no difference in infection rates between the sites. The injection site had no effect on the stromata's development or growth.

In an experiment, *Cordyceps militaris* was produced using the pupae of the silkworm *Bombyx mori* as the infecting host [32]. Against silkworm pupae, three different inoculation techniques - *viz.,* injection, spray, and immersion—were tested, all of them showing 100% infectivity. The injection method was the most successful one in shortening the time needed for the endosclerotium and fruiting body production to be fully formed. These findings suggest that the pupae of silkworms are highly efficient host insects for the development of *C. militaris*.

Table 1. Phenoloic and flavonoid profiling of *Cordyceps*

Phenolic components (µg/gm)	Control	Eri pupae	Muga Pupae	Tasar Adult	Tasar Egg	Tasar Pupae
Benzoic acid	31.06	36.30	28.60	43.47	24.41	63.08
p-hydroxy benzoic acid	0.25	0.35	0.48	1.03	0.47	0.95
Salicylic acid	0.19	0.23	0.33	2.66	0.16	0.45
3-Hydroxy benzoic acid	0.29	0.36	0.45	0.84	0.46	0.92
t-Cinnamic acid	4.62	3.27	8.63	70.88	115.18	24.44
2,4-dihydroxybenzoic acid	17.17	13.78	6.86	6.62	4.41	31.08
Gentistic acid	31.34	31.17	9.38	21.04	14.52	53.29
Protocatechuic acid	26.37	6.45	4.24	9.31	7.26	65.61
p- Coumaric acid	14.48	2.68	2.98	34.63	9.97	39.84
o-Coumaric acid	0.70	0.44	0.82	1576.71	2.22	13.42
Vanillic acid	2.41	4.44	3.71	3.16	1.95	5.17
Gallic acid	37.10	32.72	45.58	300.75	21.77	15.43
Caffeic acid	10.10	10.07	5.70	12.18	8.35	7.02
Ferulic acid	16.19	85.56	63.34	73.59	88.83	40.87
Syringic acid	0.89	1.11	0.66	0.47	0.31	1.08
Sinapic acid	0.31	0.35	0.18	0.34	0.32	0.58
Ellagic acid	0.30	0.03	0.05	0.10	0.03	0.10
Chlorogenic acid	0.01	0.00	0.00	0.00	0.00	0.00

Source: CTR&TI, 2022-23

Flavonoids (µg/gm)	Control	Eri pupae	Muga Pupae	Tasar Adult	Tasar Egg	Tasar Pupae
Umbelliferone	0.01	0.01	0.01	0.01	0.00	0.01
Apigenin	0.47	0.69	0.36	0.43	0.03	0.69
Galangin	0.01	0.01	0.00	0.01	0.00	0.01
Naringenin	5.16	6.87	6.88	15.53	13.20	12.89
Kaemperol	0.02	0.02	0.02	0.02	0.01	0.01
Luteolin	0.72	0.96	0.74	1.12	0.68	1.54
Fisetin	0.00	0.00	0.00	0.00	0.00	0.00
Eriodictyol	0.00	0.00	0.00	0.00	0.00	0.00
Catechin	1.83	4.70	5.16	5.10	3.49	12.12
Epicatechin	1.03	1.82	1.19	1.28	0.48	2.65
Hesperetin	0.12	0.13	0.09	0.14	0.09	0.16
Quercetin	1.27	0.60	0.55	1.57	0.67	1.23
Epigallocatechin	0.40	1.07	0.43	0.74	0.23	0.61
Myricetin	0.83	0.91	1.11	0.74	1.58	3.44
Rutin	0.38	0.84	0.67	0.32	0.30	1.33

Source: CTR&TI, 2022-23

3. *CORDYCEPS MILITARIS* FRUITING BODY FORMATION ON SILKWORM

Upon mounting, pupae between the ages of nine and eleven days exhibited the highest rate of infection with an injection volume of 100 µL. When injected with a hyphal suspension concentration exceeding 2×10^5 colony-forming units (cfu), silkworm pupae demonstrated an infection incidence of over 96%. Furthermore, *C. militaris* fruit bodies were generated and induced at light intensities ranging from 500 to 1,000 lux [33].

