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Biodiversity of psychrotrophic microbes and their biotechnological applications

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ABSTRACT

The extreme cold environments harbor novel psychrotrophic microbes. The psychrotrophic microbes have been reported as plant growth promoters and biocontrol agents for sustainable agriculture, in industry as cold-adapted hydrolytic enzymes and in medicine as secondary metabolites and pharmaceutical important bioactive compounds. Inoculation with psychrotrophic/psychrotolerant strains significantly enhanced root/shoot biomass and nutrients uptake as compared to non-bacterized control. The psychrotrophic microbes play important role in alleviation of cold stress in plant growing at high hill and low temperature and conditions. The psychrotrophic microbes have been reported from worldwide from cold habitats and belong to all three domain archaea, bacteria, and eukarya including different phylum such as Actinobacteria, Ascomycota, Bacteroidetes, Basidiomycota, Chloroflexi, Chlamydiae, Planctomycetes, Cyanobacteria, Euryarchaeota, Firmicutes, Gemmatimonadetes, Verrucomicrobia, Mucoromycota, Proteobacteria, Spirochaetes, Thaumarchaeota and Nitrospirae. The most dominant genera belong to *Arthrobacter, Bacillus, Exiguobacterium, Paenibacillus, Providencia, Pseudomonas,* and *Serratia* have been reported from the cold habitats. The Psychrotrophic microbes have biotechnological applications in agriculture, medicine, industry, food, and allied sectors.

1. INTRODUCTION

The extreme environment of low temperature is one of the major abiotic stresses acting as the limiting factor affecting the agricultural productivity. 20% of the Earth's surfaces were covered frozen soils (permafrost), glaciers and ice sheets, and snow cover area. Extreme low temperature represents unique ecosystems which harbor novel biodiversity which has been extensively investigated in the past few years with a focus on culture-dependent and culture-independent techniques [1-6]. The psychrotrophic microbes have been reported from all three domains of life archaea, bacteria, and eukarya and belong to different phylum, namely Actinobacteria, Planctomycetes, Acidobacteria, Ascomycota, Bacteroidetes, Spirochaetes, Basidiomycota, Chlamydiae, Chloroflexi, Nitrospirae, Cyanobacteria, Verrucomicrobia, Firmicutes, Gemmatimonadetes, Mucoromycota, Proteobacteria, Thaumarchaeota, and Euryarchaeota [3-10]. The microbial diversity has opened up new possibilities for potential biotechnological agricultural and industrial applications of beneficial and efficient microbes for diverse sectors including agriculture, industry, and medicine. The cold-adapted microbes attracted the attention of the scientific community due to their aptitude in plant growth promotion, adaptation of plants at low-temperature conditions.

The novel microbes have been isolated using the culture-dependent techniques from cold environments worldwide including *Actinoalloteichus spitiensis,* RMV-378^T [11], *Agrococcus lahaulensis,* K22-21^T [12], *Arthrobacter psychrochitiniphilus,* GP3^T [13], *Azospirillum himalayense,* ptl-3^T [14], *Bacillus lehensis,* MLB2^T [15], *Desulforhopalus vacuolatus,* ltk10 [16], *Dioszegia antarctica,* ANT-03-116^T [17], *Exiguobacterium himgiriensis,* K22–26^T [18], *Exiguobacterium soli,* DVS 3Y^T [19], *Flavobacterium frigidarium,* A2i^T [20], *Flavobacterium omnivorum,* ZF-8^T [21], *Flavobacterium phocarum,* SE14^T [22], *Flavobacterium urumqiense,* Sr25^T [23], *Gelidibacter algens,* ACAM 536 [24], *Geopsychrobacter electrodiphilus,* A1^T [25], *Glaciecola pallidula,* ACAM 615^T [26], *Glaciimonas frigoris,* N1-38^T [27], *Halobacterium lacusprofundi,* ACAM 32^T [28], *Hymenobacter rubripertinctus,* NY03-3-30^T [29], *Massilia eurypsychrophila,* B528-3^T [30], *Nocardiopsis antarcticus* [31], *Paenibacillus glacialis,* KFC91^T [6], *Pedobacter arcticus,* A12^T [32], *Pseudomonas deceptionensis,* M1^T [33], *Psychrobacter pocilloporae,* S6-60^T [34], *Sphingobacterium antarcticus,* 4BY [35], and *Sulfitobacter brevis,* EL-162^T [Table 1] [36].

The cold habitats such as cold deserts, glaciers, and subglacial lakes are hot spots of a great microbial diversity of psychrophilic, psychrotolerant,

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Table 1: Novel psychrotrophic microbes from diverse cold habitats

Novel microbes	Habitats	References
Actinoalloteichus spitiensis, RMV-378T	Spiti Valley	[11]
Arthrobacter flavus, CMS 19YT	Antarctica	[90]
Azospirillum himalayense, ptl-3T	Chamba Valley	[14]
Bacillus cecembensis, PN5T	Pindari Glacier	[91]
Bacillus lehensis, MLB2T	Leh, JK	[15]
Cenarchaeum symbiosum, Fosmid 4B7	Sponge Symbiotic	[92]
Chryseomicrobium imtechense, MW 10T	Bay of Bengal	[93]
Cryobacterium psychrotolerans, 0549T	China No. 1 glacier	[94]
Cryobacterium roopkundense, RuGl7T	Roopkund Lake	[95]
Desulforhopalus vacuolatus, ltk10	Kysing Fjord	[16]
Dyadobacter hamtensis, HHS 11T	Hamta glacier	[96]
Exiguobacterium himgiriensis, K22–26T	Spiti Valley	[18]
Exiguobacterium soli, DVS 3YT	Antarctica	[19]
Flavobacterium frigidarium, A2iT	Antarctica	[20]
Flavobacterium omnivorum, ZF-8T	China No. 1 Glacier	[21]
Flavobacterium xinjiangense, ZF-6T	China No. 1 Glacier	[21]
Gelidibacter algens, ACAM 536	Burton Lake	[24]
Geopsychrobacter electrodiphilus, A1T	Marine Sediment	[25]
Glaciimonas frigoris, N1-38T	Siberian Permafrost	[27]
Halobacterium lacusprofundi, ACAM 32 T	Antarctic Lake	[28]
Halohasta litchfieldiae, tADLT	Antarctic Lake	[97]
Hymenobacter rubripertinctus, NY03-3-30T	Antarctica	[29]
Kocuria himachalensis, K07-05T	Spiti Valley	[98]
Massilia eurypsychrophila, B528-3T	Muztagh Glacier	[30]
Nocardiopsis antarcticus,	Antarctica	[31]
Octadecabacter arcticus, 307T	Antarctica	[99]
Octadecabacter arcticus, 238T	Antarctica	[99]
Oleispira antarctica, RB-8T	Antarctic	[100]
Ornithinimicrobium kibberense, K22-20T	Spiti Valley	[101]
Paenibacillus glacialis, KFC91T	Kafni Glacier	[32]
Polaromonas vacuolata, 34-PT	Antarctic	[102]
Pseudomonas extremaustralis, 14-3T	Antarctic	[103]
Psychrobacter pocilloporae, S6-60T	Andaman Sea	[35]
Psychroflexus torquis, ACAM 623T	Sea Ice Antarctica	[104]
Psychromonas aquimarina, JAMM 0404T	Kagoshima, Japan	[105]
Rhodobacter changlensis, JA139T	Changla Pass, HP	[106]
Rhodotorula himalayensis, 3AT	Roopkund Lake	[107]
Shewanella frigidimarina, ACAM 591	Antarctic Sea Ice	[108]
Shewanella gelidimarina, ACAM 456	Antarctic Sea Ice	[108]
Sphingobacterium antarcticus, 4BY	Antarctica	[35]
Sphingobacterium psychroaquaticum, L-1T	Michigan Lake	[109]

and psychrotrophic microbiomes. The cold-adapted microbes possess diverse genes responsible for cold adaptation and genes for diverse molecules and alleles with potential applications in diverse fields. There are several reports on whole genome sequences of novel and potential psychrotrophic microbes such as *Arthrobacter agilis* [37], *Cenarchaeum symbiosum* [38], *Clavibacter* sp. [39], Colwellia chukchansi [40], *Colwellia psychrerythraea* [41], *Exiguobacterium antarcticum* [42], *Exiguobacterium oxidotolerans* [43], *Exiguobacterium sibiricum* [44], *Methanococcoides burtonii* [45], *Octadecabacter antarcticus* [46], *Paenibacillus* sp. [47], *Planomicrobium glaciei* [48], and *Rheinheimera* sp. [Table 2] [49]. The whole genome sequences of cold-adapted microbes help to understand the adaptation on microbe under the extreme cold habitats and also potential genes for functional attributes, for example, *A. agilis* L77, are an important psychrophilic

Table 2: Genome sequencing of psychrophilic and psychrotrophic microbes isolated from diverse cold habitats worldwide

Psychrotrophic microbes	Source	Size (Mb)	G+C (%)	CDS	References
Acinetobacter sp.	Lahaul-Spiti	4.31	40.75	4017	[110]
Arsukibacterium ikkense	Cold Habitat	4.13	49.7	3605	[111]
Arthrobacter agilis	Pangong Lake	3.60	69.79	3316	[37]
Arthrobacter alpines	Sikkim	4.30	60.64	4154	[112]
Arthrobacter sp.	Chandra Tal	3.60	58.97	3454	[113]
Cenarchaeum symbiosum	Marine	2.05	57.40	2017	[38]
Clavibacter sp.	Mongolia	3.12	73.5	2888	[39]
Colwellia polaris	Canada	4.43	37.5	3686	[40]
Colwellia psychrerythraea	Sea Ice, Arctic	5.37	38.00	4634	[41]
Cryobacterium roopkundensis	Roopkund	4.36	65.30	4048	[114]
Exiguobacterium antarcticum	Lake Fryxell	2.82	47.50	2746	[42]
Exiguobacterium sibiricum	Permafrost	3.03	47.70	2981	[44]
Hymenobacter sp.	Antarctica	5.26	60.7	4328	[115]
Idiomarina sp.	Pangong Lake	2.59	45.50	2299	[116]
Methanococcoides burtonii	Ace Lake	2.54	44.08	2406	[45]
Microterricola viridarii	Glacier	3.70	68.70	3456	[117]
Nesterenkonia sp.	Permafrost	3.70	69.50	2886	[118]
Octadecabacter antarcticus	Sea Ice, Arctic	4.81	54.60	4428	[46]
Paenibacillus	Lahaul-Spiti	8.44	50.77	7335	[119]
Planomicrobium glaciei	Chandra River	3.90	46.97	3934	[48]
Pseudomonas trivialis	Lahaul-Spiti	6.45	59.91	6032	[120]
Rheinheimera sp.	Pangong Lake	4.52	46.23	3942	[49]
Saccharomyces eubayanus	Cold Habitat	1.27	39.60	589	[121]
Zhihengliuella sp.	Pangong Lake	3.53	69.84	3363	[122]

CDS: Coding sequence

bacteria isolated from Pangong lake, Northwest (NW) Himalayas, India. The strain L77 has abilities to produced cold-adapted hydrolytic enzymes and shows that the plant growth-promoting (PGP) attributes are different low-temperature conditions. The whole genome sequences of psychrophilic bacteria revealed different genes for adaptation and metabolic activities [37]. The novel psychrophilic/psychrotolerant microbes and their products will be applicable in broad range of agricultural, industrial, and medical processes. The cold-tolerant psychrotrophic microbes can be valuable in agriculture as inoculants biofertilizers and biocontrol agents. The present review describes the microbial diversity analysis from cold habitats and its potential applications in agriculture, industry, medicine, and allied sectors.

2. BIODIVERSITY PSYCHROTROPHIC MICROBES

The extreme of cold represents hot spots of microbial biodiversity for psychrotrophic, psychrophilic, and psychrotolerant microbiomes [9,50,51]. The biodiversity of psychrotrophic microbes inhabiting cold habitats has been extensively investigated worldwide and has been reported from phylum, namely Actinobacteria, Gemmatimonadetes, Ascomycota, Acidobacteria, Bacteroidetes, Basidiomycota, Chlamydiae, