Caterpillar Fungus in the Himalaya

Current Understanding and Future Possibilities

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Table of contents

Foreword

The Indian Himalayan Region (IHR) is known for richness of wild bio-resources, which are intricately linked with livelihoods of local indigenous communities. A large proportion of rural poor, especially among ethnic groups, depend on these resources as sources of food, nutrition, medicine, and other useful materials. Further, collection and marketing of selected bio-resources has traditionally been a major source of rural income and revenue to the government. Among others, Himalayan medicinal plants, all through the history, have served the people in remote localities as an effective means of curing diseases. In recent times, with an upsurge of global interest on herbal drugs, several Himalayan plants have become globally popular. More recently one particular species, *Ophiocordyceps sinensis* (Caterpillar fungus; locally known as Keera-jari), from higher altitudes of the Himalaya, has attracted special attention with fast increasing market demand.

With its distribution confined to larger part of higher Himalaya, in Bhutan, Tibetan Autonomous Region of China, India and Nepal, this caterpillar fungus has become globally popular as Himalayan Herbal Viagra and resulted in multifold increase in its price within a small period of time. The increased market demand has resulted in a significant increase in collection by scores of collectors thereby posing severe pressure on its natural populations and habitats in sensitive alpine ecosystems.

Reports indicate, availability of the resource has declined, and harvesting has become difficult. This calls for attention with respect to sustainability of its habitats. The emergence of caterpillar fungus as game changer, both in socio-economic and ecological domain, brings issues pertaining to governance of this common's resource on forefront. Effective guidelines and mechanism for harvesting, marketing and trade are mostly lacking. While China has made good progresses in research fields and product development of caterpillar fungus Bhutan, India and Nepal remain way behind.

I am extremely happy to note that a team of researchers at G.B. Pant National Institute of Himalayan Environment (NIHE) has comprehensively analyzed and synthesized available knowledge on this important resource. The synthesis, as presented in this book, will serve diverse groups of stakeholders. More importantly, extensive bibliography appended with this document, will prove a good source material for future researchers. The team of authors deserve appreciation. I hope, readers will enjoy contents of this book and provide their feedback to the Institute.

C.K. Mishra
Secretary Government of India
Ministry of Environment, Forest and Climate Change
6th May 2020

Preface

During last three decades or so, interest on caterpillar fungus (*Ophiocordyceps sinensis*) from the high altitude areas of the Himalaya has grown across the globe. Fast growing global market demand and year by year increasing price at international markets have made this fungus very lucrative to local indigenous communities inhabiting higher Himalayan villages, which has transformed their socio-economic status. Such collection and marketing of this fungus has emerged as an important source of income in parts of Bhutan, China, India and Nepal. However, increasing popularity and growing demand of caterpillar fungus has also become a curse to the unique alpine ecosystems. Hundreds of people camp in high alpine areas for the collection of this fungus every year, and stay there for one-two months (i.e., during May and June). During this prolonged stay, collectors damage the local biodiversity and ecosystem in several ways, including illegal poaching of high altitude animals and harvesting of other medicinal plants. All this affects the pristine alpine habitats severely. While the fungus has been in use for long in Chinese traditional medicine system, it became globally famous with its recognition as Himalayan Herbal Viagra in recent decades. The species is enriched with over 30 bioactive compounds, which are having various pharmacological activities like anti cancer, aphrodisiac, immunomodulatory, anti-inflammatory, antioxidant, etc.

The major occurrence of caterpillar fungus in India has been reported from alpine ranges of Sikkim and Uttarakhand. However, alpine areas of Pithoragarh and Chamoli districts of Uttarakhand are specifically important, where local indigenous communities of high altitude villages are intensively engaged with its collection. Despite such an importance, the research based information on this species is surprisingly meagre from the Indian Himalayan Region. The present effort, therefore, targets to review the available global studies on this fungus to provide more authentic details of its status, contribution in local livelihoods, marketing problems, and future prospects. Review has clearly indicated that conservation of this species to sustain livelihoods in long run is very important. Further, the communities dependent on this resource have become highly vulnerable in the wake of decreasing production of caterpillar fungus due to changing climate and over harvesting. This calls for immediate attention to make appropriate interventions so as to build resilience of vulnerable communities under changing circumstances.

The book contains chapters on collection, grading and market; caterpillar fungus linked socio-economic development; evolving trade and marketing; and ecological consequences of fungus collection. Also, an attempt has been made to touch upon governance issues, and provide a way forward. Extensive bibliography at the end brings all available researches on target species at one place. We sincerely believe the book will be of immense value for the diverse stakeholders, ranging from local communities to researcher, from practitioners to policy people.

Authors
May 2020

1. Introduction

All through the human history, wild bioresources have played a key role in sustenance of a large portion of human population across the world. However, in recent times, issues pertaining to elimination of hunger and ensuring food and health security have necessitated new ways for collection, consumption and trade in wild resources (Negi et al. 2011; SDG 2019). Estimates suggest about 1.6 billion people, including 60 million indigenous ethnic people across the globe depend directly on forest based products for their livelihoods and food security (FAO 2011; Vedeld et al. 2007). Indigenous forest dwelling communities depend on wild resources not only for their livelihoods, but also to generate a substantial amount of income. It is reported, forests contribute 22-28% of household income in developing countries (Angeles et al. 2014), and over 90% of extremely poor people depend on forests for all or part of their livelihoods (OECD, 2009; Pouliotv and Treue 2013). Among various forest products, collection of non-timber forest produce (NTFPs) and medicinal plants from wild habitats form an important activity in the mountains regions, including the Himalaya (Dhar et al. 2000, 2002; Rawat 2006; Negi et al. 2018a).

The Himalaya, which forms one of the Global Biodiversity Hotspot, is well recognized for richness, uniqueness of its biodiversity, and numerous goods and services (Rawal et al 2013). Local and indigenous ethnic communities in the region have rich traditions of use of bioresources for food shelter and medicine. The Himalaya is also diverse in indigenous ethnic communities who inherit rich traditional knowledge on the use of medicinal plants and health practices (Rawat 2006; Negi et al. 2018a). In different parts of the Himalaya people follow different folk systems of medicine in addition to the codified medicine systems like Ayurveda, Amchi, Unani, Sidha, etc. In India, 1178 species of medicinal plants are under trade largely for use in several systems of medicine (Goraya and Ved 2017), many of these have their natural habitats in the high altitude regions of the Himalaya. In general, alone in Indian Himalaya over 1700 plant species have been documented as species of medicinal use; some of these species have very high market value.

Demand of a particular species in trade varies with time following the requirement in the industries. Depending upon the growing demand, a particular species emerges as high value and its natural populations begin to face heavy pressure. One such example, in recent decades, has been reported in the form of collection of *Ophiocordyceps sinensis* (Caterpillar fungus) from the high altitude habitats of the Himalaya including Tibetan plateau. In last three decades collection of high-value, low-volume caterpillar fungus has become an important livelihood activities and source of income in the mountainous parts of Bhutan (Wangchuk et al., 2012), China (Winkler 2008, 2009), India (Kuniyal and Sundriyal 2013; Negi et al. 2014) and Nepal (Shrestha and Bawa 2014a).

1.1 The species-caterpillar association

Ophiocordyceps sinensis (Berk.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora (earlier known as *Cordyceps sinensis*) is a high altitude Himalayan fungus-caterpillar association found in alpine meadows of Bhutan, China, India and Nepal. It belongs to Ophiocordycipitaceae family of Division Ascomycetes, which parasitizes on underground dwelling larva of moths belonging to the family Hepialidae (Lepidoptera), particularly on the species of *Thitarodes* (Wang and Yao 2011; Jang et al. 2016; Zhong et al. 2016). The body of the insect host is used by the fungus as substrate to form the mycelium, which is finally converted into a sclerotium covered by the intact exoskeleton of the insect to withstand the winter (Wang and Yao 2011; Li et al. 2011).

The stroma (fruiting body) of the fungus grows from the sclerotium and emerges above the ground with the advent of snow melt during the following spring and early summer (Pegler et al. 1994). It is collected with the sclerotium as a whole for medicinal use and the traded product is thus a fungus – caterpillar complex (Wang and Yao 2011). This species has been in use in the Traditional Chinese Medicine (TCM) system for over 2000 years (Pegler et al. 1994; Zhang et al. 2009; Li et al. 2011). Its demand has grown substantially during last 2-3 decades and collection from the alpine areas of Bhutan, China, India and Nepal has become a common practice. On account of its ever increasing demand and rapid decline in natural populations, the species has been listed in the endangered category by China (Wang and Yao 2011).

The common name of species varies from place to place. For instance, it is popularly known as *Dong Chong Xia Cao*, in China, *Yartsa Gunbu* in Tibet, *Tockukaso* in Japan, *Yarsagumba* in Nepal, *Keerajadi* in India and the Chinese caterpillar fungus in English (Belwal et al. 2019). Species is confined to high altitude habitats and flourishes well in subalpine and alpine grasslands or meadows as well as on open dwarf scrublands around the potential timberline and along gentle mountain slopes of the Tibetan Plateau and high Himalaya (Baral et al. 2015).

Un-mature stroma of caterpillar fungus: it is harvested at this stage

The species is used for the treatment of many ailments like diarrhea, headache, cough, rheumatism, asthma, pulmonary diseases, cardiovascular disorder, sexual dysfunction, renal and liver disease for centuries in Chinese traditional medicine and Bhutanese indigenous medicine (Jiang and Yao 2002; Chakraborty et al. 2014; Belwal et al. 2019). Zhang et al. (2009) reported over 30 bioactivities of caterpillar fungus including immunomodulatory, antitumor, anticancer, anti-inflammatory and antioxidant. The species has been officially classified as a drug in the Chinese Pharmacopoeia since 1964. More recently, use as an aphrodisiac and a tonic has been highlighted (Zhou et al. 2009). The product named as *Himalayan Herbal Viagra* with its widely popularized aphrodisiac properties has resulted in multifold increase in price of caterpillar fungus within a small period of time. The reports indicate value range from USD $20,000 to USD $40,000 per kg in the international market (Winkler 2008, 2009; Negi et al. 2014).

1.2 Production, collection and trade

In the past 20-25 years, in all countries with its occurrence, caterpillar fungus has become a major source of cash income for rural people. It is collected and sold by thousands of people in Bhutan, China, India and Nepal and plays a significant role in socio-economic development of high altitude rural areas in the Himalaya (Negi et al. 2015; Pant et al., 2017; Shrestha et al. 2017). The collection camps are established by individual families or small groups of closely related individuals comprising men, women and children. They stay in tented temporary camps around the habitat of this species and collection activity generally starts in the spring when the snow melts and lasts for one to two months. The reported production of the caterpillar fungus ranges between 84.2 tons/year to 182.5 tons/year globally, which varies considerably in Tibetan Plateau and other parts of the Himalaya (Belwal et al. 2019). Winkler (2009) reported highest production of the caterpillar fungus from Tibetan plateau (80–175 tons/year) followed by Nepal (1.0–3.2 tons/year), India (1.7–2.8 tons/year) and Bhutan (0.5–1.5 tons/year).

after 1993 World Athletic Championships in Stuttgart, Germany, when Chinese athletes reportedly trained with dietary supplements of caterpillar fungus and turtle blood, set multiple records in distance running (Winkler 2009). The present prices of caterpillar fungus are very high and its regional trade forms an annual multibillion dollar business (Pouliot et al. 2018).

A single unit of caterpillar mushroom if neatly dried and cleaned may fetch upto US$ 50/- in China (Yeh and Lama 2013). The increasing trade and high demand of this fungus is often attributed to its hyped fame as *Himalayan Herbal Viagra* all over the world (Shrestha and Bawa 2013). In the context of Himalaya, the caterpillar fungus is mainly traded directly from Katmandu to China's mega-cities. The local traders make advance payments in cash or in the form of ration to the collectors directly or via agents based on oral agreement to facilitate value creation. Market networks are operated through informal trust-based relationships (buyer and seller negotiating prices) enabling the marketing of this resource from remote areas to urban centers (Pouliot et al. 2018).

1.3 Caterpillar fungus in Indian Himalaya

In India caterpillar mushroom mostly grows in the alpine region of Uttarkhand, Sikkim and Arunachal Pradesh. Of these, Uttarakhand has the highest volume of trade owing to its proximity and accessibility to market in Nepal and Tibetan Autonomous Region (TAR) in China. As such, the use of this species in traditional system in the region is not very strong and evident. Likewise, the scientific information in the form of research is very limited from India. Research gaps on various facets of *O. sinensis* i.e. ecological, life cycle, factors affecting the distribution and abundance of mushroom, sustainable harvesting practices, etc., are evident.

Review of the literature on caterpillar fungus shows that largest volume of research has been conducted in China followed by Taiwan, Japan and least by India. China dominates the research in all aspects of the studies including medicine, biochemistry, immunology and ecology. This book is an attempt to review the current status of research on caterpillar fungus especially in light of Indian scenario to identify the research priorities and opportunities on the species in the Indian Himalayan region. This attempt would be of much use to natural resource managers and researchers in the Himalayan region to find the gaps and opputunities for conducting research work on the caterpillar fungus.

Natural habitats of caterpillar fungus in Nanda Devi National Park

2. The Review

2.1 Literature survey

An exhaustive literature survey on the Web of Science (https://login.webofknowledge.com) and Scopus (https://www.scopus.com) databases was performed to systematically identify peer-reviewed journal and book articles. To filter the literature we used combination of the keywords *Ophiocordyceps sinensis* OR *Cordyceps sinensis* OR caterpillar fungus for article titles search in these databases. Articles were searched for all periods and in all languages irrespective of the number of citations. We excluded the papers published in non-peer reviewed journals and conference proceedings. For each selected publication, the following information was retrieved: author name(s), title, year of publication, journal title, and article language, country of the first author, funding country, funding agency and research discipline. Based on the information available in the keywords we classified the articles into five research discipline i.e. Medicine, Biochemistry, Molecular biology, Ecology and Immunology.

We found a total of 770 peer reviewed papers and articles (759 journal articles and 11 book chapter). Among these, 623 (81%) articles have been published in English language, 140 (18%) in Chinese and 7 (1%) in other languages with translated abstracts in English that is available in Scopus database. Based on the spatial, temporal and thematic information available for the research articles a trend analysis for the research on caterpillar fungus was conducted. Towards developing a comprehensive understanding on caterpillar fungus, available literature was analysed and the outcomes are documented under various aspects such as geographical distribution, habitat association, life cycle, molecular composition, medicinal properties, economic uses, conservation status, policy issues, etc.