4. CULTURE OF *CORDYCEPS MILITARIS* ON SYNTHETIC SUBSTRATES UNDER ARTIFICIAL CONDITIONS

At the moment, *Cordyceps militaris* is extremely rare due to overexploitation in the wild. Thus, it is necessary and has been effectively explored to cultivate *Cordyceps militaris* on artificial substrates under artificial conditions. Huy and Phuong [34] discovered that the *Cordyceps militaris* fungus grew quickly (covering the medium's surface after six days of culture) and produced a large number of fruiting bodies (an average of 60 fruitbodies per jar) when grown on a synthetic medium made of 35g brown rice per box, 60ml mineral solution, and 5% dry pupae powder.

5. CHITINASE –A KEY FACTOR IN THE FRUITING BODY DEVELOPMENT OF *CORDYCEPS MILITARIS*

Chitin concentration ranges from 2.6% to 4.2% in *Bombyx mori* L. pupae [35]. During the growth of *C. militaris* fruiting bodies, there was a considerable rise in both the transcription level and the enzyme activity of chitinase. Upon knocking down of the Chi1 and Chi4 genes (chitinases genes) by RNA interference, the primordium's ability to differentiate was hindered, resulting in a notable 50% reduction in fruiting bodies as compared to the wild-type (WT) strain. In strains with silenced Chi1 and Chi4, chitin contents were far higher and cellwalls were thick. The length of the single mature fruiting body in these strains was reduced by 27% and 38%, respectively against the control [36]. On the other hand, strains that were silenced for Chi1 and Chi4 had far higher chitin contents and thicker cell walls. The findings of this investigation shed fresh light on the biological roles of chitinase and the role that *Bombyx mori* pupae plays in the development of *C. militaris*' fruiting bodies [37,38].

6. EFFORTS OF THE CENTRAL SILK BOARD, MINISTRY OF TEXTILES, GOVT. OF INDIA IN POPULARIZATION OF THE CONCEPT

A project with Project ID: BPC 04005SI entitled “Tasar waste to wealth by *Cordyceps*” (March 2020- Feb 2023) with PI: K. Jena, Scientist- D, Central Tasar Research and Training Institute, (CTR&TI), Ranchi was launched with an aim to utilize the Tasar waste in the generation of additional revenue in the sector. Dr. P.K. Mishra Retd. Director (Tech), Central Silk Board, Bengaluru suggested for commercialization of the *Cordyceps*, as patent has already been filed. The Research Advisory Committee (RAC) of suggested Principal Investigator (PI) to submit the final report in RMIS10 during the 52nd meeting of Research Advisory Committee (RAC) of CTR&TI held on 20th - 21st June, 2023 at CTR&TI, Ranchi. Also, a patent *viz*., ‘Process to Mass Produce *Cordyceps militaris* on Vanya Silkworm Refuses’ (NRDC/IPR/PC/22075/2022) was filed during the year 2020-23 (CTR&TI, Annual Report, 2022-23).

Challenges:

1. Since silkworms are live creatures, using them to cultivate *Cordyceps militaris* presents moral dilemmas pertaining to the handling of animals. Given that silkworms are essentially being used as hosts for the growing of another creature, some people may view the use of silkworms for this reason as unethical.
2. Several parties, including distributors, silkworm farmers, and Cordyceps growers, must work together to manage the supply chain for the production of silkworm pupae and *Cordyceps militaris*. It might be logistically difficult to deliver healthy silkworm pupae on schedule to *Cordycep*s farms and to meet quality standards all along the way.
3. Regulations and limitations may need to be addressed, depending on the location and scope of the growing of *Cordyceps militaris* and silkworm pupae. Adherence to regulations pertaining to food safety, animal welfare, and the environment may augment operational intricacy and escalate expenses.

