

Cold-Tolerant Microbes

Subjects: **Microbiology**

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Cold adapted microorganisms represent a large fraction of biomass on earth due to the dominance of low temperature environments. Himalaya is one of the most important low temperature environments on Earth because it possess environmental similarities to Polar Regions. The extreme cold environments of Himalaya are mainly dependent on the tiny life forms because of climatic restrictions to higher plants and animals. These cold loving microbes are known to possess several structural and functional adaptations in order to perform various life processes under the stressful low temperature environments. Their biological activities maintain the nutrient flux in environment and contribute in the global biogeochemical cycles. The culture dependent and culture independent studies revealed their diversity in community structure and functional potential. Apart from the ecological importance, these microorganisms have been recognized as a source of cold active enzymes and novel bioactive compounds. These products have several applications in biotechnological industries.

Cold-adapted microorganisms

Himalaya

Bioprospection

Extremophiles

1. Introduction

The cold-adaptive microorganisms are recognized as potential source of cold-active enzymes and bioactive compounds^[1]. In the present scenario, the industries are diverting towards green chemistry to use enzyme-based reactions rather than involve chemicals such as in the textile industries^[2]. Working with enzymes has several advantages, such as less interference on byproducts, reduced energy consumption with negligible pollution, and no compromise of product quality. The cold-active enzymes have shown low activation enthalpy and flexibility in structures. Such thermodynamic parameters help these cold-active enzymes to perform catalytic actions under the low kinetic energy of cold environments^[3]. Lipase, cellulase, amylase, invertase, protease, and lignin-degrading enzymes, produced by cold-adaptive microorganisms, have various applications in detergent, food, the pharmaceutical industry, and so forth^[4]. Antifreeze proteins from cold-adaptive organisms have also been recognized for their important physiological and biotechnological contributions. They are the group of proteins that control the shape and size of ice crystals and allow the biochemical activities below freezing temperatures. The production of AFPs from different organisms is the result of convergent evolution through the pressure of extreme cold temperature. The AFPs are reported for other industrial applications too^{[5][6]}.

2. Bioprospection

The microorganisms colonizing the extreme colder regions are adapted to cope with various stress conditions (limited nutrient availability, radiations, desiccation, etc.) and produce novel metabolites that are absent in the

mesophiles. These metabolites have significant importance in various industries such as food, textiles, therapeutics, and so forth^{[7][8]}. Bioactive compounds related to antimicrobial and immunosuppressive activities, for example, have also been isolated from the cold environment microorganisms^[9].

The low-temperature environments of Himalaya are seen as a promising source for novel products, bioactive compounds, and other industrially relevant substances/compounds^{[10][11][12]}. Metagenomic investigations reveal the functional potential of the inhabiting soil microbial communities and allow to study the metabolic pathways and interactions associated with the uncultured biological components also^[13]. For example, cold-active enzymes (amylases, endocellulases) were obtained from the clone library and are highly active at low temperatures^{[14][15]}. These low-temperature active products can be used in industries to reduce energy consumption. Apart from this, the multicopper enzymes, well known as versatile and efficient tools against a range of complex compounds, are highly distributed in the region. Potential to produce laccase enzyme from the cold-adapted microorganisms of glacial sites and the hot springs of Himalaya have been reported through culture-dependent and culture-independent methods^{[16][17]}. The cold-adapted microorganisms of Himalayan soils have also been reported as an abundant source of diverse cold-active lipases^{[18][19]} that have importance in bioremediation, food industries, and cleaning industries^[20]. The Himalayan soils are found to possess high diversity of bacteria that produce carbonic anhydrase, which is an important candidate for investigations related to carbon sequestration^[21]. Among the microorganisms, cold-adapted yeasts are recognized as an important group for their survival strategies and biotechnological benefits^[22]. There are some records available on these single-cell eukaryotes from Himalaya; however, more investigations are awaited for their ecological contributions^[23].