2.2 Geographical distribution and habitat association

The caterpillar fungus is a restricted range species confined to Tibetan Plateau and high altitude areas of the Himalaya. Tibet is called as Xizang in Chinese (This is also spelt as Xinjiang, Zheijiang, Zijhiang). Hence, it has to be carefully matched under localities in China (Li et al. 2011; Nakamura et al. 2015; Jang et al. 2016) given in Table 2.1. The species is widely distributed in the alpine and sub-alpine areas of Bhutan, Nepal and Indian states of Arunachal Pradesh, Sikkim and Uttarakhand (Negi et al. 2006, 2014; Kuniyal and Sundriyal 2013).

The general distribution of *O. sinensis* in China is from Central Yunnan Plateau to the Qilian Mountains in Qinghai Province, and from Mount Daloushan in Guizhou Province to the wide areas of the Himalaya has been reported by Zang (1979). The habitat association of this fungus, however, appears limited due to its strict host-specificity on moth insects and limited geographical distribution. The altitudinal range of caterpillar fungus is reported between 2200-5000 m in China, between 4200-5200 m in Bhutan, between 3500-5050 m in Nepal and between 3200-4800 m in India. In India, caterpillar fungus was first reported during late 1990s (Negi et al. 2006). The species has been documented from alpine meadows of some protected area like Kanchendzonga Biosphere Reserve in Sikkim, Dehang-Debang Biosphere Reserve in Arunachal Pradesh, Nanda Devi Biosphere Reserve and Askot Wildlife Sanctuary in Uttarakhand.

Although, the species is reported from three states in Indian Himalaya but most of the product for trade is reported from Uttarakhand along the border lines with Nepal and China (Negi et al. 2014). The information available from the region suggests the reported locations are mostly in Uttarakhand (Table 2.1). However, authentic reports of collection and trade of the product are lacking.

Table 2.1: Reported locations in four countries having distribution range of caterpillar fungus

Country	Reported regions of occurrence	Altitudinal range (m asl)	References
Bhutan	Namna (North WesternBhutan), Bumthang Valley (North Central Bhutan), and Bumdeling Wildlife Sanctuary	4200-5200	Balfour-Browne (1955), Kobayasi (1980), Cannon et al. (2009)
China	Xinjiang, Yunan, Jilin, Shanxi, Shaanxi, Hubei, Zhejiang, Jiangxi, Guizhou, Taiwan, Guangdong, Guangxi, Sichuan and Hainan Province, and Lhasa and Shannan in Tibet	2260-5000	Winkler (2009), Li et al. (2011)
India	Uttarakhand (Darma valley, Choudans valley, Ralamdhura, Panchachuli base, Moist alpine areas of Dharchula and Munsyari Blocks especially, Pindari catchment in Bageshwar district, Niti valley, Nanda Devi Biosphere Reserve, Sutol, Kanol in chamoli district, Sikkim (North aand East Sikkim i.e. Luchung, Khangchendzanga national Park and Wildlife Sanctury, etc. and Arunanchal Pradesh	3200-4800	Negi (2003), Negi et al. (2006, 2009, 2014), Kuniyal and Sundriyal (2013), Sharma (2004), Pradhan (2016)
Nepal	Dolpa, Darchula, Jumla, Bajura, Kalikot, Mugu, Humla, Rukum, Bajhang, Manang, Mustang, Gorkha, Lamjung, Dhading, Rasuwa, Dolakha, Sindhupalchowk, Solukhumbu, Sankhuwasabha, and Taplejung districts	3540-5050	Shrestha and Sung (2005), Adhikari (2008), Devkota (2008, 2010)

Natural habitat of caterpillar fungus in Chipla Kedar, Pithoragarh

Alpine and sub alpine grasslands and shrub lands that receive a minimum of 350 mm average annual precipitation form the typical habitat of caterpillar fungus (Winkler 2009). It grows optimally between altitudinal range of 3000-5000 m asl but upper altitude limit however may reach the snowline areas above 5000 m asl (Jang et al. 2016). Major classes of alpine vegetation where Chinese caterpillar fungus grows in higher abundance are: (i) Mixed Herbaceous Formations (i.e. *Bistorta affinis, B. vivipara, Potentilla* spp., *Ranunculus* spp., *Anemone* spp., *Iris kumaonesis*, *Geranium* spp., *Geum elatum, Allium* spp., *Carum carvi*) dominated by short forbs, (ii) Kobresia sedge meadows and (iii) Edges and gaps of moist alpine scrub. Caterpillar fungus mainly grows in association with herbaceous species of genera like *Saussurea, Ranunculus, Delphinium, Aconitum, Potentilla, Euphorbia, Saxifraga, Primula, Corydalis, Cremathodium, Anemone, Epilobium, Nardostachys, Bistorta, Geum,* etc.

2.3 Caterpillar fungus-*Life cycle*

Caterpillar fungus grows on larvae of host insects, which remain underground for their entire larval stage of three to four years or longer. These larvae feed on roots and caudexes of alpine plants, and usually die once infected by the fungus in the winter (Fig. 2.1). With the rise of outside temperature at the beginning of the spring, the endosclerotium starts germinating and extrudes through the head part of the larva and ultimately protrudes through the soil usually known as stroma (fruiting bodies). Its head contains mature perithecia full of thread-like ascospores. On maturity, the fruiting body of the fungus releases thousands of ascospores in the surrounding environment (primarily soil) and when the freshly hatched Caterpillars come in contact they get infested (Chakraborty et al. 2014; Li et al. 2018). Most likely the infestation occurs at first instar stage, as their hatching period overlaps with the discharge and dispersal of the ascospores (Cannon et al. 2009). The fungus enters the hemocoel of the larvae, fragments into fusiform hyphae, and multiplies. The fungal cells spread inside the body through the circulatory system, and consume all the internal organs of the larva except its exoskeleton. The infected larva moves to 2–5 cm below the surface of the soil and dies with its head facing upward. Subsequently following a period of dormancy, a yeast-like stage develops that spreads throughout the haemocoel and concentrates within the caterpillar's lipid reserves (Cannon et al. 2009). Growth of the fungus therefore results in depletion of host's internal nutrient supply, which causes effective death of Caterpillar due to starvation.

Following the death of Caterpillar, the fungus changes to a mycelial growth phase which spread inside the body through the circulatory system and consume all the internal tissues of the larvae except its exoskeleton (Xing and Guo 2008). A small stroma bud usually emerges from the head of the sclerotium (host larvae) before the soil freezes. It is a dormant stage in the life cycle which can resist unfavorable snow cold conditions. Hyphae of *O. sinensis* can grow at about 2°C with the optimum temperature between 15-18°C temperatures. The hyphal growth is checked when temperature reaches 25°C, and stops below 0°C (Liu 1988; Dong and Yao 2010).

2.4 Biochemical and pharmacological studies

2.4.1 Active Bio compounds

Use of caterpillar fungus is known from ancient time for curing multiple disorders and diseases, including kidney, respiratory, liver, cardiovascular diseases, sexual impotency, diarrhea, headache, cough, rheumatism, asthma, allergic rhinitis, irregular menstruation, etc. (Zhou et al. 1990; Wang and Shiao 2000), and extensively utilized by people in Asian countries. It has been designated as nutraceutical or medicinal mushroom (Smith et al. 2000), owing to its novel biologically active compounds (Table 2.2) and especially those associated with various pharmacological activities (Table 2.3). Some of the known bio-active constituents of caterpillar fungus are discussed below:

(i) Nucleosides

Various nitrogenous compounds, like nucleosides, are known to be the active components in caterpillar fungus. More than ten nucleosides and their related compounds, including adenine, adenosine, inosine, cordycepin, cytidine, cytosine, guanine, uridine, thymidine, uracil, hypoxanthine, and guanosine, have been isolated from caterpillar fungus. Reports indicate almost all of the nucleotides and nucleosides in caterpillar fungus can be transformed reciprocally (Yang et al. 2010). Among the nucleosides, thymine, adenosine and cordycepin are found to be major compounds in a range from 138.5–174.2, 79.6–186.5 and 31.3–91.2 µg/g, respectively (Xie et al. 2010). The other known important compound is cordycepic acid, an isomer of quinic acid, is one of the main active medicinal components in a range of 7-29% which varies across growth stages (Jiang 1987). High content of Adenosine in caterpillar fungus plays a key role in the pharmacological applications and helps in maintaining coronary and cerebral circulation (Toda et al. 1982), prevention of cardiac arrhythmias (Pelleg and Porter 1990), control of blood flow (Berne 1980; Berne 1983) and nerve tissue function such as the inhibition of neurotransmitter release and the modulation of adenylate cyclase activity (Ribeiro 1995).

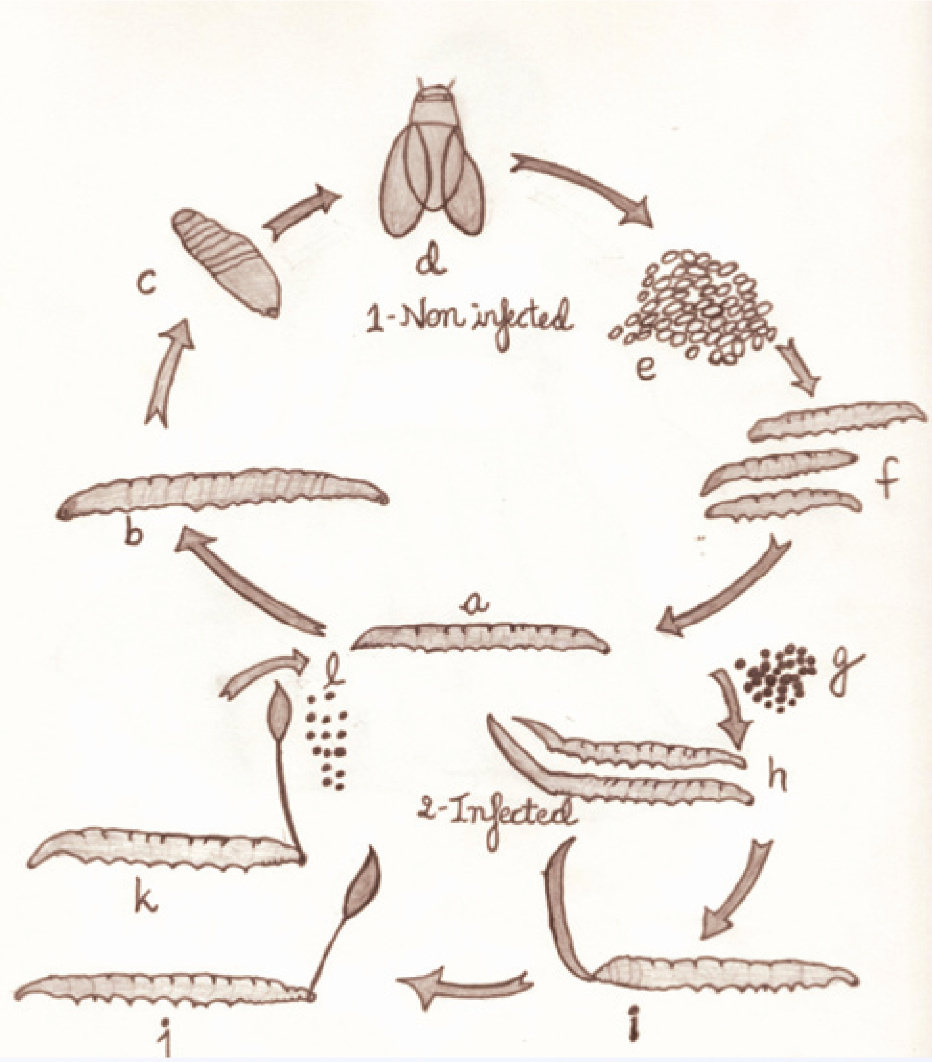

Figure 2.1. Life cycle of caterpillar fungus; 1. Stage - Non Infected (a-Normal larva stage; b- 5 year larva; c-Pupa; d-Insect ; e- egg; f-larva) and 2. stage –Infected (g –spores; h-germination, i- k-mature OS and l-spore spread (Based on Chakraborty et al. 2014)

Engagement of woman in cooking during collection

(ii) Sterols

The available information suggest caterpillar fungus contain 21 type of sterol compounds. Among these, ergosterol is considered as an important source of vitamin D2.This is present in two forms, free and esterified ergosterol having different physiological functions (Yuan et al. 2007).

(iii) Proteins: Amino acid and Polypeptides

A number of crude proteins are present in caterpillar fungus ranging between 29-33% (Hsu et al. 2002). Following hydrolysis of crude proteins, and 18 amino acid have been reported with glutamate, arginine and aspartic acid having highest content (Ji et al. 1999).

(iv) Fatty acids and other organic acids

Caterpillar fungus contains both unsaturated and saturated fatty acids like palmitic acid, lauric acid, myristic acid, linoleic acid, etc. The maximum unsaturated fatty acids (e.g., linoleic acid) are reported in the fruiting body, which comprises of about 70% of the total fatty acids (Hyun 2008).

(v) Polysaccharides

Polysaccharides which form the medicinally active compound are found in large availability between 3–8% of the total weight of caterpillar fungus (Zhou et al. 1990; Li et al. 2002). Cordyceps polysaccharides mainly include extracellular polysaccharide and intracellular polysaccharide. Guan et al. (2010) has determined 10 monosaccharides (rhamnose, ribose, arabinose, xylose, mannose, glucose, galactose, mannitol, fructose and sorbose) from caterpillar fungus.

2.4.2 Pharmacology

Wide ranges of biological activities have been reported from caterpillar fungus which include anti-inflammatory, antioxidant, anti-tumor, anti-metastatic, immunomodulatory etc. As several bio-active compounds can be responsible for a particular pharmacological activity, attempt has been made to summarize pharmacological activities of major effective compounds that have been reported for caterpillar fungus (Table 2.3).

(i) Anti-tumor/anticancer activity

The extract of caterpillar fungus is used in the treatment of cancer or tumor cells (He and Zhang 2006). Nitrogenous compounds (Adenosine, Cordycepin, Cordyceamides A, Cordyceamides B and Cordycedipeptide A), sterols (Ergosterol peroxide; 5α,8α-epidioxy-22-E-ergosa-6,9(11); 22-trien-3β-ol,5α,8α-epidioxy-24(R)-methylcholesta-6,22-dien-3β D-glucopyranoside; Ergosta-4,6,8(14), 22-tetraen-3-one; β-sitosterol) and polysaccharide [Cordysinocan (Glc:Man:Gal = 2.4:2.1] are the major bioactive compounds in O. sinenesis that have anticancer activity (Jia et al. 2005, Zhang et al. 2005, Ji et al. 2009, Matsuda et al. 2009) (Kobori et al., 2007; Zhao et al., 2011; Awad et al., 2009; Cheung et al., 2009).

(ii) Aphrodisiac activities

In TCM caterpillar fungus has been in use for centuries to treat sexual troubles. Human clinical trials have also demonstrated the effectiveness of caterpillar fungus in combating decreased sex drive and virility (Guo, 1986). Therefore owing to this it has also been named as 'Himalayan Herbal Viagra'. Cordycepin (Leu et al., 2011), β-sitosterol (Zhang et al. 2011) and D-mannitol (Ohkuma et al. 1998) are the important chemical constituents which are responsible for aphrodisiac activities of caterpillar fungus.

(iii) Anti-oxidant activity

The extracts of caterpillar fungus possess high antioxidant activities. Water extracts using three different assays, the xanthine oxidase assay, the induction of hemolysis assay and the lipid peroxide assay has been used to analyze antioxidant activity of caterpillar fungus (Nakamura et al. 1999). The results showed that extract possess a strong antioxidant activity. Among the compounds, polysaccharides of caterpillar fungus have showed maximum antioxidant activity (Table 2.3).

(iv) Hepatoprotection

Use of caterpillar fungus has been reported to increase the efficient functioning of liver and protects against various disease like hepatitis A, chronic hepatitis B, chronic hepatitis c, hepatitis fibrosis, etc. (Liu and Shen

2003).The polysaccharides [CS-F10 (Gal:Glc:Man = 43:33:24); CSP-1 (Glc:Man:Gal = 1:0.6:0.75)] of caterpillar fungus are reported for hepatoprotection activity (Kiho et al. 1996; Le et al. 2006).

(v) Hypoglycemia activity

Caterpillar fungus has an antidepressant-like activity which prevents the diabetes induced higher blood glucose concentrations. Evaluation of anti-diabetic effect of caterpillar fungus has revealed that extracts of caterpillar fungus inhibits the diabetes in rats(Shi et al. 2009). Cordycepin and polysaccharides [CS-F10 (Gal:Glc:Man = 43:33:24) and CSP-1 (Glc:Man:Gal = 1:0.6:0.75)] are the main compounds which showed hypoglycemia activity (Kiho et al. 1996; Le et al. 2006).

(vi) Immunomodulatory activity

Caterpillar fungus extracts are known for both immune suppressive and immune stimulating functions. The extracts of caterpillar fungus activate the immune cells, such as lymph proliferation response, natural kill cell activity and phytohaemagglutinin stimulated interleukin-2 and tumor necrosis factor (Kuo et al., 1996). Studies have shown that following bioactive compounds work in immunosuppression [Cordycepin↓, sterols (Ergosta-5-8(14),22-trien-7-one, 3β-ol (H1-A)↓, immunostimulation↑,β-sitosterol↑], and polysaccharides [Cordysinocan (Glc:Man:Gal = 2.4:2.1)↑ and CS-PS (Man:Rhm:Ara:Xyl:Glc:Gal = 38.37:2.51:2.21:5.22:27.44:24.45)↑] (Yang et al. 2003, Zhou et al. 2008, Zhang et al. 2011; Fraile et al. 2012; Cheung et al. 2009).

(vii) Improving physical stamina

Caterpillar fungus is well known for improving the physical stamina among the athletes by increasing the production of ATPs (Dai et al. 2001). Caterpillar fungus extract has been found effective in enhancing aerobic exercise capability, endurance exercise performance and exercise metabolism and alleviating fatigue in healthy humans. The presence of adenosine, cordycepin, cordycepic acid, d-manitol, polysaccharide, vitamins and trace elements can be attributed for such effects.

Table 2.2: Major bioactive compounds reported from caterpillar fungus	
Compounds	**References**
Nitrogenous compounds (27 Nos.)	
Uracil; adenine; guanine; hypoxanthine; adenosine; cordycepin; dideoxyadenosine; N6-(2-hydroxyethyl) adenosine; inosine; guanosine; thymine; , thymidine; uridine; dideoxyuridine; cordyceamides A; cordyceamides B; aurantiamide acetate; cordysinin A; cordysinin B; cordysinin C; cordysinin D; cordysinin E; cordycedipeptide A (3-acetamino-6-isobutyl-2,5-dioxopiperazine); 3-isopropyl-6-isobutyl-2,5- Dioxopiperazine; 3,6-di(4-hydroxy)benzyl-2,5-dioxopiperazine; caffeine; N-(2'-hydroxy-tetracosanoyl)-2-amino-1,3,4-trihydroxy-octadec-8E-ene (tetracosanamide), 2-nicotinic acid	Huang et al. (2003); Li et al. (2003); Jia et al. (2005); Li et al. (2006); Holliday and Cleaver (2008); Jia et al. (2009); Liu et al. (2010); Yang et al. (2011)
Sterols (21 Nos.)	
Ergosterol, ergosteryl-3-O-â-D-glucopyranoside; ergosterol peroxide; 5α,8α-epidioxy-24(R)-methylcholesta-6,22-dien-3α- D-glucopyranoside; (24R)-ergosta-7,22-diene-3α,5α,6α-triol (cerevisterol); ergosta-4,6,8(14); 22-tetraen-3-one, 4,4-dimethyl-5á-ergosta-8,24(28)-dien-3α-ol, 3-O-ferulylcycloartenol; 5α,6α-epoxy-24(R)-methylcholesta-7,22-dien-3α-ol; ergosta-5-8(14),22-trien-7-one; 3â-ol [H1-A], 22,23-dihydroergosteryl-3-O-α-D- glucopyranoside; â-sitosterol; âsitosterol 3-O-acetate;daucosterol; stigmasterol; stigmasterol 3-O-acetate; cholesterol; campesterol; dihydrobrassicasterol [D5-ergosterol]; fungisterol [D7-ergosterol]; (17R)-17-methylincisterol	Kadota et al. (1986); Bok et al. (1999); Lin et al. (1999); Li et al. (2003); Yang et al. (2011)
Proteins: nucleic acids, amino acids and polyamines- (20 Nos.)	
Cyclo-(Gly-Pro); cyclo-(Leu-Pro); cyclo-(Val-Pro); cyclo-(Ala-Leu); cyclo-(Ala-Val); cyclo-(Thr-Leu) 1,3-diamino propane, cadaverine, spermidine, spermine putrescine, flazin, perlolyrine, 1-methylpyrimidine-2,4-dione, 1-acetyl-α-carboline, 1-(5-hydroxymethyl-2-furyl)-β-carboline (perlolyrine), cyclo(L-Pro3-L-Val), cyclo(L-Phe-L-Pro), cyclo(L-Pro-L-Tyr), cordymin, L-tryptophan	Zhang et al. (1991); Holliday and Cleaver (2008), Yang et al. (2011); Qian (2012).
Fatty acids and other organic acids (11 Nos.)	
palmitic acid; lauric acid; myristic acid; pentadecanoic acid; palmitoleic acid; linoleic acid; oleic acid ; stearic acid; docosanoic acid; lignoceric acid; succinic acid	Li et al. (2003); Yang et al. (2009); Yang et al. (2011)
Phenolics and acids (15 Nos.)	
p-hydroxybenzoic acid; vanillic acid; syringicaci; p-methoxybenzoic acid; p-hydroxyphenylacetic acid; 3,4-dihydroxyacetophenone; 4 hydroxyacetophenone;	
protocatechuic acid; 3, p-methoxyphenol; acetovanillone; salicylic acid; 3-hydroxy-2-methyl-4-pyrone; methyl p-hydroxyphenylacetate; 2-deoxy-D-ribono-1,4-lactone; furancarboxylic acid	Yang et al. (2011)
Isoflavones (4 Nos.)	
32 ,42 ,7-trihydroxyisoflavone; glycitein; daidzein orobol;, genistein	Yang et al. (2011)
Polysaccharide and sugar derivatives (12 Nos.)	
CS-F30 [Gal:Glc:Man = 62:28:10]; CS-F10 [Gal:Glc:Man = 43:33:24]; CT-4N [Man:Gal =3:5]; CS-81002 [Man:Gal:Glc = 10.3:3.6:6.1]; SCP-I [D-glucan]; CSP-1 [GlC:Man:Gal = 1:0.6:0.75]; CPS1[Glc:Man:Gal = 2.8:2.9:1]; cordysinocan [Glc:Man:Gal = 2.4:2.1]; PS-A [Glc:Gal:Man = 2:1:1]; CS-PS [Man:Rhm:Ara:Xyl:Glc:Gal=38.37:2.51:2.21:5.22:27.44:24.45]; mannoglucan [Man:Glc = 1:9]; D mannitol	Kihoet al. (1986); Gong et al. (1990); Kiho et al. (1993); Kiho et al. (1999); Li et al. (2003); Wu et al. (2006); Wu et al. (2007); Cheung et al. (2009); Wang et al. (2009); Kim (2010); Zhang et al. (2011); Yang et al. (2011)
Vitamins (5 Nos.)	
B1, B2, B12, E, and K	Zhu et al. (1998a)
Inorganics (19 Nos.)	
K, Na, Ca, Mg, Fe, Cu, Mn, Zn, Pi, Se, Al, Si, Ni, Sr, Ti, Cr, Ga, V, and Z	Zhu et al. (1998a)

Table 2.3: Pharmacological activity of selected bio-active compounds of caterpillar fungus

S.N.	Compounds*	Pharmacological Activities								
		Anti-cancer[A]	Aphrodisiac[B]	Anti-inflammation[C]	Antioxidant[D]	Hepatoprotection[E]	Hypoglycemic[F]	Anti-asthemia[G]	Hypolipidemic[H]	Immunomodulatory[I]
Nitrogenous Compounds										
1.	Adenosine	+			+			+		
2.	Cordycepin	+	+	+	+		+	+		+
3.	Cordyceamides A	+								
4.	Cordyceamides B	+								
5.	Cordycedipeptide A	+								
Sterols										
6.	Ergosterol peroxide	+		+						
7.	5α,8α-epidioxy-22-E-ergosa-6,9(11), 22-trien-3β-ol	+								
8.	Ergosteryl-3-O-β-D-glucopyranoside			+	+					
9.	5α,8α-epidioxy-24(R)-methylcholesta-6,22-dien-3β-Dglucopyranoside	+								
10.	(3β,5α,6β,22E)-ergosta-7,22diene-3,5,6 triol (cerevisterol)							+		
11.	Ergosta-4,6,8(14),22-tetraen-3-one	+								
12.	Ergosta-5-8(14),22-trien-7-one, 3β-ol (H1-A)					+				+
13.	β-sitosterol	+	+							+
14.	Stigmasterol			+						
Proteins										
15.	1-(5-hydroxymethyl-2-furyl)-β-carboline (perlolyrine)			+	+					
16.	Cordymin			+	+					
Isoflavones										
17.	3',4',7-trihydroxyisoflavone				+					
Polysaccharide and sugar derivatives										
18.	CS-F10 (Gal:Glc:Man = 43:33:24)					+	+			
19.	CS-F30 (Gal:Glc:Man = 62:28:10)					+				
20.	CSP-1 (Glc:Man:Gal = 1:0.6:0.75)				+		+			
21.	Cordysinocan (Glc:Man:Gal = 2.4:2.1)	+			+					+
22.	CPS1 (Glc:Man:Gal = 2.8:2.9:1)				+					
23.	PS-A (Glc:Gal:Man = 2:1:1)				+					
24.	CS-PS (Man:Rhm:Ara:Xyl:Glc:Gal = 38.37:2.51:2.21:5.22:27.44: 24.45)				+					+
25.	D-mannitol		+					+		
Phenolic Compounds										
26.	Butylated hydroxytouline				+				+	

*Each compound number is followed by reference and pharmacological activities A-I: **(1)**Nakamura et al. (2006)[A] , Maggirwar et al. (1994)[D], Yue et al. (2008)[G]; **(2)** Matsuda et al. (2009)[A], Holliday and Cleaver (2008)[A], Leu et al. (2011)[B], Kim et al. (2006)[C], Yang et al. (2011)[C], Xiao et al. (2012)[D], Yun et al. , (2003)[F], Yue et al. (2008)[G], Zhou et al. (2008)[I], **(3)** Jia et al. (2005, 2009)[A], **(4)** Jia et al. (2005, 2009)[A], **(5)** Jia et al. (2005)[A]; **(6)** Kobori et al. (2007)[A and C], **(7)** Matsuda et al. (2009)[A], (8) Yang et al. (2011)[C and ,D,] **(9)** Matsuda et al. (2009)[A], Bok et al.(1999)[A], **(10)** Lin et al. (2004)[G], **(11)** Zhao et al. (2011)[A], **(12)** Lin et al. (1999)[E], Yang et al. (2003)[I], **(13)** Awad et al. (2009)[A], Zhang et al. (2011a)[B], Fraile et al. (2012)[I], **(14)** Gabay et al. (2010)[C], **(15)** Yang et al. (2011)[C and D], **(16)** Wang et al. (2012)[C and D], **(17)** Yang et al.(2011)[D], **(18)** Chen et al. (2009)[A], **(19)** Kiho et al. (1996)[E], **(20)** Li et al. (2006b)[D and F], **(21)** Cheung et al. (2009)[A and D], **(22)** Wang et al. (2009)[D], **(23)** Kim (2010)[D], **(24)** Zhang et al. (2011b)[D and I], **(25)** Ohkuma et al. (1998)[B], Ilowite et al. (2008)[G] **(26)** Babu and Wu (2008)[D], Jilal and Devraj (1996)[H]

2.5 The Research & Development Investments

A large number of workers in the field of medicine, entomology, mycology and TCM have undertaken in depth studies on various aspects of caterpillar fungus. Detailed review of literature reveals that highest numbers of papers on this species have been published by Chinese authors. Among others authors from Taiwan, Japan and India are most prominent which have published on caterpillar fungus (Fig. 2.2). However, their contribution in each case remains less than 15% of research publications by China. From India 43 research articles have appeared that is only 8.5% of China. Besides in English language, China has also published 140 research papers in Chinese which forms nearly 30% contribution to the literature published from the country. Further analysis of publications reveal largest volume of research has been conducted in the field of Medicine followed by Biochemistry, Molecular biology, Ecology and Immunology (Fig. 2.3). Along temporal ranges an abrupt increase in the research on caterpillar fungus is evident around the year 2000 with recorded higher growth in publication under Medicine, Biochemistry and Molecular biology (Fig. 2.4). Numbers of ecological researches have shown a gradual rise till 2005 and an upsurge is evident thereafter. Studies related to Immunology have however remained more or less consistent over the years.

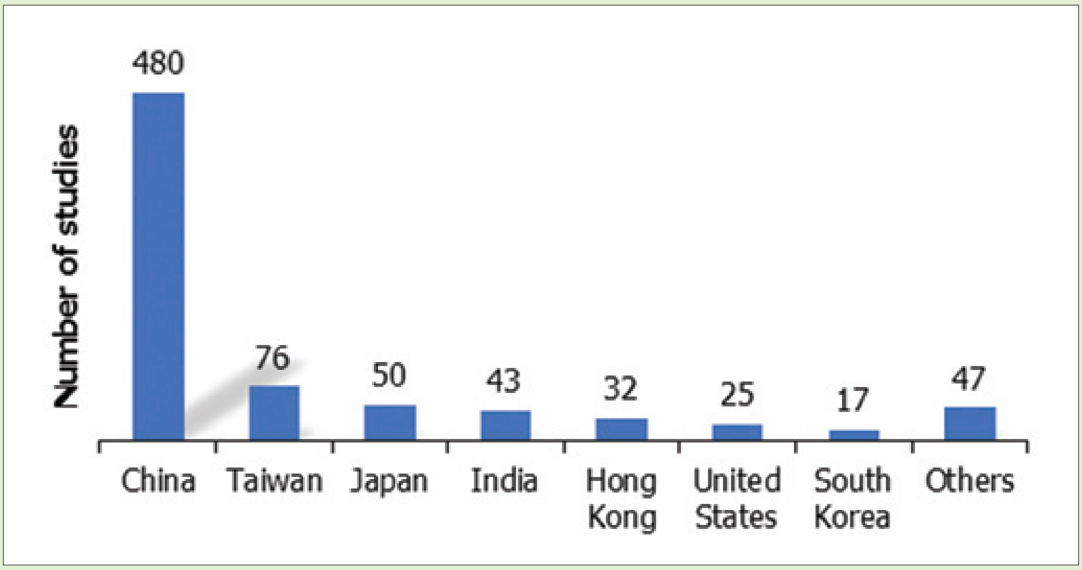

Figure 2.2: Top contributing countries for research publications on caterpillar fungus

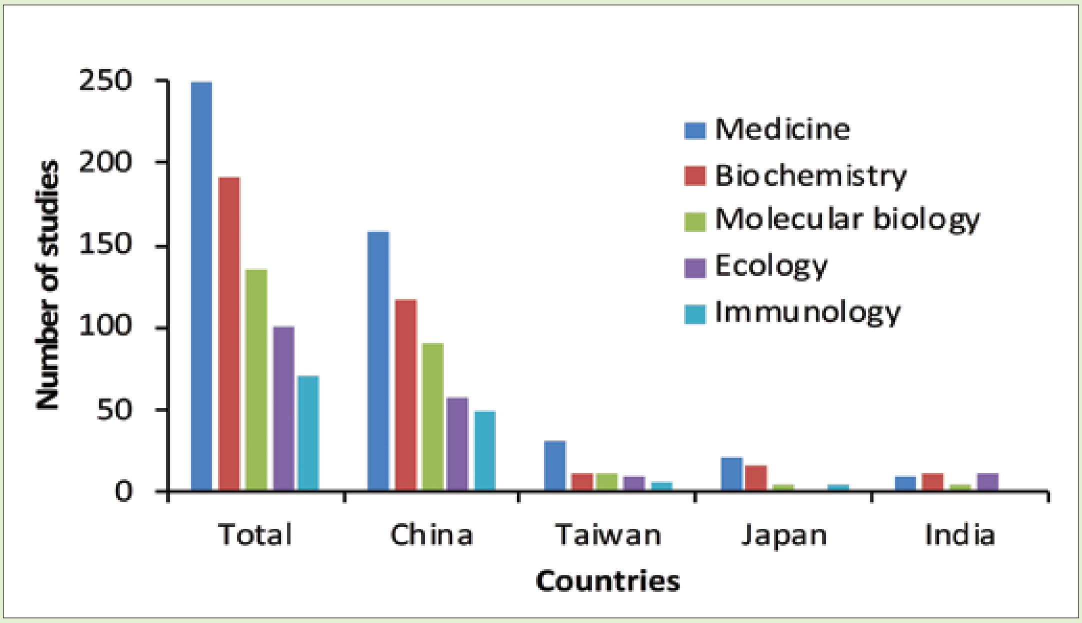

Figure 2.3: Publications across disciplines of research from different countries.

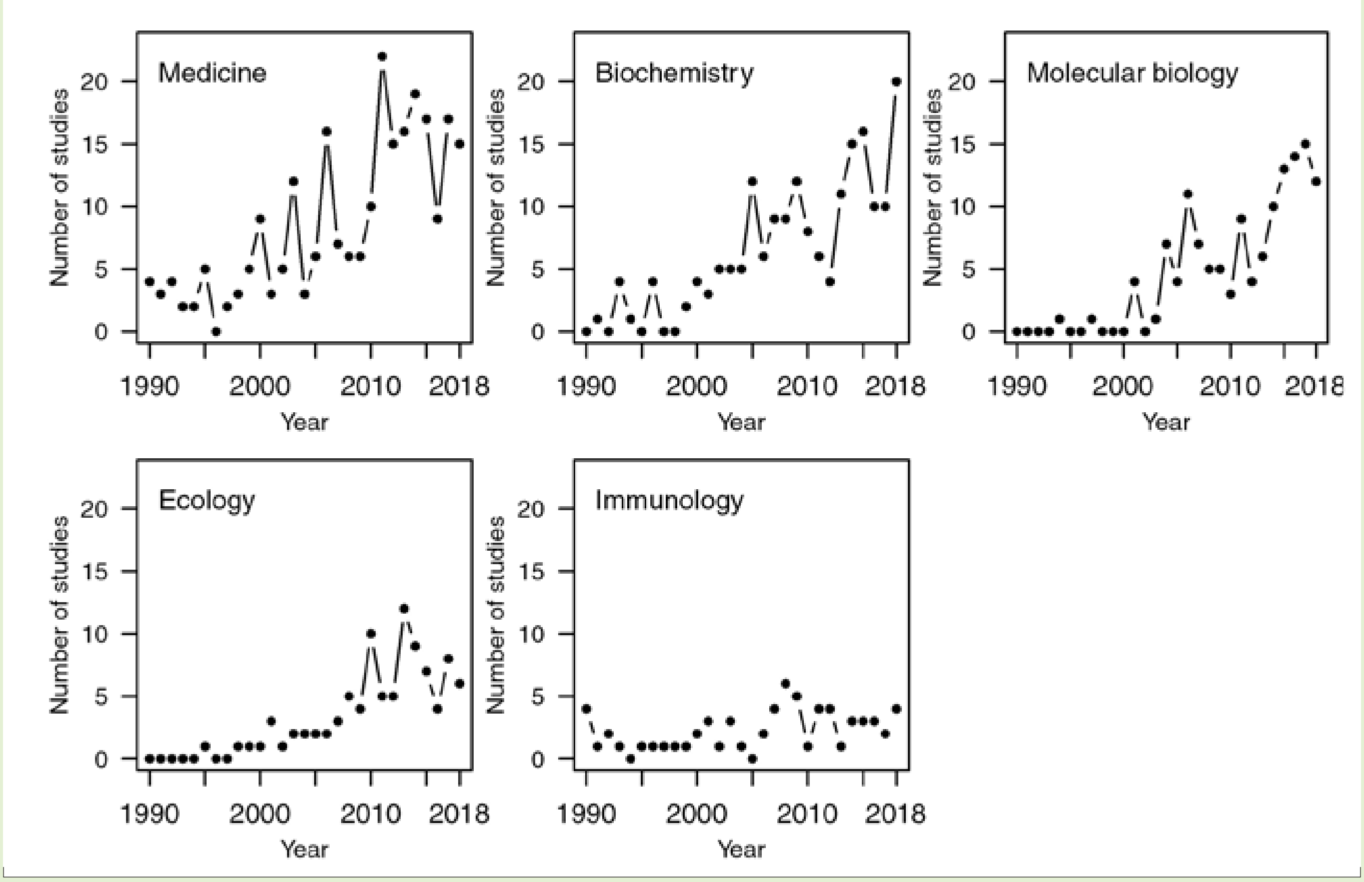

Figure 2.4: Temporal trends in publications on caterpillar fungus across research disciplines

China with 61% share of total studies that have been funded for research and development on caterpillar fungus occupies the top rank. Taiwan and Hong Kong, with 17% and 5% contribution respectively, are other countries which have invested on R&D of caterpillar fungus whereas India and Japan each contribute only 2% to the R&D funding on this species (Fig. 2.5). In terms of research funding across disciplines, Medicine receives highest investment in all the countries; except Hong Kong, which has funded more on Biochemical studies on caterpillar fungus, while other countries have shown very less interest on research in these fields. China had also funded equally for the research on Biochemical and molecular studies in these fields (Fig. 2.6).

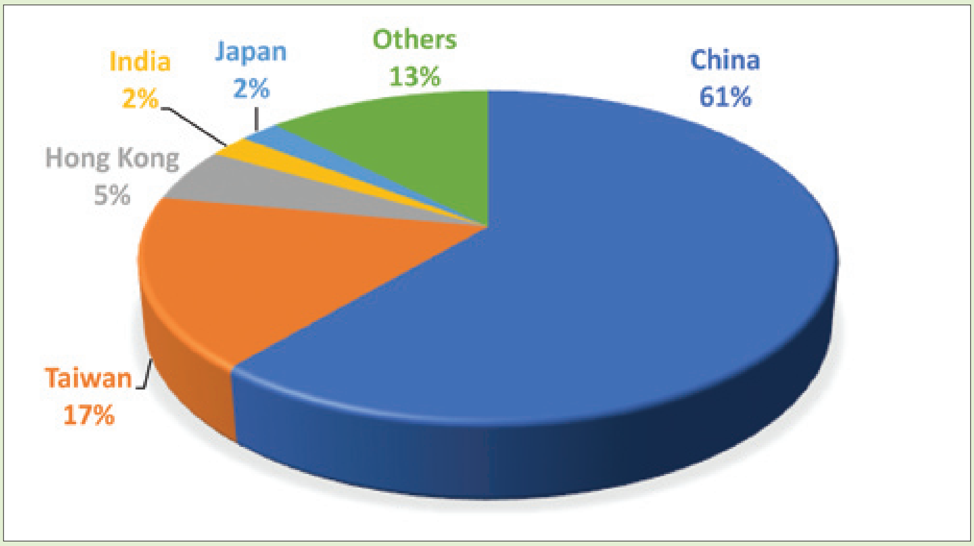

Figure 2.5: Proportional distribution of studies funded by countries for research on Caterpillar fungus

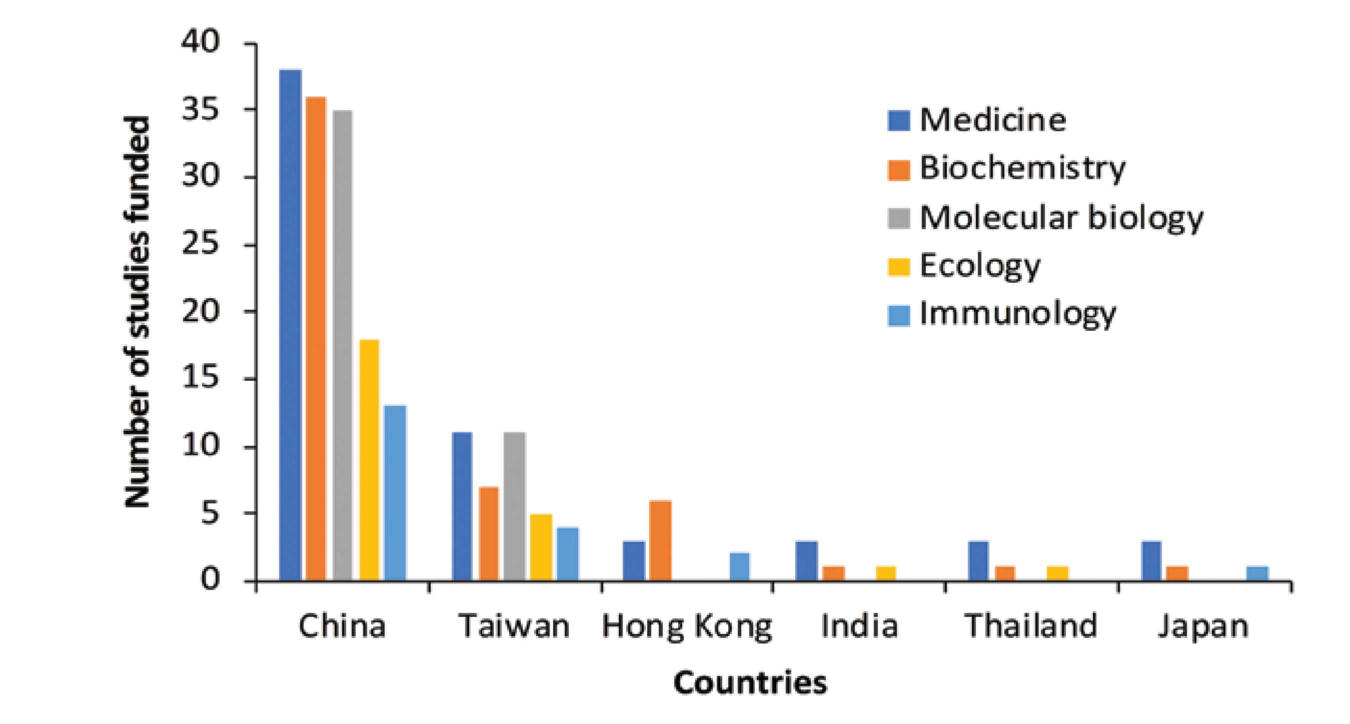

Figure 2.6: Studies funded across disciplines in different countries

All the top funding agencies for research on caterpillar fungus are from China. National Natural Science Foundation of China has funded highest number of 86 studies followed by Chinese Academy of Science and Technology (20 studies) and Chinese Ministry of Science and Technology (16 studies). National Science Council, Taiwan is the top most funding agency outside China which has provided financial support to 13 studies (Fig. 2.7). In terms of journals, maximum (32) researches on caterpillar fungus have appeared in Chinese journal Zhongguozhongyaozazhi (English meaning: China Journal of Chinese Materia Medica). International Journal of Medicinal Mushrooms ranked number two (26), followed by Faseb journal (20; Fig. 2.8).

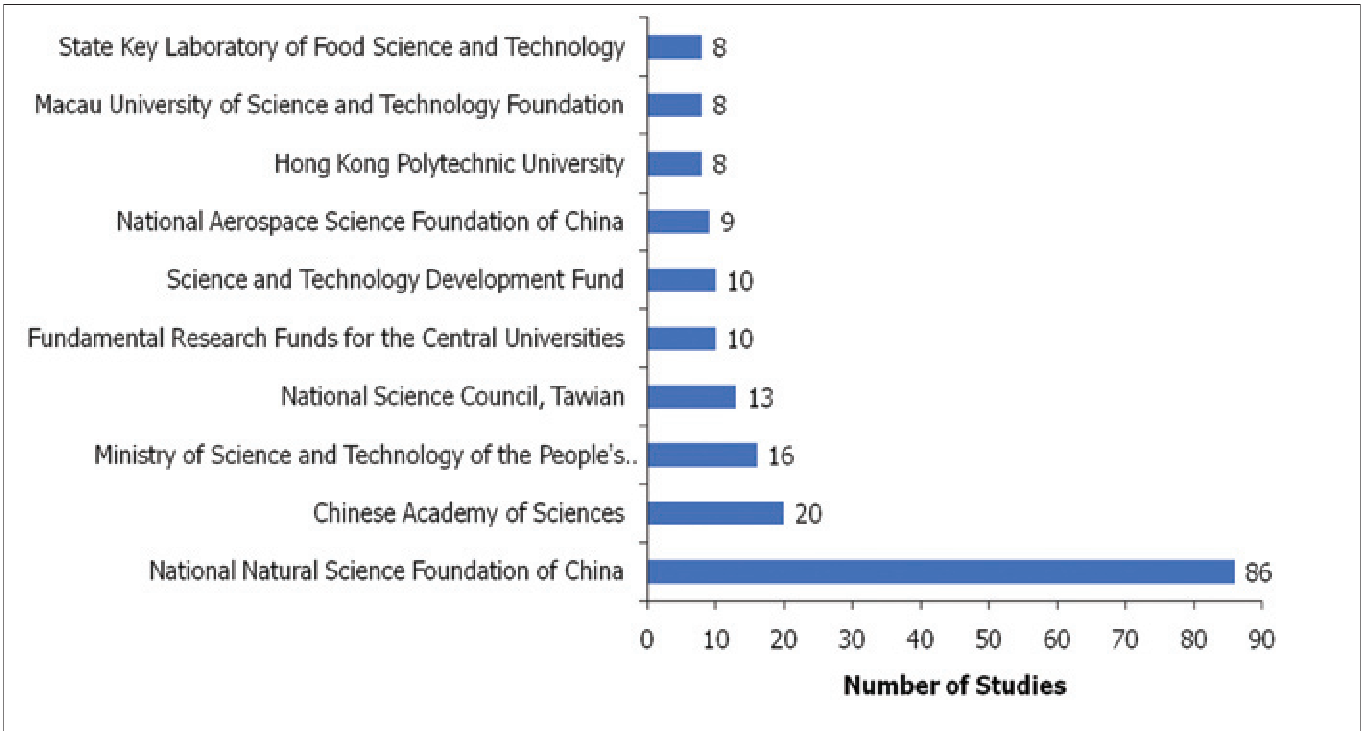

Figure 2.7: Top funding agencies for research on caterpillar fungus

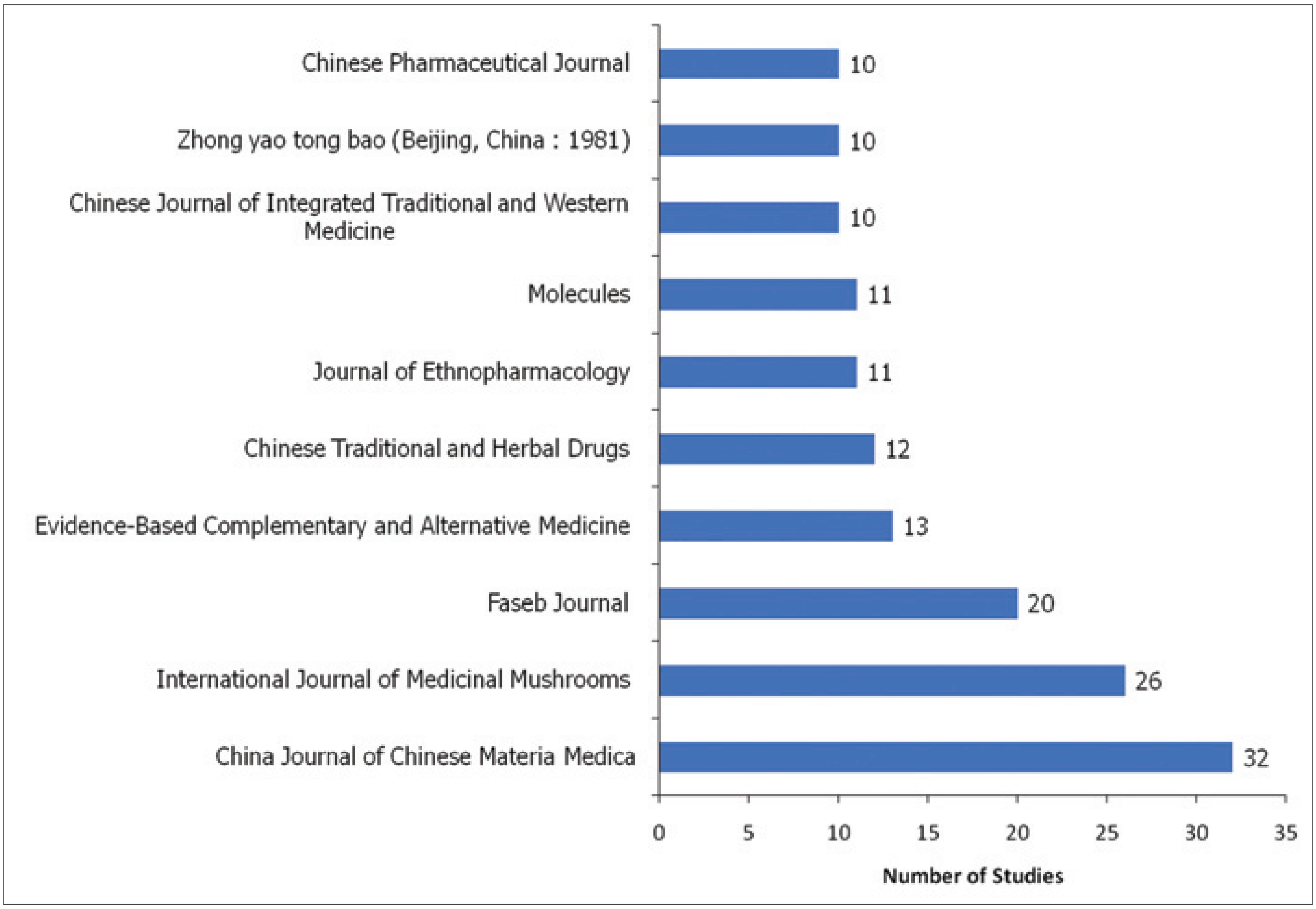

Figure 2.7: Top funding agencies for research on caterpillar fungus

3. Collection, Grading and Market

3.1 Camping and collection

The collection season begins in the early May and goes up to the end of June (Box 3.1). However, it varies considerably depending on two main factors i.e. the local weather and amount of snow in the collection area (Negi et al. 2014). The collection generally begins when the snow melts off and the meadows are sufficiently exposed to sun which allows for the growth of the caterpillar fungus. The end of the season often correlates with the emergence of the monsoon rains. There are broad similarities in collection and trade of the caterpillar fungus across its distribution range (Cannon et al., 2009; Weckerle et al., 2010; Woodhouse et al., 2013; Shrestha and Bawa 2014; Negi et al. 2014).

Experiences from Indian Himalaya especially in Uttarakhand suggest that meadows shared by two or more villages have mutually agreed upon camp locations for each village. Camping by collectors is generally made near the large boulders which provide shelter (Caplins and Halvorson 2017).

Until a few years ago, women were not allowed to enter the alpine meadows (considered sacred), which obviously restricted the number of harvesters. However, with increase in the price of the commodity, now women are actually encouraged to go for collection (Negi et al. 2014). Harvesting of few medicinal plants is also carried out along with the collection of caterpillar fungus.

The collectors remain careful for selecting camping site on flat land having availability of water and fuelwood. Collectors from individual family usually work in two groups i.e. cooking and collection group, otherwise big families cook and tent separately. Collection groups set out in the field early in the morning and collect till mid-day.

Searching involves careful scanning of the ground for the fruiting body of the fungus (Caplins and Halvorson 2017; Negi et al. 2014). Fungus searching is very intense and often done while standing, kneeling or crawling. Collection groups usually return from the meadows to the villages after 20-30 days depending on the availability of food and weather conditions.

Box 3.1 Preparation for collection

Collectors make adequate preparations before they hike to alpine meadows. The major content of preparation include (i) weather assessment (ii) discussions over snow and trail conditions, (iii) identification of pastures for collection, (iv) selection of group members and review of their preparedness, (iv) purchase and packing of food and other essential items including tent, sleeping bags/mattress, blankets and personal apparel. Food supplies vary across groups but most commonly it contains a mix of easy to prepare foods and traditional cuisine. The preparations also draws from experiences shared by others and lessons learnt in previous years.

Fresh collected caterpillar fungus

3.2 Grading of material

The main criteria defining the quality of the produce, in order of preference are: lower water content (completely dried samples), the state of processing (cleaned), and the size (Box 3.2). The degree of dryness of caterpillar fungus is an important factor that controls weight – a price determining factor (Negi et al. 2014). Collectors and traders generally put the material in 4 grades of quality.

(i) Superior quality: the caterpillar is golden yellowish, undamaged, completely dried with stroma a bit shorter than the larva. Traders purchase such material at highest prices even superior individuals are priced individually.

(ii) Good quality: the caterpillar is golden yellowish, undamaged and having good size (completely dried samples are preferred over the fresh ones). Traders purchase these at good prices.

(iii) Broken (damaged): the caterpillar is broken and the fungus fruiting body may be entirely missing; Traders purchase these at lower prices.

(iv) Fused: Improperly dried, infected, and black coloured caterpillars. traders do not usually purchase such material.

Thus, while setting prices, the degree of dryness of caterpillar fungus becomes an important factor that controls the weight. Flexibility of fungus is considered for assessing the moisture content. The ratio of size of the stroma versus the size of the insect larva forms another important criterion for quality determination. Highest value is given to the material where stroma is a bit shorter than the larva (Pouliot et al. 2019; Negi et al. 2014).

Broken (damaged) caterpillar fungus

Fused caterpillar fungus

Superior quality dried caterpillar fungus

Good quality dried caterpillar fungus

Box 3.2 Post collection processing and storing

Once the collection is brought back to the camp or the village in case of bad weather, the material is then processed and stored for sale. The cleaning process involves brushing to remove soil particles and the outer thin blackish skin with a soft toothbrush. Further processing is limited to air-drying at camp site or back in the villages and storing in soft muslin cloth till the product is sold. More aware collectors for example Bhotia families in Uttarakhand, adopt different means to keep the caterpillar fungus in good condition even during bad weather including (i) wrapping every individual in tissue paper, (ii) wrapping all material together in fabrics, and (iii) placing the caterpillar fungusloose in boxes without any wrappings. During sunny days in monsoon many families place stored material in the sun for further drying.

Information based on Caplins and Halvorson (2017; Pouliot et al. 2018)

4. Caterpillar fungus and socio-economic development

4.1 Contribution to rural economy

A number of studies have analyzed the economic importance of caterpillar fungus to rural economy in Bhutan (Cannon et al. 2009), China (Yeh and Lama 2013), India (Kuniyal and Sundriyal 2013; Caplins and Halvorson 2017), and Nepal (Shrestha and Bawa 2013, 2014b; Childs and Choedup 2014). An estimate made by Shrestha and Bawa (2013) suggests of the total global production of caterpillar fungus; the largest producer is China that share 95-96% production. Nepal contributes 1.2-1.8% , India 1.5–2.0%, and Bhutan 0.6–0.8% of total global production. Contribute to rural economy in different parts is as below.

The boom of caterpillar fungus has facilitated integration of rural Tibetan households into regional, national and international economic cycles. The enormous price increase in recent years has turned this fungus into the most important source of cash income in contemporary rural Tibet (Winkler 2008). Per capita income from caterpillar fungus collection at rural and small town level (i.e., 93% of the Tibetan plateau population) accounts between 50-80% of overall rural income. Over 300,000 Chinese individuals in respective local regions depend on collection and sale of this resource (Winkler 2009).

In Nepal, this species makes relatively high contribution to income for the rural poor, and therby playing a significant role in education and food security (Shrestha and Bawa 2013). Income from caterpillar fungus accounted for >65% of the total household cash income, on average, and its contribution was highest in case of poorest households in many villages of Nepal (Shrestha et al., 2014). In Bhutan, caterpillar fungus harvest provides a far greater income compared to their traditional activities for most of the yak herders. One individual earns more than US $2500, which is almost the annual salary of a graduate teacher in Bhutan (Cannon et al. 2009).

In India, it has emerged as an important contributor to the economy in many high altitude villages especially for those who were traditionally engaged in pastoral activities. For instance, Bhotiya, the main high land ethnic group in Uttarakhand state, have been practicing a form of seasonal migration (i.e., transhumance) for decades . They migrate to higher altitude settlements during summer.

A study has reveal approximately 110 villages (2511 harvesters) are engaged and dependent on the collection of caterpillar fungus in the

Pithoragarh district of Uttarakhand (Negi et al. 2014). The collection of caterpillar fungus has also emerged as an important source of income in Sikkim and Arunachal Pradesh. Available information indicates that the collection of caterpillar fungus per family averages between 150 and 300 specimens, which means an earning between Rs. 1-3 lakhs per annum in the Kumaon part of Uttarakhand (Negi et al. 2014). The estimated annual income contribution of caterpillar fungus in Munsyari block of Uttarakhand between 2004 and 2009 was reported around US $972–1485 per collector (Pant and Tewari 2014). A more recent study from Gori valley in Kumaon Himalaya (Laha et al. 2018) has reported that the earnings from caterpillar fungus contribute 60–78% to the annual household income. Ever increasing interest in its collection have resulted in congestion in collection areas and triggered conflicts among collectors (Box 4.1).

4.2 Socio-economic transformation

The fast changing rural economy of the inhabitants engaged in collection of caterpillar fungus in the Himalayan and Tibetan villages has resulted in socio-economic transformation. The quick flow of cash income to rural communities from collection and trade of this fungus has caused far-reaching impact on the social and economic conditions of rural communities (Winkler 2009; Shrestha and Bawa 2013). For example, trade in caterpillar fungus has facilitated the integration of rural Tibetan households even into international economic cycles. The income derived from its trade has led to an empowerment of marginal communities living in extremely harsh climates of high altitude. These communities, otherwise, were used to secure their survival through agro-pastoral activities (Winkler 2009; Pant et al., 2017; Shrestha et al. 2017). Studies from Nepal (Shrestha et al. 2013, 2014), India (Kuniyal and Sundriyal 2013; Negi et al. 2014; Pant et al., 2017) and various parts of Tibet Autonomous Region, China (Winkler 2008, 2009; Woodhouse et al. 2013; He et al. 2018) exhibit that soaring prices of caterpillar fungus have led to remarkable increase in annual cash income of the engaged households. This income thus contributes for better educational opportunities, health care and management of basic daily needs like food, clothes, etc. in areas of harsh climate, like theTibetan Plateau. The availability of cash also allows for the outsourcing of services in construction work and agriculture activities in these areas.

In India, engagement in collection and trade of caterpillar fungus has significantly contributed for uplift of the socio-economic condition in the high altitude villages particularly in Pithoragarh and Chamoli districts of Uttarakhand (Negi et al. 2006, 2014; Kuniyal and Sundriyal 2013). This income has resulted in better living standards, improved houses and education in the remotely located high altitude villages. Increasing incidences of in-migration for the collection of caterpillar fungus have been reported during recent decades. However, this quick flow of money has also brought several negative impacts, which includes declining interest of villagers in agricultural and pastoral activities (Negi et al. 2006, 2014). Such change may have long term implications for food and nutrient security in remote high altitude villages. Also, it will affect the diversity of genetic resources being maintained by villages in remote high altitudes. Available literature reveals the big income earned from trade of this species are often not only a blessing, but also has become a challenge (Shrestha and Bawa, 2014; Pant et al., 2017; Shrestha et al. 2017).

Families in high altitude villages have grown in subsistence based economy through agriculture and animal husbandry system. Therefore, they are not so mature in managing big and quick amounts (Shrestha and Bawa, 2014; Shrestha et al. 2017). This lack of management often results some families running out of funds at some point during the year and thereby forcing them to borrow money. Yet another looming challenge associated with the annually guaranteed access to substantial cash income, generated in a relatively short period, is in the form of disinterest of young people about learning a trade or getting into a profession.

A study by Negi et al (2015) indicates that with the passage of time there has been an increase in income, efforts of collection, and number of collectors of caterpillar fungus, but the yield has remained constant or declined. Furthermore, we may expect significant impact of global warning on overall production of this species, hence the dependent people becoming more vulnerable. For example, Negi et al. (2015) reported a comparatively higher increase in the income than the yield of caterpillar fungus from the Pithoragarh district of Uttarakhand in India (Fig. 4.1).

Box 4.1 Access to Caterpillar fungus- Cause of dispute

With caterpillar fungus collection becoming a major source of livelihood and income to most of the pastoral and other communities in higher altitude region of Bhutan, China, India and Nepal there have been increasing incidences of disputes. Ever increasing interest in its collection have resulted in congestion in collection areas and triggered conflicts among collectors. Historically in Himalayan high altitudes, community disputes were mostly reported over grazing rights. However, in recent times access to caterpillar fungus resources of particular regions have emerged as major cause of conflict. Since the prices of caterpillar fungus have been increasing continously, a large number of people from lowlands and neighboring areas have also become interested in the collection of this species to earn quick money. However, inhabitants of caterpillar fungus growing areas do not want such outsiders to enter in the area hence resulting in severity of conflicts. Incidents have been frequently reported in recent years, with some conflicts resulting in physical assault, accidental death, and even in reported murder. All these have increasingly made Caterpillar fungus collection an intense cause of conflict within and among communities.

Information based on Winkler (2010); Shrestha and Bawa (2014); Negi et al. (2014)

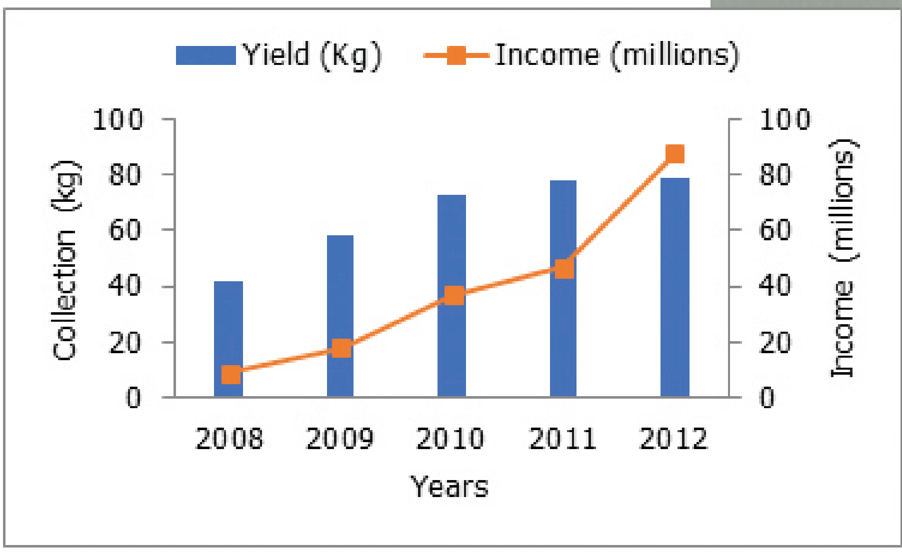

Figure 4.1: Total collections of caterpillar fungus and income generated in Pithoragarh district, Uttarakhand (Based on Negi et al. 2015)

5. Evolving trade and marketing

One can find traces of the trade of caterpillar fungus from 17th century in the Tibetan Plateau, when Tibetan people bartered it for tea and silk with China (Winkler 2008). With time, the trade of this species has grown significantly in China. Harvesting of caterpillar fungus was considered illegal until 2004 in Bhutan; thereafter, restricted harvesting was introduced in an effort to deter poaching and encourage stewardship by villagers (Cannon et al 2009). In Nepal, its trade began around 1987 and was legalized in 2001 (Shrestha and Bawa 2013). In India, caterpillar fungus harvesting began in the early 1990s, and was rapidly popularized during 1995-2000. Negi et al (2006) reported a 1256% increase in the price of caterpillar fungus locally in Kumaon between 1999 and 2004. The global trade is estimated at about US $5-11 billion annually (Shrestha 2012). By weight, the prices of caterpillar fungus are more expensive than gold. The high-quality products cost as much as US $60,000 per kilogram (Lei et al. 2015). Many products based on caterpillar fungus are now sold in the global markets as well as by online shopping websites. A list of products available from online shopping websites is given along with the prices of the products (Table 5.1).

Table 5.1: Commercially available products containing caterpillar fungus as an active ingredient

S. No	Product name	Approximate price ($)	Uses	Manufacturing company
1	Yarsagumba	$28571.43/Kg	Clinical	Aditya Agni Trading Co., India
2	A Grade IC PRO *Cordyceps sinensis*	$12857.14/Kg	Clinical	IC Pro, India
3	Cordyceps Extract	$22.85/g	Clinical	Herbal creative, India
4	*Cordyceps sinensis* Extract (200 g)	$138.34/200 g	Supplement	G & E Nutrition
5	IRISS HERBALS *Cordyceps sinensis* Yarsagumba Capsules	$85.71/60 capsules (500 mg each)	Boosts immunity	Iriss Herbals, India
6	Mystique Hills Organic *Cordyceps sinensis* Powder (Caterpillar Fungus)	$34.28/100 g	Beneficial for the heart, lungs, reproductive organs	Mystique Hills- Organic Living
7	Urban Platter Cordyceps Mushroom Extract Powder	$10/50 g (50g/ 1.76oz)	Boost energy level	Urban Platter
8	*Cordyceps Sinensis* Capsules -SGS and cGMP Certified, 99.6% rDNA Proven -60 Per Bottle	$78.87/350 mg	Boost energy level	Tonicology, LLC
9	Organo Gold Red Tea	$ 33/box	Revitalizing drink	Organo Gold Enterprises Inc., Canada
10	CordyMax CS-4	$ 53.30/120 capsules	Dietary supplement for stamina and vitality	Pharmanex, Inc., USA
11	Le'JOYva Gourmet Arabica Black Instant Healthy Coffee	$ 29.99/pack	Revitalizing drink	Le'JOYva Inc., USA
12	Cordyceps Soap	$ 9.79/unit	Skin nourishment	Full and Fill Bio, Thailand
13	Cordyceps organic mushroom	$ 3/unit	Sexual tonic, lowers blood glucose and cholesterol levels	Full and Fill Bio, Thailand
14	Mountain Fresh Organic Cordyceps Homeopathic Cream	$ 108.92/unit	Helps to brighten and whiten the face	Mountain Fresh, UK
15	YanWo drink with rose bud and Cordyceps extract	$ 60.22/unit	Revitalizing drink, antiaging, smooth skin	QiYun B.V, UK
16	New China Cordyceps *sinensis* whitening cream	$ 17.65/unit	Removes dark spots	Smile, China
17	Cordyceps Mushroom Extract Powder	$ 0.50/gram	Dietary supplement	Real Mushrooms, Canada
18	Cordyceps Capsules	$ 44.96/pack (120 capsules)	Dietary supplement	Host Defense Inc., USA
19	Now Foods Cordyceps	$ 12.34/750 mg	Dietary supplement	Now Foods Inc., USA
20	Mdrive Elite performance	$ 79.99/box (90 capsules)	Dietary supplement	Dream Brands, Inc., USA
21	Kala health Cordyceps	$ 97.95/ box (600 capsules)	Dietary supplement	Kala Health Inc., USA
22	Cordyceps Capsules - 650mg - Cordyceps sinensis - Vegan	$20.679/120 capsules (17.30/100 gm)	Dietary supplement	Fair & Pure

Source: amazon.in, amazon.com, amazon.co.uk, alibaba.com, aliexpress.com, indiamart.com

Value added as well as sustainable use of caterpillar fungus, Temi Tea Estate in South Sikkim, Government of Sikkim has launched a new product 'Sikkim Cordyceps Green Tea' on the occasion of World Entrepreneur's Day on 21st August, 2018. NP Establishing and understanding trade route is one of the most important aspects of the trade and marketing. High price index of caterpillar fungus has remained uncertain and unpredictable among global market as trade of the product involve multiple channels (Fig. 5.1). The payment varies at different levels of trade routes, which starts from the collector households in the field to brokers and their agents who collect the caterpillar fungus at various locations. China, being the major market for the produce, account for the most of trade. The caterpillar fungus is mainly traded directly from Katmandu, Nepal to China's mega-cities particularly Guangzhou (He et al. 2018). In most cases, Chinese regional wholesalers travel to Katmandu to buy the product directly from central wholesalers. A small volume of this valuable fungus is also traded at the traditional border markets, mostly directly to local retailers or transported to Lhasa for sale to tourists. Trade by local traders (intermediaries) who are well familiar with local communities and villagers is the most common practice in all the countries (i.e., Nepal, China, India, Bhutan). These intermediaries usually remain in contact with central wholesalers in Katmandu. The central wholesalers in Katmandu send it in China through Lhasa or Shigatse via Gyilong and Zhangmu (He et al. 2018).

Over the years, the market for caterpillar fungus has evolved considerably. According to the Winkler (2009), the price for average grade caterpillar fungus may go up to US $9000 to US $10000/Kg and for good quality grade it may rise to US $500000 per kg. In Nepal, market price of caterpillar fungus has increased up to 2300% from 2001 to 2011 (Shrestha and Bawa 2013).However, in India the price increased six folds (US $ 3333/kg to US $20,000/kg) between 2008-2012 (Negi et al. 2014). As per the existing information, in 2001, the resource was sold at INR 80,000 (US $ 1677.43) per Kg, while its price went up to INR 1,25,000-1,30,00 per KG in 2002 and INR 400000 to 500000 per Kg in 2012 (Rana 2004; Sharma 2004; Bhandari et al., 2012). Negi et al. (2014) reported that approximately 400-500 Kg of caterpillar fungus trafficked annually to Nepal from Dharchula, Pithoragarh (Uttarakhand) in India. According to Lo et al. (2013), the price in international market has increased from US $ 20,000 to 40,000/Kg. Study by Winkler (2008) and Weckerle et al. (2010), revealed that 40 to 90% of the collectors depend on caterpillar fungus for the cash income. Shestha and Bawa (2014) reported that this is the second largest source of income for collector households in Nepal. Similar trend was reported from Bhutan (Cannon 2009, Wu et al. 2016) and from India (Negi et al. 2015, Caplins and Halvorson 2017). Temporal changes in economic contribution by trade of caterpillar fungus is given in Table 5.2.

Market networks of caterpillar fungus operate through informal trust-based relationships (buyer and seller negotiating prices); enabling the marketing of this resource from remote areas to urban centers (Pouliot et al. 2019). In most areas, local traders provide pre-collection advance payments to the collectors directly or via local agents based on oral agreement to create an environment of confidence.

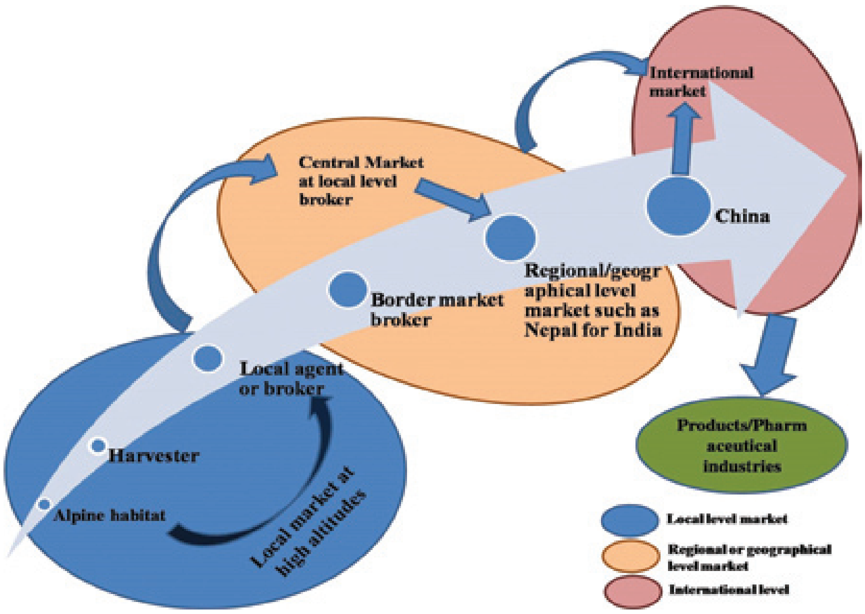

Figure 5.1: Different levels of caterpillar fungus trading from highlands to international market

Grading and marketing of caterpillar fungus: in theworkshop at Bhutan

'Sikkim Cordyceps Green Tea'

Table 5.2: Economic contribution through trade in caterpillar fungus

Country	Place	Remark regarding economy (year)	Reference
China	China	$140,000/kg (2011)	Shrestha and Bawa (2014)
	Tibet	$225 million/50,000Kg (2004)	Winkler (2008)
	Tibet (Chamdo and Nagchu)	70-90% households benefitted by selling caterpillar fungus	Winkler (2009)
	Domkhok Township, Qinghai	$26,600/kg/household	Sulek (2012)
	Tibet, Yunnan province, Diqing and Shangri-La	$6-10/piece, 157 households	He et al. (2018)
	Baima Xueshan Nature Reserve	$1560.72, 54 households, five villages	Weckerle et al. (2010)
Nepal	Dolpa district, Majphal village development committee (five villages)	$130,000/kg (2011), 203 harvesters	Shrestha and Bawa (2013)
	Jumla district, Garjyangkot village development committee	$2,287.2/year, Caterpillar fungus accounted for 65% of the total household cash income	Shrestha et al. (2017)
	Darchula district	$10,070/kg (2015-2016) $16,110/kg (2014-2015) $16,110/kg (2013-2014)	Pouliot et al. (2018)
	Nubri and Tsum	$4,700/household (2014)	Childs and Chodup (2014)
	Dolpa district	$1843.66/household (second biggest contributor in income generation)	Shestha and Bawa (2014)
	Dhorpatan hunting reserve	$1.5-3/piece	Thapa et al. (2014)
India	Dharchula	19 villages, 80% population, $1333/kg	Negi et al. (2006)
	Chamoli district	$850-1000/kg	Singh et al. (2010)
	Pithoragarh district; Byans, Johar, Darma, Gori Paar, Chaudas, Metali, Ranthi and Jumma landscapes	$142857.143 in 2008; followed by $257142.857 (2009); $5000000 (2010); $7571428.57 (2011); $13571428.6 (2012)	Negi et al. (2015)
	Chamoli district (Garhwal Himalaya)	$3,500/year/household, 88 collector groups of 13 villages	Caplins and Halvorson (2017)
Bhutan	Bhutan; Lingshi, Gasa, Thimphu	$38 to $2,541/season / household	Cannon et al. (2009)


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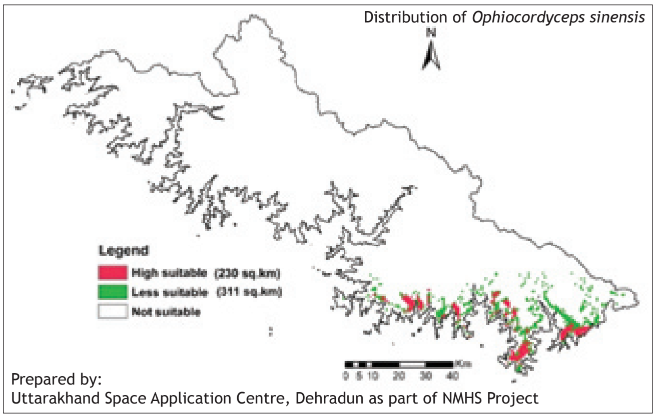
6. Ecological consequences and sustainability

6.1 Sustainability of habitats

The increased prices and market demands have obviously led to significant increase in the number of collectors of caterpillar fungus. This in turn has posed severe pressure on its natural populations and alpine ecosystems (Box 6.1). Reports indicate, the availability of the resource has declined, and harvesting has become difficult in recent years in the Tibetan Plateau, areas of Nepal, Bhutan and India. This calls for attention with respect to sustainability of its habitat in particular and alpine meadows in general. For example, in the valley of Gori Ganga in Pithoragarh district of Uttarakhand (India) alone, the number of fungus gatherers at alpine habitats has increased fourfold since the year 2000 (Negi et al. 2014). This study also exhibits that the yield of caterpillar fungus has remained more or less steady over the years, however, the price of the commodity has increased manifold. The Box 6.1 reflects views of one of the researcher engaged with field studies of caterpillar fungus during last two decades in Uttarakhand.

Box 6.1 Yartsa Gunbu: sustainability is in question

In Uttarakhand (India) Yartsa Gunbu came into the limelight in the year 1996-97. It occurs in about 230 sq.km area between 3500-4800 m in *Kobresia* dominated sedge meadows. Every year, over 10,000 people representing nearly 200 households venture this area in search of Yartsa Gunbu for almost two months (May-June). The hotspot of this resource in the state is Chiplakedar area. Sumdum, Philam, Bon, Baling, Dugtu and Daantu in Darma valley, Ralam Dhura, Panchachuli base, Nagnidhura and Namik in Dharchula-Munsyari region of Pithoragarh district are other important collection areas. Few areas surrounding Pindari, Kafni and Sundardhunga catchments in district of Bageshwar, Kunwaripass, Khrion valley, Manpai areas of Chamoli District are also known for its availability. On an average, each family earns between 1-3 laks per season (150-300 pieces). My understanding, based on field studies as well as evidences available from other studies, is that given the growing demand and destructive collection trends it would be difficult to ensure sustainability of resource in the region. However, if the local communities and management authorities establish coordination for: (i) limiting the number of people visiting and days they spend in alpine meadows, (ii) developing sustainable harvest strategies, (ii) establishing transparent mechanism for marketing and trade, and (iv) encouraging youths to work on traditional agriculture practices, there is a possibility that this resource continues to benefit communities for long.



Yartsa Gunbu collection in the Chipplakedar area (@ ID Rai)

Dr. Gajendra Singh
Uttarakhand Space Application Centre, Dehradun

The ecological impacts of caterpillar fungus harvesting include loss of pastures as a result of trampling, soil compaction, deforestation and dumping of solid wastes in the pastures. All these pose severe threats to alpine meadows and the unique biodiversity elements in these vulnerable habitats (Negi et al. 2014; Shrestha et al., 2014). Huge aggregations of people for nearly one month in the remote pastures is bound to affect the pristine nature of these ecosystems, which not only support many endemic and threatened species (Negi et al. 2014; Shrestha et al. 2014; Yadav et al. 2016) but also contribute for sustained flow of services to downstream areas (Negi et al. 2018b).

The studies have shown that the caterpillar fungus populations and its per-capita harvest is declining (Shrestha and Bawa 2013; Negi et al. 2014; Shrestha et al. 2014; Shrestha et al. 2017). Recently Shrestha et al. (2017) reported a mean annual decline of 25 pieces in the per capita harvest of caterpillar fungus in Nepal during 2010-2014, which can be attributed to the steady increase in the number of collectors every year. The major reasons for decline in availability and per capita harvest include: (i) unregulated and rampant harvesting of the resource (Shrestha et al. 2014; Negi et al. 2014; Pouliot et al. 2018), (ii) premature harvesting (Shrestha et al., 2014; Negi et al. 2014; Shrestha et al. 2017), (iii) decrease in moth and larval populations due to changing climatic conditions (Shrestha & Bawa 2013), (iv) modification of the soil microhabitats congenial to fungal spores by the harvesters (Shrestha et al. 2014), and (v) increased grazing intensity and climate change (Shrestha & Bawa 2013).

The study by Winkler (2005) explains, how in want of higher value fungus specimens are collected before sporulation and therefore minimizing chances of spore dispersal for future larvae infection. Conversely, when the caterpillar fungus is harvested very late in its lifecycle towards the end of the collection season, sporulation takes place, which has utmost ecological importance to sustain the caterpillar fungus population. However, at this stage it fetches fewer returns. Lesser the availability of mature sporocarp, lesser would be the chances that reproductive spores would find the likely host insect–the obligate out-crosser (Thitarode larva), to complete its life cycle.

It has been frequently reported that (i) exploitation of herbaceous plants as well as woody vegetation on whose roots and flowers the host larva thrives, (ii) trampling by harvesters and livestock, and (iii) prolonged stays of collectors in its habitat areas have resulted in degradation of both the habitats and the host insect in its range of distribution (Shrestha et al 2014; Negi et al. 2015). Extensive cutting of alpine shrubs particularly *Rhododendron campanulatum, Juniperus* spp., and tree species like *Betula utilis* for fuelwood and tent preparations, is further causing pressure on these species at climate sensitive timberline. Furthermore, dumping of large amount of trash in alpine pastures and open defecation has also become a challenge, especially to protect water the sources from contamination. Currently there exists no management practice to mitigate or reduce generated garbage during stay of harvesters.

6.2 Unregulated Harvesting in Conservation Areas

More importantly, unregulated harvesting of caterpillar fungus in biodiversity rich conservation sites has increasingly become a challenge. Even in India, many alpine habitats of caterpillar fungus fall in designated conservation areas such as Nanda Devi Biosphere Reserve, Gangotri National Park, Govind National Park, Askot Wild Life Sanctuary and Kedarnath Wild Life Sanctuary in Uttarakhand; Kanchendzanga Biosphere Reserve in Sikkim and Dehang-Debang Biosphere Reserve in Arunachal Pradesh. The collection of caterpillar fungus continues unabated from these sites and thereby impeding the ecological integrity of these conserved systems and their unique plants particularly high value medicinal plants. The efficacy of departmental system to monitor such vast areas in difficult terrain is always questionable, particularly in view of the limited resources available with government departments.

6.3 Overexploitation leading to population decline

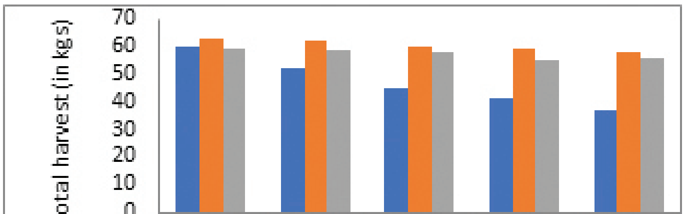
With overexploitation of caterpillar fungus its own survival is also in dilemma (Box 6.2). It is well established that harvesting, which lead to mortality of the target plant species that makes the populations more vulnerable (Cunningham 2001). In this context, caterpillar fungus with a single reproductive cycle is likely to be more vulnerable. Therefore, there is a need to leave enough individuals un-harvested during collection to ensure adequate reproduction. Unfortunately this level of understanding is missing among most of the collectors. It is reported that the harvested lot often consists of 70–80% immature samples. Therefore, inadequate number of spores dispersed by the smaller surviving population of mature individuals further increases the vulnerability of the species (Negi et al. 2015). This study also concludes, declining population of caterpillar fungus would result in resurgence of the population of the host insect (Thitarode), which in turn would affect ecology of the above-ground vegetation.

6.4 Caterpillar fungus under changing climate

Impact of climate change on this important resource has surprisingly remained less investigated area. Box 6.3 compiles some of such studies, largely from China. However, a more comprehensive study by Hopping et al. (2018), which cover its entire range of occurrence in the Himalaya, reveals that winter temperature is the key factor for both distribution and production of caterpillar fungus. The species distribution models detected upper and lower winter temperature thresholds beyond which sustainable habitats are limited. Study reports within the temperature range production decreases with increase in winter temperature. Therefore, the significant winter warming as reported throughout its distribution range in India, Bhutan and Nepal may have caused the production decline in respective countries. This study by Hopping et al. (2018) further indicates significant winter warming in exceptionally cold northeastern Tibetan Plateau may have shifted new area above the low-temperature threshold, thereby promoting the increased production there.

Box 6.2 We are hell bent on killing the goose laying the golden eggs

The caterpillar fungus (Yartsa Gunbu) offers an example of the phenomenon, where a resource of immense economic value runs into the risk of being over-exploited. Study by my team covered 110 villages in District Pithoragarh (Uttarakhand), which are engaged in its harvesting reveal: (i) there is a perceptible decline in the yield of Yartsa Gunbu over the years (Fig. 1), and (ii) a significant, 14.81% decline in the population of the host insect too within the span of 5 years (Fig. 2). Harvesting of immature specimen remains the prime factor for yield decline. Healing power of Yartsa Gunbu is believed to be concentrated in the caterpillar, filled with *Ophiocordyceps* mycelium, and not the size of the fruiting body. The harvesters are thus forced to make collections early in the season. In fact, 70 to 80% of the harvested lot consists of immature specimens. Such collection impacts negatively on reproduction and its future availability in wild. Therefore, increasing demand in international markets and ever growing price of niche commodity is likely to result in more extensive and prolonged duration of harvesting season with resultant greater degradation of the habitat, and concomitant loss of vegetation cover, upon which the host larva thrives. Given this scenario, and realizing the low level of awareness among stakeholders, my suggestion would be to regularly organize workshops, awareness programmes across the landscape. Stakeholders need to be made convinced that the present mode of exploitation invariably relates with declining yield. One sound strategy would be to make their stay 2-3 kms away from the alpine meadows, in the forest fringes, so that duration of harvest per day in the habitat sites gets reduced.



	2008	2009	2010	2011	2012
Johaar	60.31	51.96	44.97	41.04	36.83
Darma	62.99	62.18	60.04	59.05	57.8
Gori Paar	59.11	58.68	57.74	55.38	56.01

Figure 1: Decline in total harvest of Yartsa Gunbu over the five years (2008-12) in Pithoragarh district of Uttarakhand - a rough estimate of the total yield as per the informants (n=1370)

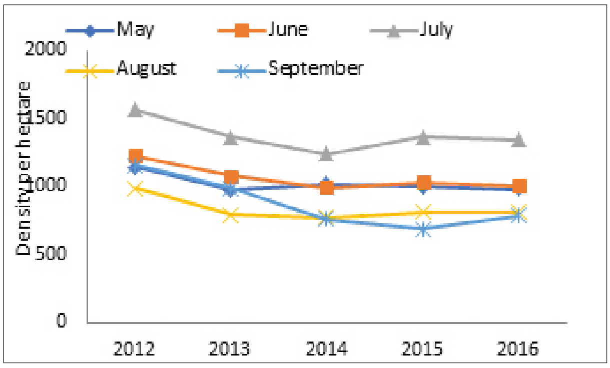


Figure 2: Perceptible decline in the population size of the host caterpillar host - Thitarode

Dr. C.S. Negi,
MBPG College Haldwani (Uttarakhand)

Box 6.3 Climate change and Caterpillar fungus

The Himalaya is warming much faster than the global average. Therefore, impacts are more apparent. Evidences reveal, climate change in the Himalaya has impacted hydrology, agriculture, ecosystems, and resulted in altitudinal shifts of vegetation communities. Several studies have shown that climate change has altered mushroom fruiting phenology (e.g., Kauserud et al., 2008, 2012), but there are very few studies concerning range shifts of fungi in response to climate change (Yang 2008; Shrestha and Bawa, 2014). According to Yang (2010), the altitudinal limits of the prime caterpillar fungus habitat have been pushed up by around 200-500m between 3900 to 4400 m in Tibetan Plateau. A recent study by Yan et al. (2017) from Tibetan Plateau, predicted net habitat loss of 19% by years 2050 and 2070 under Representative Concentration Pathways-RCP 2.6, and of 8% and 4% under RCP 8.5 for the years 2050 and 2070, respectively. The study also argues that if a non-dispersal scenario was considered, 36–39% of the current habitats would be lost in the future. A study on model based projection by Shrestha and Bawa (2014) from Nepal revealed that across all future climate change trajectories over three different time periods, the area of predicted suitable habitat of caterpillar fungus would expand, with 0.11–4.87% expansion over current suitable habitat. Climatic conditions suitable for caterpillar fungus growth would seriously undermine overall habitat availability. However, so far there is no baseline research that would allow comparing past habitat to suggested current habitats of caterpillar fungus. Therefore, in want of evidences it is difficult to say how caterpillar fungus will perform under changed condition. However, being an association of the caterpillar larvae and the fungus, any differences in response towards changing climate by either of these constituents would be influencing the overall availability of caterpillar fungus in the Himalaya.

6.5 Addressing issues of sustainability

Towards ensuring the sustainability of resource, cyclic regulation for fungus collection by the villagers or through concerned government department seems a viable option. This may help achieving conservation as well as sustainable harvesting of caterpillar fungus in long run. In the context of India, Negi et al. (2014) have suggested urgent need to educate the villagers on following (i) sustainable harvesting methods; (ii) regulating the number of harvesters per household, (iii) reducing the length of stay of collectors in the alpine meadows, (iv) garbage management in the alpine, and (v) minimizing degradation of the habitats, primarily on account of fuelwood collection.

Further, recognizing the huge market demand accompanied by limited availability in nature and realizing increasing socio-economic relevance and looming threats under changing climate, there is a definite need for finding alternative ways to meet the demand. Therefore, artificial cultivation becomes a possible solution. As a result several researchers are getting attracted towards its artificial cultivation (Box 6.4).

Box 6.4 In Vitro culture of Caterpillar fungus

Laboratory cultivation of *O. sinensis* is difficult, while the cultivation of other species of *Ophiocordyceps* such as *O. militaris* has been tremendously successful (Sung et al., 1999; Baral and Maharjan 2012, Kang et al., 2014). Available literature suggests that *Ophiocordyceps* can be cultured on potato dextrose agar plates for 96 h at 28°C temperature (Han and Liu, 2009; Liu et al., 2010). However, the success of cultivation on large-scale has not been achieved. Low survival rate of the host, low rate of infection, and the induction of primordium are the primary technical difficulties in achieving the breakthroughs in artificial cultivation. Sunshine Lake Pharma Co. Ltd. (Guangdong, China) has claimed to optimize the method on artificial cultivation of *O. sinensis*. At the Institute of Microbiology, Chinese Academy of Sciences, the cultivated samples under artificial conditions were examined for many years, and the fungus and the hosts have been identified as *O. sinensis* and *Hepialus xiaojinensis* by both morphological and molecular methods (Zhang et al., 2018). The annual yield of the company is increasing year by year like 2.5, 5, and 10 tons in 2014, 2015, and 2016, respectively, which accounts for nearly 5% of the total natural resource annually. With further refinement and scaling up of cultivation would certainly benefit the survival of natural population.

7. Governance issues - Social & Ecological implications

The emergence of caterpillar fungus as game changer, both in socio-economic and ecological domain, brings issues pertaining to governance of this common's resource on fore front. As this fungus has transformed into a highly valuable resource within a short time frame (Winkler 2019; Cannon et al. 2009; Corrina et al. 2019), the specific governance system has not evolved to the extent desired. The existing systems vary considerably within and across countries.

In Nepal, the harvest of caterpillar fungus was banned till 2000 under the Forest Act 1993 and Forest Regulations 1995. However, the collection and trade were going on illegally and secretly making the ban ineffective. Realizing this, the ban was lifted in 2001 with the provision of revenue of NRs 20,000 per kg and later that revenue was reduced to NRs 10,000 per kg in 2006 (Devkota, 2010). After legalization of trade of caterpillar fungus in 2001, earnings from the harvest have gradually increased due to the increase in market prices. Now in Nepal, caterpillar fungus collection and sale in all community forests and conservation areas is legal (MoFSC 2017), but the conflicts regarding access between villagers and distant collectors are common (ICIMOD 2015; Pant et al. 2017). A study by Corrina et al. (2019) reveals that the National policies in Nepal legalize collection and sale of NTFP, including caterpillar fungus. However, for a protected area (e.g. Api Nampa Conservation Area-ANCA) quantities of its collection are defined by the Department of National Parks and Wildlife conservation (DNPWC). ANCA authorities collect royalty for collection @ 25,000 NR per Kg. It receives revenue to the extent US$173,000 per year from collection of caterpillar fungus. The vertical integration between local and national actors and institutions remains weak. There has been a situation of governmental Institutions override customary rights and practices (Corrina et al. 2019).

In Bhutan, caterpillar fungus was placed in Schedule 1 list of the Forest and Nature Conservation Act 1995 and its harvest remained illegal until 2004, when a limited collection regime was introduced (Cannon et al. 2009). Many of the harvest sites in Bhutan are close to the border with Tibet (China), which is difficult to patrol by law enforcement agencies and hence cross-border illegal trade continues in caterpillar fungus. The law was changed in 2004 to allow limited collection of caterpillar fungus by the yak herders whose herds traditionally graze in the pastures. Various measures were put in place to restrict the overall harvest, including a ban on collection except during the month of June, and a stipulation that only one member of each household allowed to collect (Cannon et al. 2009). Rationale behind the regulation on harvest dates (in the month of June) was to lessen the collection of immature specimens. Realizing the success of these measures they have been maintained with some modifications.

In state of Uttarakhand (India), the sale of caterpillar fungus was not regulated by law, until the recent state government guidelines, which led to smuggling/illegal trade of the caterpillar fungus to Nepal and China. In order to address the problems associated with unregulated trade, the State Government of Uttarakhand, by declaring the species as an NTFP on the basis of the Indian Forest Act, 1927, has issued certain guidelines on the collection and trade of caterpillar fungus from reserve forests through village level forest councils (Van Panchayat), while commercial exploitation from wildlife sanctuaries and national parks is completely prohibited (Yadav et al. 2016). Thus, the commercial collection of caterpillar fungus is legal only in community forests managed by van panchayats (village forest councils) with the approval of the State Forest Department. However, collectors harvest caterpillar fungus wherever possible – within state forests or protected areas – regardless of rights and legal status (Negi et al. 2016). Illegal collection and trade across the border to China and Nepal is well known but the extent of the illegal harvest and trade has never been estimated so far. Dharchula (District Pithoragarh) serves as a porous border between India and Nepal which is also used as a transit location for other forms of trade between the two countries. This situation of illegal trade has emerged largely due to low profitability in legal marketing through Governmental Institution, and also on account of the absence of a formalized institutional setup.

In Sikkim State of India, Government framed the rules and regulation for collecting the caterpillar fungus known as Collection and Selling rules-2009 implemented on July 2, 2009. As per the rule, no caterpillar fungus is allowed to be collected in the State of Sikkim unless permission is obtained from the Range Officer who shall issue permission after field verification and with approval of the Principal Chief Conservator of Forest (PCCF). However, no collection is permitted in the Wildlife Sanctuary and National Parks. If a Joint Forest Management Committee or Eco Development Committee members desire to collect caterpillar fungus from their territory they shall apply to DFO concerned. The committee needs to provide a rough sketch map along with approximate quantity of collection, which shall not be more than 33% of that total stock of the area. These rules were not much effective for sustainable harvesting of the caterpillar fungus because rule is not sufficient on its own as it did not include the most important aspect i.e. the Access and Benefit Sharing (ABS) provision defined in the Indian Biological Diversity Act 2002. Therefore in 2016, Sikkim government drafted a new guidelines "*Ophiocordyceps sinenesis* (Yartsa Gunbu) Auctioning and Harvesting Guidelines 2016". The new guidelines restricts the collection period for one month and issue of the specific number of permits, strictly to the local community. On the basis of new notification, government issued 101 collection permits (free of cost) to the highlanders and facilitated open auction for its sales. However, there were negligible participation from both buyers and sellers on caterpillar fungus auction. So, the efforts of the Sikkim Government could not succeed due to various issues among State Government, buyers and sellers (Pradhan et al., 2019).

The government order (Forest Department 1790/18.01.2002) of Uttaranchal authorized van panchayats in Johar valley of District Pithoragarh with supreme powers vested on the sarpanch and that a committee of van panchayats is formed to monitor the harvesting. This arrangement also could not succeed and several conflict situations emerged. Remoteness and inaccessibility of collection sites accompanied by limitations of human and financial resources of state forest Department constraints execution of existing system of governance (Corinna et al. 2019). On October 08, 2018, the government of Uttarakhand has issued a guideline regarding collection and marketing of caterpillar fungus. Under this guideline caterpillar fungus is now considered as Non-timber Forest Products (NTFP). The collection is allowed through license system. In general, the government led governance systems in the high alpine areas have struggled to overcome the disturbances, and to set up and enforce management mechanisms for sustainable collection of caterpillar fungus (Cannon et al. 2009; Negi et al. 2015; Pant et al.

2017). Study by Corrina et al. (2019), in the context of India and Nepal, concluded that neither government nor communities alone can ensure effective governance in remote mountain areas when resource values rapidly increase. This requires a complex and complementary resource governance system consisting of both government institutions and community management arrangements.

With the recent inclusion of species in Red List of IUCN (Box 7.1) as 'Vulnerable' brings a new dimension to whole issue of governance. The respective governments are expected to respond to it in a way to strike balance between increasing conservation needs and high dependence of local communities on this resource.

Box 7.1 World's most expensive fungus threatened

International Union for Conservation of Nature (IUCN) has entered caterpillar fungus in Red List as 'Vulnerable'. The fungus is highly valued in Traditional Chinese Medicine, where it has been used for over 2,000 years to treat many diseases. Demand for the fungus has risen sharply since the 1990s. In the last two decades, the fungus has become the main source of livelihoods for thousands of indigenous people where it occurs. According to IUCN, 'caterpillar fungus populations have declined by at least 30% over the past 15 years as a result of overharvesting'.

Prof Gregory Mueller, Chair of the IUCN SSC Fungal Conservation Committee mentioned "This is one of the few documented cases of a fungus being threatened by overharvesting". Therefore, there exits an urgent need to ensure sustainable harvest of this species so as to address issues of (i) natural population decline, and (ii) long-term income/ livelihoods of dependent communities.

Based on: IUCN 2020 (IUCN.Org)

8. Way forward

Undoubtedly in recent decades, caterpillar fungus has emerged as an important resource for local communities in Himalaya, especially the local indigenous communities living in the high altitudes villages where livelihood opportunities are very limited. Increasing dependency of these inhabitants on caterpillar fungus collection and trade will leave these communities vulnerable, if the production and per capita availability continues to decline as reported in many studies. The studies on ecological status of caterpillar fungus have frequently reported that wild material gatherers extract natural resources without considering its sustainability and often use destructive harvesting methods. Given the ever-increasing demand in the international markets and the price of the commodity, populations of the species, its host as well as the associated communities and habitats become severely vulnerable to degradation. The current scenario of caterpillar fungus extraction indicates immense future impacts both on the species as well as its habitat which also might result in loss or local extinction of other rare and geographically restricted species in the pristine alpine habitats of the Himalaya. Furthermore, these high altitude habitats of the Himalaya have been predicted to be affected by the climate change, which in turn will have an enhanced negative impact on caterpillar fungus and its associated species. In view of this there exists a need for timely implementation of conservation and sustainable management strategy across the caterpillar fungus distribution range for conservation of the species, its associated communities and haibtat. National and International level collaboration and conservation forums can play an important role by way of evolving a common holistic conservation policy that integrated effective conservation and harvesting strategy.

Trade of caterpillar fungus from India is largely conducted through Nepal to China in an illegal manner but in very high intensity owing to its higher profitability. Effective guidelines and mechanism for extraction, marketing and trade of caterpillar fungus are still lacking in India. Therefore, uniform methods and guidelines needs to be developed for its sustainable harvesting and trade. Moreover, awareness of local communities regarding the problems associated with commercial exploitation is of utmost importance. Management issues need trans-disciplinary and trans-sectoral supports, including science-based research, technology development, rangeland ecosystem management, climate change adaptation, collection specification, fair and honest trade, value-added products and marketing, export and import rule, etc. Further, as be the availability the frontline staff and the local community institution such as JFMCs/

EDCs/BMCs along with the military, para military forces and local police need to be engaged on regular patrolling and monitoring the activities of the collators in the habitat areas during the harvesting seasons for controlling the habitat degradation, illegal collection, purchase and trans-boundary trade.

The fluctuation in the price of caterpillar fungus varies within the IHR states annually, which is totally controlled by the middleman largely due to least market awareness and lack of coordination between local communities and the government agencies. Therefore, there is an urgent need to have provision of market information system for caterpillar fungus in which the local community can explore possibilities of gaining maximum benefits. There exists a great opportunity to explore possibilities of the value addition in caterpillar fungus in the form of supplementary food as well as medicinal products for promoting the livelihood opportunity to the local community in the IHR states.

Much progress has been made in China where various aspects of caterpillar fungus research, like habitat management, reproduction of insect and fungus, development of new technologies and new products etc. have been investigated. However, the status of caterpillar fungus research in India is lagging far behind in all the aspects. Very few efforts have been made in India for laboratory based research to discover the medicinal potential of the caterpillar fungus. Similarly, limited number of studies have been conducted on the ecological and conservation status of the caterpillar fungus and its habitats in the Indian Himalayan region. Therefore, more focused efforts are required from scientific community for investigation on various aspects of the caterpillar fungus. Further, studies are needed for unbiased and rational investigation on the trade-off between the impact of caterpillar fungus collection on the rural economy and habitat degradation due to its extraction from the pristine alpine habitats. Thus, for a better understanding on the medicinal potential, economic values, ecology and conservation of the caterpillar fungus increased financial supports must flow in for both basic and applied research across the caterpillar fungus range.

Most importantly, in view of declining production due to overharvesting as well as changing climate, and likely implications of this decline for dependent community, there is an urgent need to find alternative livelihood options for communities associated with its harvesting. Vulnerability of these otherwise marginalized communities is therefore has increased considerably with production decline and/ or availability limitations. Appropriate attention on such communities is needed immediately.

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G.B. Pant National Institute of Himalayan Environment

G.B. Pant National Institute of Himalayan Environement (GBPNIHE) was established in 1988-89, during the birth centenary year of Bharat Ratna Pt. Govind Ballabh Pant, as an autonomous Institute of the Ministry of Environment, Forest and Climate Change (MoEF&CC), Govt. of India. The Institute has been identified as a focal agency to advance scientific knowledge, to evolve integrared management strategies, demonstrate their efficacy for conservation of natural resources, and to ensure environmentally sound management in the entire Indian Himalayan Region (IHR). The Institute has Headquarters at Kosi-katarmal, Almora (Uttarakhand) and six Regional Center, namely, Himachal Regional Center at Mohal (Kullu, HP), Garhwal Regional Center at Srinagar (Garhwal, Uttarakhand), Sikkim Regional Center at Pangthang (Sikkim), North East Regional Center at Itanagar (Arunachal Pradesh), and Mountain Division Regional Center at MoEF&CC New Delhi. More recently Institute has made functional its Ladakh Regional Centre at Leh (Ladakh)

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