4. Consumer perception of goods made from *Cordyceps militaris* and silkworm pupae can affect demand in the market.

Overall, the exploitation of silkworm pupae in the cultivation of *Cordyceps militaris* presents various challenges that need to be carefully considered and addressed to ensure ethical, sustainable and commercially viable production practices [39,40].

Future Prospects:

1. Advances in biotechnology, including genetic engineering and tissue culture techniques, may lead to improvements in the efficiency and productivity of *Cordyceps militaris* cultivation using silkworm pupae as artificial media.
2. Future developments in *Cordyceps militaris* cultivation may focus on reducing resource consumption, minimizing waste generation, and optimizing energy efficiency. This could involve innovations in recycling and reuse of silkworm pupae waste, as well as exploring alternative substrates for cultivation.
3. The integration of *Cordyceps militaris* cultivation with other agricultural or industrial processes could create synergies and promote circular economy principles. For example, silkworm pupae waste from the silk industry or agricultural residues could be utilized as feedstock for *Cordyceps militaris* cultivation, thereby reducing waste and creating value-added products.

7. CONCLUSION

The main wastes and byproducts created during the rearing process are the dead and ill silkworm larvae during rearing and the dead pupae following stifling of cocoons. Through numerous repurposing of by-products that can also boost a farm's economy, the efficient use of these goods is crucial to establishing sericulture as a potential career option in farmers' minds. In an effort to increase the sustainability of sericulture domestically and internationally, this paper attempts to highlight the waste (dead pupae and larvae) generation in sericulture (both mulberry and non-mulberry) and their collection, consolidation, and reutilization in the agriculture and pharmaceutical industry as a potential media for cultivation of *Cordyceps militaris* fungi through the most recent research findings.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Aramwit P, Bang N, Ratanavaraporn J, Nakpheng T, Srichana T. An anti-cancer cordycepin produced by *Cordyceps militaris* growing on the dead larva of Bombyx mori silkworm. Journal of Agricultural Science. 2014;6(6):41.
2. Hywel-Jones NL. *Cordyceps* myrmecophila-like fungi infecting ants in the leaf litter of tropical forest in Thailand. Mycological Research. 1996;100 (5):613-619.
3. Radwan MM, Wilson HR. The structure of cordycepin. Acta Crystallographica Section B: Structural Crystallography and Crystal Chemistry. 1980;36(9):2185-2187.
4. Huang L, Li Q, Chen Y, Wang X, Zhou X. Determination and analysis of cordycepin and adenosine in the products of *Cordyceps* spp. Afr J Microbiol Res. 2009; 3(12):957-961.
5. Yan H, Zhu D, Xu D, Wu J, Bian X. A study on *Cordyceps militaris* polysaccharide purification, composition and activity analysis. African Journal of Biotechnology. 2008;*7*(22).
6. Jin CY, Kim GY, Choi YH. Induction of apoptosis by aqueous extract of *Cordyceps militaris* through activation of caspases and inactivation of Akt in human breast cancer MDA-MB-231 Cells. Journal of Microbiology and Biotechnology. 2008; 18(12):1997-2003.
7. Jeong MH, Lee, CM, Lee SW, Seo SY, Seo MJ, Kang BW, Jo WS. Cordycepin-enriched *Cordyceps militaris* induces immunomodulation and tumor growth delay in mouse-derived breast cancer. Oncology reports. 2013;30(4):1996-2002.
8. Zhou X, Gong Z, Su Y, Lin J, Tang K. *Cordyceps* fungi: natural products, pharmacological functions and developmental products. Journal of Pharmacy and Pharmacology. 2009;61 (3):279-291.
9. Xie CY, Gu ZX, Fan GJ, Gu FR, Han YB, Chen ZG. Production of cordycepin and Mycelia by submerged fermentation of *Cordyceps militaris* in mixture natural

culture. Applied Biochemistry and Biotechnology. 2009;158:483-492.
10. Ying JZ, Mao XL, Ma QM. Zong YC, Wen HA. Icones of medicinal fungi from China. Beijing: Science Press. 1987:1-575.
11. Sung JM, Choi YS, Lee HK, Kim SH, Kim YO, Sung GH. Production of fruiting body using cultures of entomopathogenic fungal species. Kor J Mycol. 1999;27:15-9.
12. Zhu JS, Halpern GM, Jones K. The scientific rediscovery of an ancient Chinese herbal medicine: Cordyceps sinensis: Part I. Journal of Alternative and Complementary Medicine, 1998;4,289-303.
Available:http://dx.doi.org/10.1089/acm.1998.4.3-289
13. Holliday J, Cleaver M. Medicinal value of the caterpillar fungi species of the genus *Cordyceps* (Fr.) Link (Ascomycetes): A review. International Journal of Medicinal Mushrooms. 2008;10: 219-234.
Available:http://dx.doi.org/10.1615/IntJMedMushr.v10.i3.30
14. Lee HH, Park H, Sung GH, Lee K, Lee T, Lee I, Park M, Jung YW, Shin YS, Kang H. Anti-Influenza Effect of *Cordyceps militaris* through Immunomodulation in a Dba/2 Mouse Model. J. Microbiol. 2014;52: 696–701.
DOI: 10.1007/s12275-014-4300-0.
15. Jo E, Jang HJ, Yang KE, Jang MS, Huh YH, Yoo HS, Park JS, Jang IS. Park SJ. *Cordyceps militaris* Induces Apoptosis in Ovarian Cancer Cells through Tnf-Alpha/Tnfr1-Mediated Inhibition of Nf-Kappa B Phosphorylation. BMC Complement. Med.Ther. 2020;20:1.
DOI: 10.1186/s12906-019-2780-5
16. Liu F, Zhu ZY, Sun X, Gao H, Zhang YM. The Preparation of Three Selenium-Containing *Cordyceps militaris* Polysaccharides: Characterization and Anti-Tumor Activities. Int. J. Biol. Macromol. 2017;99:196–204.
DOI: 10.1016/j.ijbiomac.2017.02.064
17. Long H, Qiu X, Cao L, Han R. Discovery of the signal pathways and major bioactive compounds responsible for the anti-hypoxia effect of Chinese *Cordyceps*. Journal of Ethnopharmacology. 2021;277:114215.
18. Song Q, Zhu Z. Using *Cordyceps militaris* Extracellular Polysacharides to Prevent Pb2+-induced liver and kidney toxicity by activating Nrf2 Signals and Modulating Gut Microbiota. Food Funct. 2020;11:9226–9239.
DOI: 10.1039/D0FO01608J
19. Lu Y, Zhi Y, Miyakawa T, Tanokura M. Metabolic profiling of natural and cultured Cordyceps by NMR spectroscopy. Sci. Rep. 2019;9:7735.
DOI: 10.1038/s41598-019-44154-x
20. El-Gharabawy HM. Ecology of Wind Mushrooms. Ecology of Macrofungi: An Overview; 2023.
21. Chaubey R, Singh J, Baig MM, Kumar A. Recent Advancement and the Way Forward for *Cordyceps*. In: Yadav, A., Singh, S., Mishra, S., Gupta, A. (eds) Recent Advancement in White Biotechnology Through Fungi. Fungal Biology. Springer, Cham; 2019.
Available:https://doi.org/10.1007/978-3-030-14846-1_15
22. Mao XB, Eksriwong T, Chauvatcharin S, Zhong JJ. Optimization of carbon source and carbon/nitrogen ratio for cordycepin production by submerged cultivation of medicinal mushroom *Cordyceps militaris*. Process Biochemistry. 2005;40:1667-1672.
Available:http://dx.doi.org/10.1016/j.procbio.2004.06.046
23. Masuda M, Das SK., Fujihara S, Hatashita M, Sakurai A. Production of cordycepin by a repeated batch culture of a *Cordyceps militaris* mutant obtained by proton beam irradiation. Journal of Bioscience and Bioengineering. 2011;111(1):55-60.
24. Das G, Shin HS, Leyva-Gómez G, Prado-Audelo MLD, Cortes H, Singh YD, Patra JK. *Cordyceps* spp.: A review on its immune-stimulatory and other biological potentials. Frontiers in Pharmacology. 2021;11:602364.
25. Jeong MH, Seo MJ, Park J, Kang BW, Kim KS, Lee JY, Jeong YK. Effect of cordycepin purified from *Cordyceps militaris* on Th1 and Th2 cytokines in mouse splenocytes. Journal of microbiology and biotechnology. 2012;22 (8):1161-1164.
26. Li SP, Su ZR, Dong TTX, Tsim KWK. The fruiting body and its caterpillar host of *Cordyceps* sinensis show close resemblance in main constituents and anti-oxidation activity. Phytomedicine. 2002;9 (4):319-324.
27. Ling JY, Zhang GY, Lin JQ, Cui ZJ, Zhang CK. Supercritical fluid extraction of cordycepin and adenosine from *Cordyceps* kyushuensis and purification by high-

