10TH HIMALAYAN POPULAR LECTURE

Tek Chand Bhalla
Former Professor and Chairman
Department of Biotechnology
Himachal Pradesh University, Shimla
September 10, 2023

G.B. Pant National Institute of Himalayan Environment
(An autonomous Institute of Ministry of Environment, Forest & Climate Change, Govt. of Bharat)
Himachal Pradesh Regional Centre, Mohal, Kullu - 175 126,
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Professor T. C. Bhalla, former Chairman, Department of Biotechnology, Himachal Pradesh University, Shimla has had professional career as a teacher, researcher and administrator. He has been among the pioneer in the establishment of the Department of Biotechnology at Himachal Pradesh University to start DBT sponsored M.Sc. Biotechnology teaching programme at the University in 1995. He has been Coordinator of this programme (1999-2015), also Officer-in-charge (Coordinator), Bioinformatics Centre of the University (1998-2015) under the BTIS-net scheme of DBT. Professor Bhalla has been Dean of Studies, Dean Students' Welfare, Dean, Faculty of Life Sciences and Director, Institute of Integrated Himalayan Studies, /UGC Centre of Excellence at the Himachal Pradesh University, Shimla. He has been the recipient of fellowship awards FAMI (of the Association of Microbiologists of India), FBRSI (of Biotech Research Society of India), FNESA (of National Environmental Science Academy), and FABAP (Association of Biotechnology and Pharmacy). He has been conferred Distinguished Biotechnologists Award by the Society of Applied Biotechnology and Outstanding Achievement Award by the Himachal Pradesh University. He has visited several countries including Japan, Czech Republic, Finland, Netherlands, Ireland and UAE with academic assignments. He has successfully completed 12 DBT, DST, UGC and industry sponsored research projects. Professor Bhalla has published 160 research papers in peer reviewed journals, 18 book chapters and authored one book in the areas of enzyme technology, recombinant DNA, traditional fermented foods, and ethnobotany. He had been on the expert panel of UGC, DBT, CSIR, and private, state and central universities. He has guided 36 Ph.D., 33 M. Phil and 74 M.Sc. students for their theses, dissertations and research projects. After superannuation in 2015 as Professor of Biotechnology from Himachal Pradesh University, Professor Bhalla was awarded Basic Science Research (BSR) Faculty Fellowship (2015-2018) by UGC to continue research on nitrile metabolizing enzymes. Presently, Professor Bhalla is associated with several Universities as member or Chairman of their research degree committees, board of studies and institutional ethical committees.

Microbial Diversity and Resources of Himachal Pradesh

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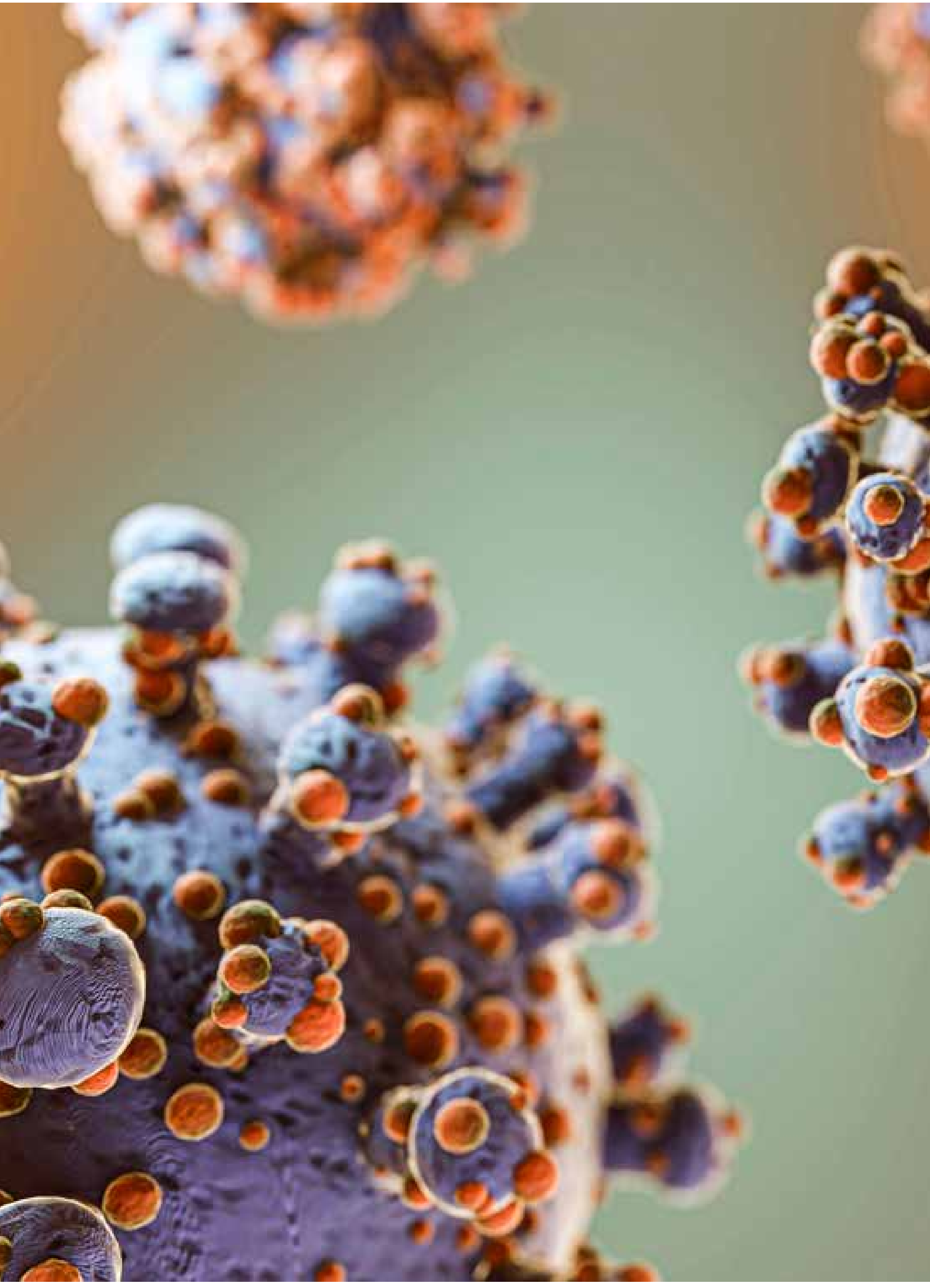

Microbial Diversity and Resources of Himachal Pradesh

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(Write up of the Popular Lecture delivered on September 10, 2023 at G B Pant National Institute of Himalayan Environment, Himachal Regional Centre, Mohal, Kullu-175126, Himachal Pradesh)

Introduction:

The Himalayas are the highest and youngest mountain ranges in the world known as 'water tower' of Asia that spans approximately 2400 km north west to north east of India and consisting of more than 40 mountains which exceed 7000 m in height. The entire Himalayan mountain range displays unique plant, animal and microbial diversity. Moreover, traditional agricultural practices in these mountains have conserved the treasure of agro-biodiversity. Situated in the Himalayan region, Himachal Pradesh is not only known for its beautiful landscapes but also for its rich floral and faunal diversity including microbial diversity. This northern Indian state harbours a variety of ecosystems, ranging from alpine meadows to dense conifer and non-conifer forests, providing a unique habitat for a myriad of microorganisms (Bhalla et al., 2015, Jaggi et al., 2020). The Indian Himalayan regions are valuable ecosystems for exploring microbial diversity. Microorganisms, including bacteria, viruses, archaea, fungi, and protists, (Figure 1) are ubiquitous and inhabit diverse

Figure 1: Microbial diversity and diversity within the microbial groups ((Dasauni and Nailwal (2020) (modified)

environments ranging from the bottom of oceans to the high mountain peaks (Sagar, 2005). The microscopic world of microorganisms, often overlooked in our day to day lives, is a very astonishing and captivating realm that shapes the very basic fabric of our existence on the earth. The exploration into the world of microorganisms reveals the extraordinary diversity, adaptability, and impact these tiny creatures have on our planet (Suyal et al., 2021). Some microbes are extremophiles, thriving in extremes of environmental conditions such as high temperatures, acidity, or pressure which display their remarkable adaptability. The Himalayas' cold habitats have a wide variety of psychrophilic (low temperature loving) microbes. These cold-adapted microbes have vast applications in medicine, agriculture, industry, and environment. Microbial diversity and resources in general and in context to Himachal Pradesh will be discussed in the proceeding sections.

Microbial Diversity:

Microbes are categorised as prokaryotes (e.g. bacteria – unicellular, cyanobacteria – unicellular and multicellular filamentous) and eukaryotes (e.g. yeast, some algal forms, protozoa – the unicellular ones, and algae and moulds –multicellular ones). Microorganisms display diversity not only in forms (Figure 1) but also within the groups in terms of size, shape, arrangement of cells and appearance. Prokaryotes are smallest of all organisms (size of bacteria ranges 0.5 to 2 μm in diameter, some cyanobacteria are 60 μm long or more). A bacterium Epulopsium fishelsoni residing symbiotically inside the intestine of sturgeon fish measures 600 μm long and 80 μm in diameter which is visible with naked eye. Regardless of their small size, these microbes profoundly impact the planet's ecosystems, human health, and industrial processes and play a crucial role in sustaining life on the Earth. Studies have revealed the presence of microorganisms in the extreme environments on other planets and moons, raising fascinating possibilities of life beyond the Earth. Understanding microbial life in extremes of environmental conditions on Earth provides interesting and valuable insights into the search for extra-terrestrial life (Jaggi et al., 2020).