Not only the biotechnological benefits but also the inhabiting cold loving microorganisms contribute to several ecological processes in different ecosystems located in Himalaya (Figure 1). In the environmental importance, biodegradation and agriculture (such as plant growth promoting activities and biocontrol) under the colder regions are well supported by the inhabiting microbes^{[24][25]}. These microorganisms have the capability to degrade a range of compounds that have been identified as strong agents in bioremediation. They are also involved in the carbon cycle and contribute in the energy flux in the environment. *Pseudomonas*, *Acinetobacter*, *Rhodococcus*, *Bacillus*, and *Sphingobium* have been found to contribute significantly to the degradation of complex hydrocarbons (such as petroleum products) under low-temperature environments^{[26][27][28][29]}. The presence of a particular hydrocarbon compound also affects the environment on the ecological ground. For example, a colder area (China–Russia) contaminated with petroleum revealed the microbial shifts and the abundance of efficient degraders (endemic communities)^[30].

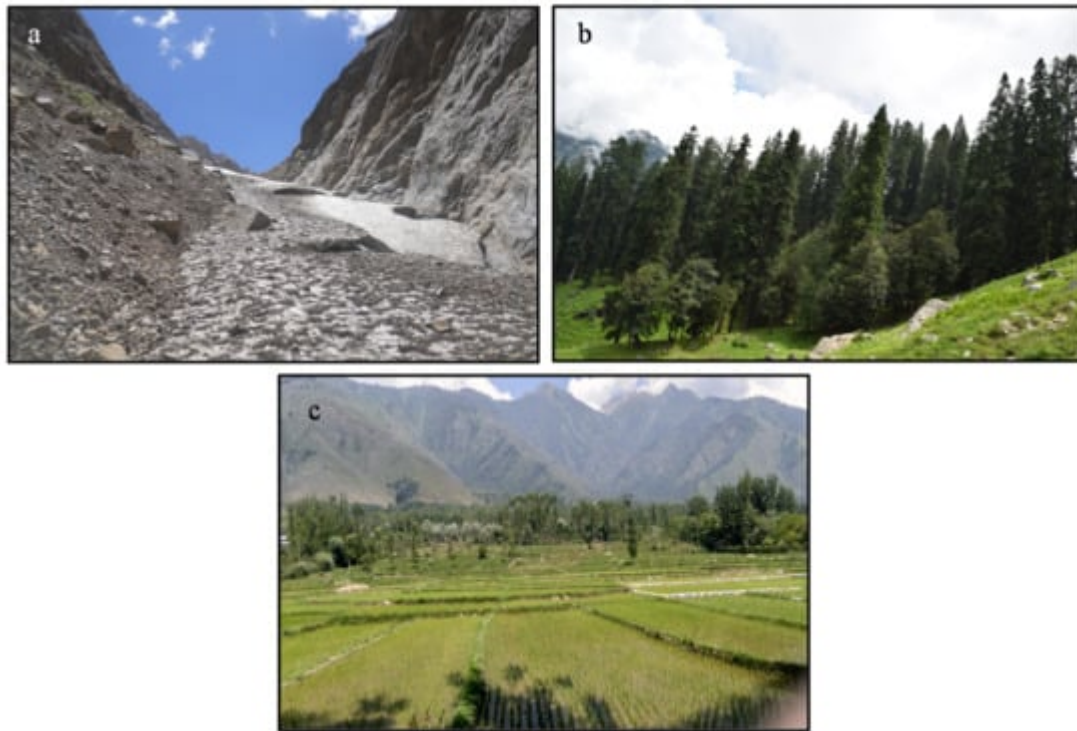


Figure 1. Ecological processes regulated by cold-adapted microorganisms in different ecosystems. **(a)** Biogeochemical cycles in the barren lands of glacial regions (>3500 m asl). **(b)** Nutrient cycles/energy flow in the high-altitude forests. **(c)** Agriculture system under the low-temperature regions of mountains (Photo credit: Khashti Dasila).

The biodegradation process in low-temperature environments is very slow and restricted. Organic carbon is sequestered and accumulates in these environments (in the form of lignocellulosic material). These cold-adapted bacteria were also found to possess different hydrolytic enzymatic activities indicating their contribution in the cycling of nutrients including carbon^{[31][32][33]}. Studies from Indian Himalaya have proved that the associated psychrotolerant spp. (bacteria and fungi) have the potential to produce lignin-degrading enzymes at a wide range of temperature and pH^{[16][34]} (Figure 2).

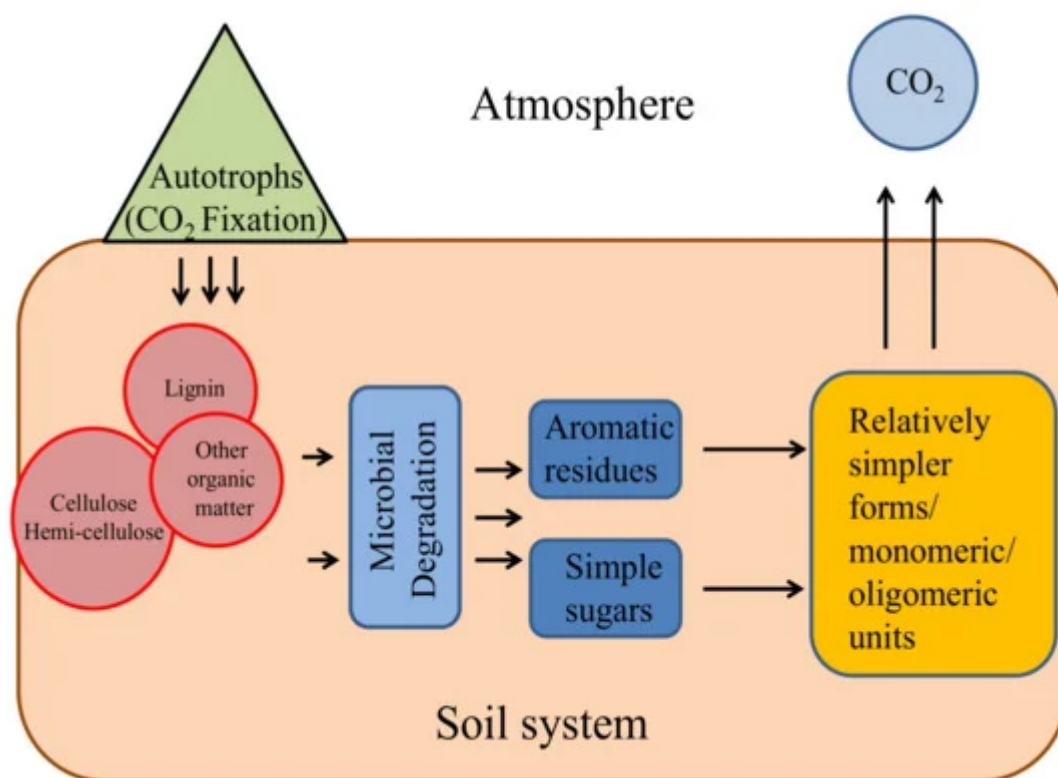


Figure 2. Conversion of different forms of carbon through microbial activities under the biodegradation process.

Apart from degradation, the inhabiting microbial communities have shown their immense contribution to improve the agriculture in low to extreme low temperature environments of Himalaya. These psychrotrophic/psychrophilic microorganisms have been reported for their potential in plant growth promotion activities. They are found to possess activities, such as phosphate solubilization, indole acetic acid production, and siderophore secretion, that are useful in agriculture under low-temperature environments^{[35][36]}. In the recent two decades, several researchers have published the potential utilization of microbial strains from Indian Himalaya. *Rhodococcus*, *Pseudomonas*, *Bacillus*, *Serratia*, and Ascomycetous fungi (*Trichoderma*, *Aspergillus*, *Penicillium*) have been recognized as promising candidates in agriculture and forestry^{[25][37][38][39][40]}, but they need further attention for obtaining a form of valuable product. Recently, a strain of *Stenotrophomonas* with multiple plant growth promoting activities and possibilities to utilize as biofertilizer has been reported^[41]. In last few years, a range of endophytes have been isolated and screened for their importance in agriculture under the low-temperature environments of Himalaya^{[42][43]}; except for this, they have also been recognized as a good source of antimicrobial compounds^[44]. Towards ecological aspects, the specific dark septate endophytes have been also investigated from the high altitude of Himalaya, and they await their recognition for their role as indicators of the changing climate under the mountain ecosystem^[45]. By considering the ecological and biotechnological importance of the endophytes, it is important to investigate this group effectively because they are likely to be the important players that help in the nutrient flux between soil and plants (especially in the nutrient-poor soils of high altitudes of Himalaya).

Additional information on the taxonomic and functional aspects of microbial communities of Himalayan regions is provided in Table 1.

Table 1. Taxonomic and functional information associated with the microbial communities of Himalayan region.

Serial. No.	Location	Microorganisms	Report	References
1	Northwestern Himalaya, India	Fungi	Plant growth promoting activities of <i>Penicillium</i> spp.	[46]
2	Uttarakhand, India	Bacteria	Antagonistic activity	[47]
3	Uttarakhand, India	Bacteria	Thermophiles from hot springs	[48]
4	Uttarakhand, India	Bacteria	Plant growth promoting activities	[49]
5	Kargil, India	Bacteria	Cold-active amylases (culture independent)	[15]
6	Annapurna and Sagarmatha region, Nepal	Microbial communities	Microbial biomass and associated ecological processes	[50]
7	Langtang Valley, Nepal	Bacteria	Bacterial diversity of glaciers (culture independent)	[51]
8	North-Central Nepal	Phototrophs	Diversity of cyanobacteria and Chlorophyceae (culture independent)	[52]
9	Arunachal Pradesh, India	Fungi	Antimicrobial activity	[53]
10	Northeast India	Bacteria	Bacterial diversity (culture dependent)	[54]

11	Uttarakhand, India	Microbial communities	Comparative study of soil microbial communities by PLFA (culture independent)	[55]
12	Northwestern Himalayas, India	Bacteria	Plant growth promoting activities of <i>Pseudomonas</i>	[56]
13	Khumbu Valley, Nepal	Micro-eukaryotes	Planktonic diversity (culture independent)	[57]
14	Uttarakhand, India	Bacteria	Plant growth promoting activities	[58]
15	Himachal Pradesh, India	Bacteria	Plant growth promoting activities (culture dependent)	[35]
16	Ladakh, India	Bacteria	Cyanobacterial communities	[59]
17	Uttarakhand, India	Functional aspect of bacterial communities	Distribution of <i>nifH</i> gene through metagenomics	[60]
18	Ladakh, India	Microbial communities	Metagenomics based study of Pangong lake water	[61]
19	Indian Himalaya (Himachal Pradesh and Sikkim)	Bacteria	Potential of hot spring inhabiting bacteria to produce thermostable enzymes (culture dependent)	[62]
20	Khumbu Valley, Nepal	Bacteria	Bacterial diversity associated to snow (culture independent)	[63]
21	Uttarakhand, India	Microbial communities	Microbial biomass associated to the forests and their relation to ecological processes	[64]

22	Ladakh, India	Bacteria	Metagenomics	[65]
23	Himachal Pradesh, India	Bacteria	Bioplastic-producing bacterial communities (culture independent)	[66]
24	Sikkim, India	Bacteria	Contribution of thermophiles in nitrogen and sulfur cycle	[67]
25	Indian Himalaya	Bacteria and fungi	Degradation potential of cryoconites inhabiting microbial communities (culture dependent)	[68]
26	Himachal Pradesh, India	Bacterial and Archaeal viruses	Abundance of viruses in the Manikaran hot spring through metagenomics	[69]
27	Sikkim, India	Bacteria	Culture-dependent diversity	[70]
28	Northwestern Himalaya, India	Cyanobacteria	Diversity of cyanobacteria in hot spring (culture dependent)	[71]
29	Himachal Pradesh, India	Bacteria	Cellulolytic potential	[72]
30	Himachal Pradesh, India	Bacteria	Potential to degrade enzymes from bacteria colonizing hot spring	[73]
31	Himachal Pradesh and Uttarakhand, India	Bacteria	CO ₂ mineralization through carbonic anhydrase	[21]

32	Uttarakhand, India	Bacteria	Potential of cold-tolerant bacteria in hill agriculture (culture independent)	[74]
33	Himachal Pradesh, India	Bacteria and Archaea	Taxonomic and functional potential of hyperthermophiles through metagenomics	[75]
34	Sikkim, India	Bacteria	Culture-independent diversity	[76]
35	Uttarakhand, India	Actinomycetes	Antimicrobial activity	[77]

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