speed counter-current chromatography. Separation and Purification Technology. 2009;66(3):625-629.

28. Paterson RRM. *Cordyceps*–a traditional Chinese medicine and another fungal therapeutic biofactory?. Phytochemistry. 2008;69(7):1469-1495.
29. Lee JS, Hong EK. Immunostimulating activity of the polysaccharides isolated from *Cordyceps militaris*. International Immunopharmacology. 2011;11(9):1226-1233.
30. Chellapandi P, Saranya S. Cordycepin and its Nucleoside Analogs for the Treatment of Systemic COVID-19 Infection. Coronaviruses, 2022;3(1):3-8.
31. Siripuk S, Chandasekar R. Mycelium production of *Cordyceps militaris* thai strains on thai rice varieties mixed with yolk and pupal powder of Thai silkworm, Bombyx mori. Sericologia. 2016;56(4):266-270, 2016
32. Sung JM, Choi YS, Shrestha B, Park YJ. Cultural characteristics of mycelial growth by *Cordyceps militaris*. Kor J Mycol. 2002; 30:1-5.
33. Hong IP, Kang PD, Kim KY, Nam SH, Lee MY, Choi YS, Kim NS, Kim HK, Lee KG, Humber RA. Fruit Body Formation on Silkworm by *Cordyceps militaris*. Mycobiology. 2010;38:128–132. DOI: 10.4489/MYCO.2010.38.2.128
34. Huy NN, Phuong HA. The culture of *Cordyceps* (*Cordyceps militaris*) on synthetic substrates under artificial conditions. Int. J. Innovation Sci. Res. Rev. 2021;3(11):1999-2002.
35. Battampara P, Sathish TN, Reddy R, Guna V, Nagananda GS, Reddy N, Radhakrishna PG. Properties of chitin and chitosan extracted from silkworm pupae and egg shells. International Journal of Biological Macromolecules. 2020;161: 1296-1304.
36. Zhang ZJ, Yin YY, Cui Y, Zhang YX, Liu BY, Ma YC, Liu GQ. Chitinase Is Involved in the Fruiting Body Development of Medicinal Fungus Cordyceps militaris. Life. 2023;13(3):764.
37. Anonymous. Annual Report, 2022-23, Central Tasar Research and Training Institute (CTR&TI), Ranchi. 2023: 4-7.
38. Chen R, Ichida M. Infection of the silkworm, *Bombyx mori*, with *Cordyceps militaris*. Journal of Insect Biotechnology and Sericology. 2002;71(1):61-63.
39. Jo WS, Choi YJ, Mm HJ, Lee JY, Nam BH, Lee JD, Jeong MH. The anti-inflammatory effects of water extract from *Cordyceps militaris* in murine macrophage. Mycobiology. 2010;38(1):46-51.
40. Lee SM, Park NS, Cho SY, Hwang JS, Jin BR. Production of the wild entomopathogenic fungi, *Cordyceps militaris*, in the silkworm, Bombyx mori. International Journal of Industrial Entomology. 2001;3(1):105-108.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/114869