Microbial diversity in Himalayan hotspots provides valuable information on extremophiles, phyllosphere and rhizosphere microbes and microbial associations with plants and animals (Jaggi et al., 2020). Although biodiversity hotspots are zones with extremely high microbial activities, yet the knowledge of microorganism from these areas is comparatively limited, hence microbes explored from the diverse (coldest to the hottest) habitats of the Himalayan region are of immense significance. Himachal Pradesh presents a remarkable microbial biodiversity due to its varied topography and environmental conditions. The state harbours a wide varieties of microorganisms, including bacteria, fungi, algae, and protozoa, adapted to different altitudes and environments (Sagar 2005). Unique microorganisms thrive in the diverse ecosystems, such as the cold deserts of Lahaul and Spiti, the lush green valleys of Kangra, and the dense forests of Shimla (Srivastava et al., 2019). They flourish in extreme environments such as hot springs, acidic lakes, and frozen tundras and high altitude areas of the Himalayan Regions shown in the Figure 2. The microbes from cold deserts are the source of novel antibiotics, anti-freezing compounds, bio-pigments, and cold-adapted enzymes (Thakur et al., 2015, Joshi et al., 2017).

Figure 2: Various extreme habitats in Himachal Pradesh for exploring microbial diversity.

The wide amplitude of adaptability of microorganisms enables them to colonize almost every niche on the planet. Scientists estimate that the number of microbial species on the Earth could be in millions, and yet, only a small fraction have been isolated, studied and identified. Within the microbial world, there are astonishing organisms that change and challenge our perceptions of life (Suyal et al., 2021). The microbial community structure of mountain ecosystems is governed by a number of factors including temperature and altitudinal gradients, climate change, soil characteristics, and floral and faunal diversity. Forests and agriculture are primary livelihood source in Himalayas, so investigation of microbes in these habitats becomes important. Acidobacteria, Actinobacteria, and Proteobacteria are dominant phyla in high-altitude cold desert soil while Firmicutes and Bacteroidetes at lower altitude. Firmicutes followed by Proteobacteria dominate thermal springs, whereas Acidobacteria followed by Actinobacteria in alpine vegetation (Jaggi et al., 2020). Microbes are inherent biotic components of mountain agrarian ecosystems, however, these face constraints like inaccessibility, fragility in terms of water stress, soil conditions and a short growing season. Therefore, in-depth exploration of microbes of these diverse niches and habitats in the Himalayas including Himachal Pradesh is required as a long-term strategy for sustainable agriculture and environment. Microorganisms are instrumental in medical breakthroughs from the discovery of antibiotics to developments in genetic engineering (Joshi et al., 2017). The human microbiome, consisting of trillions of microbes residing in and on our bodies, plays a crucial role in maintaining health and preventing diseases. The stunning ways in which microbes interact with our body continue to be a vital area of research. Microorganisms act as environmental stewards and play a big role in the purification of water, soil, and air. They are involved in the degradation and decomposition pollutants and reduce the impacts of anthropogenic activities. Exploiting the power of microbes and microbial communities offers sustainable solutions to many of our environmental problems. Microorganisms are integral part of biotic component of ecosystems and play very important role in ecological interactions and biogeochemical cycles. They are involved in nutrient cycling, breaking down organic matter, and recycling of essential elements. In symbiotic relationships, microorganisms form association with plants and animals, impacting their growth, health, productivity and existence (Suyal et al., 2021). Exploring and understanding the complicacies of microbial diversity is not only an activity of scientific and microbiological interest but has enormous practical utility and significance for agriculture, medicine, and environmental conservation (Jaggi et al., 2020). Microorganisms isolated from soil include a wide variety of bacteria, fungi, archaea, and other microbes (Srivastava et al., 2019). Some important examples include Bacillus spp., Rhizobium spp., Pseudomonas spp. Streptomyces spp., Trichoderma spp., Penicillium spp., Aspergillus spp., Saccharomyces spp., Candida spp., Actinomycetes spp., Nitrosomonas and Nitrobacter spp., Arbuscular Mycorrhizal Fungi (AMF), etc. (Bhalla et al., 2015, Lakhanpal, 1996). Table 1 shows microbes which have been isolated, identified from soil and water samples of various habitats in Himachal Pradesh and other Himalayan regions. The potential of these microbes for applications in sustainable growth and development has been well documented (Gupta 2023). It is estimated that about 85 to 90% of the plant and animal diversity of the world has been described, however, it is conservatively estimated that <1% of the bacterial species and <5% of fungal species are currently known. In view of this there is immense scope for basic and applied studies in the area of microbial diversity. India accounts for world's 8.1 % described species despite the fact that it shares only 2.4 % of the world's land area (Source: NBA, 2009).

Table 1: Some microorganisms isolated and identified from various Himalayan habitats.

Types of Microbes	Groups	Examples	Reference
Bacteria	Mesophiles	*Acetobacter, Acidomonas, Acidophilum, Acinetobacter, Actinomyces, Aerococcus, Alcaligenes, Azotobacter, Bacillus, Campylobacter, Carnobacterium, Cellulomonas, Cornybacterium, Flavobacterium, Listeria, Mesophilobacter, Micrococcus, Renibacterium, Rhizobium, Streptococcus genera, Bacillus amyloliqefaciens, Burkholderia gladioli, Enterobacter hormaechei, E. sakazakii, Enterococcus faecium, E. lactis, Lactobacillus amylophilus, L. amylovorus, L. brevis, L. casei, L. fermentum, L. plantarum, L. salivarius, Lactococcus lactis, Leuconostoc mesenteroides, Pediococcus pentosaceus, Pseudomonas putida, Pseudomonas synxantha, Serratia marcescens, Staphylococcus sp., and Weisella cibaria*	Johnson 1991
	Thermophiles	*Bacillus licheniformis, B. megaterium, B. sporothermodurans, Brevibacillus thermoruber, Geobacillus pallidus, Geobacillus subterraneus, Hydrogenobacter sp., Paenibacillus sp., Pyrobaculum aerophilum, P. caldifontis, Thermus brockianus, and T. thermophiles*	Arbab et al., 2022
	Halophiles	*Halobacillus sp., Halomonas sp., Marinomonas sp. and Shewanella sp.*	Oren, 2002
	Psychrophiles and psychrotrophs	*Janthinobacterium lividum, Serratia quinivorans A5-2 and S. quinivorans B8.*	Bhatia et al., 2021

Actino-mycetes	*Frankia sp., Gordonia terrae, Micromonospora endolithica, Nocardia globulera, Rhodococcus rhodochrous, Streptomyces griseus, and Streptomyces sp.*	Tiwari and Gupta, 2013
Cyano-bacteria	*Aphanocapsa, Calothrix brevissima, C. parietina, Chroococcus, Coelosphaerium, Leptochaete hansqirgi, Lyngbya, Microcytic stagnalis, Oscillatoria, Phormidium, Plectonema notatum, Spirulina subsalasa and Synechococcus elongates.*	Dvorak et al., 2017
Yeast	*Candida bombicola, C. chiropterorum, C. glabrata, C. tropicalis, Debaromyces sp., Endomyces fibuligera, Geotrichum candidum, Kluyveromyces thermotolerans, Pichia anomala, Pichia kudriavzevii, P. burtonii, Saccharomyces cerevisiae, Saccharomyces spp. and Zygosaccharomyces bisporus.*	Boekhout et al., 2022
Mould	*Alternaria, Aspergillus, Cephalosporium, Cladosporium, Cunninghamella, Curvularia, Drechslera, Epicoccum, Fusarium, Gliocladium, Monilia, Mucor circinelloides, M. hiemalis, Rhizopus chinensis, Rhizopus oryzae and R. stolonifer*	Rico-Munoz et al., 2019

Microbial Repositories – The Culture Collection Centres:

Microorganisms isolated and characterised as source for production of particular metabolite or biomolecule or for specific application are stored and preserved in the culture collection centres for future use (Gupta 2023). A number of microbial culture collection centres have been established as depicted in Table 2. These centres serve as repositories of microbial germplasm which are used for research and commercial activity in academia and industry, respectively (Kumar et al., 2023). Microbial culture repositories not only find applications in research but also play a significant role in biosecurity, quality control, and compliance with international guidance for management of biological resources (Joshi et al., 2017). Asia is emerging as biotechnology and scientific innovation hub, and in this scenario the expansion and maintenance of microbial cultures in these centres need to be strengthened at regional and national level. Many a time very interesting cultures are isolated by a researcher but due to lack of funds these are not identified and unidentified cultures are usually not accepted for preservation by the repositories. Such microbes vanish after some time as it is very difficult in small setup laboratories to keep the culture for long time. It has also been observed that microbes once isolated from a particular habitat are difficult to get isolated second time as the microclimatic conditions vary in that habitat which result in varied profile of the microbes in the next attempt of isolation. In view of this the culture collection centres should provide culture identification services at affordable charges. Exchange of cultures among these centres will further foster collaboration, knowledge dissemination and optimum utilization of microbial resources. State and national funding agencies need to provide liberal support to culture collection facilities so as to make microbial diversity exploration and

Table 2: List of some microbial culture collection centres of India (Kumar et al. 2023 (modified))

S. No.	Microbial culture collection centres	Acronym	Microbial Diversity
1.	Anaerobic Bacterial Resource Centre	ABRC	Bacteria
2.	Bank A Bug	BAB	Bacteria, fungi, archea
3.	Biological Nitrogen Fixation Project College of Agriculture	MPKV	Algae, bacteria, fungi
4.	Col. Sir R. N. Chopra, Microbial Resource Centre, Jammu	MRCJ	Bacteria, fungi
5.	Collection of Insect Pathogens, Dept. of Entomology	CIPDE	Bacteria, fungi, protozoa, virus: insect
6.	Culture Collection, Department of Microbiology	CCDMBI	Bacteria, fungi, yeasts
7.	Culture Collection, Microbiology, and Cell Biology Laboratory	NTCCI	Bacteria, fungi, yeasts, viruses: animal,
8.	Delhi University Mycological Herbarium	DUM	Fungi
9.	DMSRDE Culture Collection	DMSRDE	Bacteria, fungi
10.	Food and Fermentation Technology Division, University of Mumbai	UMFFTD	Bacteria, fungi, yeasts, algae
11.	Fungal Culture Collection	VPCI	Fungi
12.	Global Collection of Cyanobacteria	GCC	Cyanobacteria
13.	Goa University Fungus Culture Collection and Research Unit	GFCC	Archea, bacteria, yeast, fungi, algae
14.	Indian Type Culture Collection	ITCC	Bacteria, fungi
15.	MACS Collection of Microorganisms	MCM	Bacteria, fungi

16.	Microbial Culture Collection	MCC	Bacteria, fungi
17.	Microbial Type Culture Collection & Gene Bank	MTCC	Bacteria, fungi, yeasts, plasmids
18.	Mushroom Biodiversity-Western Regional Centre	CMBB	Fungi: mushrooms
19.	National Agriculturally Important Microbial Culture Collection	NAIMCC	Bacteria, fungi, yeasts, cyanobacteria
20.	National Collection of Dairy Cultures	NCDC	Bacteria, fungi, yeasts, dairy starter Cultures
21.	National Collection of Industrial Microorganisms	NCIM	Algae, bacteria, fungi, yeasts
22.	National Culture Collection of Pathogenic fungi	NCCPF	Fungi
23.	National Facility for Marine Cyanobacteria	BDU	Cyanobacteria
24.	National Fungal Culture Collection of India	NFCCI	Fungi
25.	NII Microbial Culture Collection	NIICC	Bacteria, fungi, yeasts
26.	North Maharashtra Microbial Culture Collection Centre	NMCC	Bacteria, fungi, cyanobacteria, Actinomycetes
27.	Visva-Bharati Culture Collection of Algae	VBCCA	Algae
28.	Whylabs Resource Centre for Microorganisms	AYL	Bacteria, fungi

conservation efforts worthwhile and successful.

Applications of microorganisms:

Microbes are tiny invisible creatures but their impact (harmful and beneficial) is very visible and make dent in every sphere of life. Microorganisms particularly prokaryotic ones are small in size so their surface to volume ratio is very large and the movement of materials from the surrounding environment and their distribution within the cell is at an enormously fast rate as compared with large eukaryotic cells. The metabolic rate per unit volume of microbial cells is very high. Thus, the microbial cells are considered as miniature factories which process mass and energy at a very fast rate into useful products. Microbes interact with the surrounding environment and in order to compete with other organisms for food and its survival and that process these produce many biomolecules e.g. antibiotics, vitamins, amino acids, organic acids, solvents, biofuels, polymers, enzymes, hormones, food additives, etc. The basic study on the interaction of microbes with physical, chemical, and biological surroundings is not limited to symbiosis or antibiosis types of interactions ((Joshi et al., 2017) but the chemistry of such interactions has led to consider and use microbes for industrial production of large numbers of commodity and fine chemical. Thus, microbes and microbial enzymes have emerged as green chemistry tools for organic synthesis. When biodiversity is screened for a particular benefit and a particular species / strain / organism is selected in terms of quality and quantity for the economic gain or commercial activity it becomes a resource. There should be continuous efforts to assess, isolate, identify, preserve microbial diversity of various habitats and transform it into bio-resources. Some of the areas where microbes have emerged and recognised as big players are briefly discussed below.

Medical and Pharmaceutical Sector:

The microbes hold great promise for applications in medical and pharmaceutical sector. Researchers in the academia are bioprospecting microorganisms for novel antibiotics, enzymes, bioactive compounds and as probiotics (Jaggi et al., 2020).

Figure 3: Applications of microorganisms in human health and pharmaceutical sector (Suyal et al., 2021) (modified)

Applications of the microorganisms that play pivotal role in human health and pharmaceutical sector are summarised in Figure 3.

Microbes are the source of antibiotics which are most commonly prescribed medicines in treating bacterial or fungal infections. The major problem with antibiotic therapy is the emergence of antibiotic resistance in many of the human pathogens. The microbes from the Himalayan regions can play an important role in the development of novel pharmaceuticals to control drug-resistant pathogens. Probiotic organisms from Himalayan fermented food and beverages also hold potential application in developing products that are beneficial for human health.

The human body is a complex ecosystem harbouring trillions of microorganisms collectively called as the human microbiome. These microbes are present on various body sites, such as the skin, gut, mouth, and reproductive organs, and play vital role in food digestion, immune system modulation, and protection against

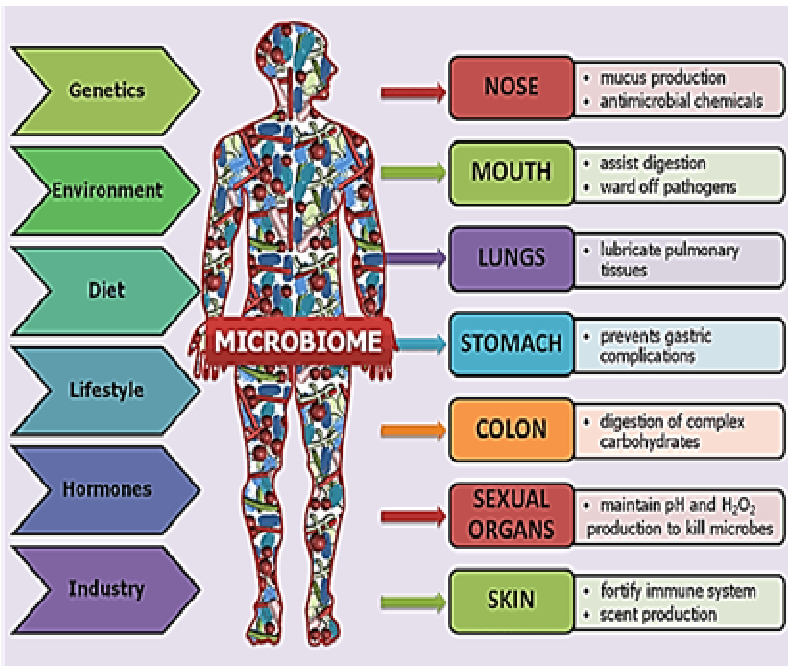

Figure 4: Human gut microbiome and its impact on human health
(Hayes and Sahu (2020) modified)

pathogens. The human microbiome contains about 10-100 trillion symbiotic microbial cells in/on a human body and these are primarily bacteria in the gut. Scientists are exploring the important role these microbes play and their impacts on human health (Figure 4). These beneficial bacteria offer therapeutic benefit by promoting gut health and mitigating the gastrointestinal disorders.

Hill people especially tribals of Himachal Pradesh consume fermented foods and beverages containing probiotics since antiquity and this is linked with their good health and longevity. Saccharomyces cerevisiae, Candida tropicalis, Pichia kudriavzevii, Lactobacillus plantarum, Pediococcus pentosaceus, Serratia spp. are some microbes used as probiotics while Kluyveromyces lactis and Saccharomyces cerevisae SAA-612 find their application as prebiotics. Research on the human microbiome has opened new vistas for understanding and treating various health conditions, including metabolic disorders and autoimmune diseases (Suyal et al., 2021). Harnessing the power of microbes through advancements in microbiome research holds very good potential for novel therapeutic interventions, preventive healthcares, and personalized medicines.

Microbes and Food Industry:
In the food processing area, microbes are employed in food fermentation to produce bread, curd, yogurt, kefir, cheese, pickles, sauerkraut, beverages and food additives while some food products are made from processing of microbial

Table 3: Some applications of the microorganisms in food industry (Hayes and Sahu (2020) modified)

Product	Contribution of Microorganisms
Alcoholic beverages	Yeast Saccharomyces cervisiae is used to convert sugar, grape juice, or malt-treated grain into alcohol.
Yogurt/dahi	Lactobacillus bulgaricus and Streptococcus thermophilus are used for making yogurt while Lactobacillus lactis, Strptococcus thermophilus may be starter cultures for making dahi
Cheese	Bacteria (Lactobacillus bulgaricus, L. helveticus, L. delbrueckii, Strptococcus thermophilus) and fungi (Penicillium roquefortis, P. camemberti, Mucur spp., Fusarium domesticum) that are involved in ripening and flavouring of cheese. Lactobacillus spp are used in making many other fermented dairy products

Citric acid	Certain fungi (e.g. Apergillus niger) are used to make citric acid, a common ingredient of soft drinks and other foods.
Vinegar	Acetobacter aceti is used to convert alcohol into acetic acid, which imparts sour taste to vinegar.
Vitamins	Microorganisms are used for production of vitamins including C, B2, B12.

cells e.g. yeast extract, pigments, mycoproteins, etc (Joshi et al., 2017). Microbes significantly change the flavours, enhance nutritional value and prolong shelf life of foods. Some applications of microbes in food industry are listed in Table 3.

Plant and Microbe Interaction for Sustainable Agriculture:

Some microbes form symbiotic relationships with plants and help them to absorb nutrients from the soil. Plants secrete specific metabolites that attract particular microbes in the rhizosphere and a dynamic interaction between plants and microorganisms essential for plant growth and health sets in. Beneficial microbes such as mycorrhizal fungi make symbiotic relationships with plant roots which enhance nutrient uptake and water absorption; and improve overall health of plants (Ambardar and Vakhlu 2013). Nitrogen-fixing bacteria add to soil fertility while other microbes modulate plant defence against pathogens leading to increased productivity (Gupta and Vakhlu 2015). In Himachal Pradesh efforts are being made by agriculture and horticulture universities to explore diversity of rhizosphere microbes, understand the plant-microbes interactions and develop these microbes as soil inoculants and substitutes for agro-chemicals. Microbes from Himalayan regions have been suggested as better biofertilizers and biopesticides for the crops cultivated in cold and mountainous areas, as they also help in the mitigation of low temperature and biotic stresses (Borker et al., 2022). Microorganisms from the same areas have the better capability to enhance plant growth by making available nutrients in soluble form. They are also known for producing plant growth regulators like abscisic acid, auxin, cytokinin, ethylene, and gibberellins that enhance the productivity of crops and some secondary metabolites of therapeutic importance in the plants (Ambardar and Vakhlu, 2013) In view of climate change, further understanding and harnessing these microbial resources is inevitable for sustainable agricultural practices and enhancing crop yield.

Microbes and Environment:

Microorganisms play an important role in nutrient cycling, decomposition, and maintaining ecological balance in nature. Bacteria and fungi decompose organic matter and release essential nutrients that sustain plant and animal life (Yadav et al., 2015). Cyanobacteria and algae significantly contribute to the production of oxygen through photosynthesis thus playing a very crucial role in global biogeochemical cycles. The active interaction between microbes and plants maintains ecological harmony and shapes the health and vitality of ecosystems (Suyal et al., 2021). The microorganisms are used for bio-remediating the pollutant (pesticides, heavy metals, and xenobiotics) contaminated soil, water and air, thus playing very significant role in environmental sustainability (Ambardar and Vakhlu 2013).

Microorganisms are used to convert organic wastes into fuel e.g. ethanol and biogas. Some algal systems have been explored for the production clean fuel hydrogen (Gupta 2023, Suyal et al., 2021). Their wide amplitude of adaptability enable them to survive in extreme environments, from deep-sea hydrothermal vents to snow bound areas, arid deserts, acid, alkaline saline habitats. The extremophiles from Himalayan regions have potential application in waste management and the restoration of ecosystems.

Market Potential of Microbial Products:

The market of microbial products is characterized by on-going research and innovation, collaborations between industry and academia, and emphasis on sustainable and eco-friendly solutions. Microorganisms comprise versatile resources with remarkable implications for industries and entrepreneurs in science. Microbes like bacteria, yeast and moulds are employed in the fermentation processes that yield myriads of valuable products. The diverse metabolic capabilities of microbes make them important assets in biotechnology, medicine, agriculture, and environmental management (Joshi et al., 2017). With the increasing emphasis in industry for eco-friendly use and production of chemicals and other products (i.e. to practice green chemistry), microbes and microbial routes have emerged as substitute for chemical processes and products. The microbes are presently used for the production of enzymes, biofuels, vitamins, hormones, amino acids, organic acids, antibiotics, anticoagulants, antidepressants, biopolymers, antioxidants, biopigments, and numerous other bio-based products (Chauhan et al., 2023). Table 4 lists some industrially important enzymes produced by microorganisms reported from the state.

Table 4: Some microorganisms as source of commercially important enzymes (Thakur and Bhalla (2023) (modified)

Microbes	Enzyme
Bacillus sp. LPB-6, *Cercospora* sp., *Aspergillus niger*	Laccase
Aspergillus fumigatus	Tannase
Bacillus sp. APB-6, *Geobacillus* sp. RL-2a, *Pseudomonas* sp. BR-1	Amidase
Fungal isolate PPF-6	Phytase
Bacterial UPB-6	Urease
*Serratia marcescencs*MTCC-97	Peptidase
Pseudomonas sp. XPB-6	Xylanase
Bacillus sp. APB-6 , *Rhodococcus rhodochrous* PA-34	Nitrile hydratase
Bacterial isolate PAB-6	Penicillin acylase
Pseudomona ssp CS-2, *Bacillus* sp.	Collagenase
Citrobacter freundii MTCC 2424	L-Methionine-γ-lyase
Serratia marcescens	Protease
Bacillus aerius, Bacillus licheniformis MTCC-10498, Bacillus thermoamylovorans BHK67	Lipase
Aspergillus sp., Byssochlamysfulva MTCC 505	Polygalacturonase
Acetobacter sp.	Dextransucrase
Bacillus sp. CHTM-12	Chitosanase
Nocardia globerula NHB-2, Rhodococcus sp. NDB 1165 , Rhodococcus rhodochrous PA-34, Gordonia terrae	Nitrilase

The rise in demand for microorganisms or their products in diagnostics, healthcare and treatment of infectious or non-infectious diseases has resulted in expansion of microbial product market. This sector is expected to grow at a much faster rate in future because of the increase in diseases like cancer, life style related health issues, cardiovascular and neural disorders. The advances in genetic engineering and fermentation technology have proven boon in making economical and eco-friendly microbial products available in the market (Suyal et al., 2021). The enzyme market is increasingly swelling as the paper, leather, food, biogas, biofuel industries are substituting chemical treatments with enzymes. Increased awareness of sustainable practices and microbe based solutions for the problems we facing in environment management, agriculture, medicine and industry has further expanded the market for microbial products and processes (Thakur et al. 2015). Some key segments within the microbial products market include: biopharmaceuticals, probiotics and prebiotics, agro-microbials, industrial enzymes, bioremediation products and microbial fuel cells (Chauhan et al., 2023). The global and Indian market and estimated growth for some microbial products are presented in Table 5. In view of these data, it becomes

Table 5: Global and Indian market and estimated growth for some microbial products (Hayes and Sahu (2020) modified)

Product	World		India	
	Market (USD Billion)	Growth Rate (%)	Market (USD Billion)	Growth Rate (%)
Probiotics	43	10	32	20
Bio-fertilizers	02	13	100	11
Bio-pesticides	07	14	200	10
Bio-pharmaceutical	478	08	04	13
Enzymes	6.3	07	390	20
Antibiotics	51	2.5	15.7	4

evident that there is a huge scope for start-up and entrepreneurship in microbial products and services.

Emerging Challenges:

Microorganisms have vast applications and benefits starting from household to agriculture, medicine, industry and environment as discussed above, however, they also present challenges. Emerging bacterial and viral diseases in humans, pose serious threats to global health what we experienced during covid-19 pandemic. Excessive use of antibiotics has led to the development of antibiotic-resistance in pathogens and indiscriminate use and release of toxic chemical in the environment have greatly affected human life; microbial, plant and animal populations. Global warming and climate change is impacting our agriculture. Population rise, food security, malnutrition, substitute for fossil fuels, clean energy sources; agricultural, municipal and industrial wastes disposal are the other challenges we are facing. The Himalayan microbial diversity may provide solutions to overcome some of these challenges. Present tools and techniques employed are not suffice to assess, isolate and characterise complete microbial diversity of a particular habitat and thus more refined, versatile and genius approaches need to be developed to further explore and get holistic view of the diversity. The existing infrastructure and manpower in culture collection centres have limitation to handle increasing volume of cultures these receive for identification and preservation. It will be worthwhile to create awareness among administrators, policy planners, entrepreneurs, agriculturists, environmentalists, industrialists and the common people about the importance of microbial diversity and microbial resources in sustainable practices and this will contribute to strengthen microbial diversity conservation efforts vis-à-vis its exploitation for economic development.

Conclusion:

Himachal Pradesh harbours unique ecological niches comprising cold deserts, hot water springs, saltmine areas, temperate forests, alpine vegetation, grasslands, lakes, rivers, rivulets, waterfalls, orchards, agricultural field , etc., which make the state a hot spot of biodiversity including microbial diversity. Microbial diversity of Himachal Pradesh has been explored by researchers of several institutions located in and out of the state and many of the microbes have been well documented as probiotics, soil or plant inoculants or as source of enzymes, pharmaceuticals, bioactive compounds, bio-pigments, biopolymers, etc. Microbial diversity hitherto explored is only a small fraction of what exists in the rare habitats of the state. Planned, focussed and coordinated efforts are needed to further explore the stunning and hidden treasure of microbial world of the Himalayas and translate it into microbial resources. Understanding and preservation of Himalayan microbial diversity is not only of ecological importance but also offer immense opportunities for academia and industries for basic and applied research, sustainable agriculture, and pharmaceutical discoveries. A culture collection for identification and preservation of the microbial wealth of the state is needed to be established. The exploration of microbial diversity and harnessing its benefits for the society are only possible with skilled manpower in place in academic and research institutions, and industry.

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G.B. Pant National Institute of Himalayan Environment (NIHE)

G.B. Pant National Institute of Himalayan Environment (formerly known as G.B. Pant National Institute of Himalayan Environment and Sustainable Development, was established in 1988-1989, 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 integrated 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 functions under a Society, guided by a Governing Body and Science Advisory Committee. It has a decentralized set up, with its Headquarters at Kosi-Katarmal, Almora, and at present six regional centres are operational at Srinagar (Garhwal Regional Centre), Mohal-Kullu (Himachal Regional Centre), Tadong-Gangtok (Sikkim Regional Centre), Itanagar (North-East Regional Centre), Ladakh (Ladakh Regional Centre) and Mountain Division (at MoEF&CC, New Delhi). The R &D programmes of the Institute have been reoriented in to four functional Centres based of stakeholder needs, viz., Centre for Land and Water Resource Management (CLWRM), Centre for Socio-Economic Development (CSED), Centre for Biodiversity Conservation and Management (CBCM) and Centre for Environmental Assessment & Climate Change (CEA&CC). (Details: http://gbpihed.gov.in).

Himachal Pradesh Regional Center (HPRC)

Himachal Regional Center is located in Mohal of the Kullu district of Himachal Pradesh state. The Himachal Regional Center was established on July 01, 1992, in a rented building at Dhalpur, District Kullu, and continued up to June 1993. The foundation stone of the center's office and residential complex was laid by Shri Kamal Nath, Hon'ble Union Minister for Environment and Forests on June 2, 1993, in Mohal village of Kullu district. During the construction of the office and residential complex, the work of Himachal Regional Center was conducted from June 1993 to March 1999 at the rent building of Shamshi, Kullu. After the construction of a permanent building in Mohal in the year 1998, on April 02, 1999, the office and residential complex were duly inaugurated by Hon'ble Shri Suresh Prabhu, Environment Minister, Ministry of Environment and Forests, Government

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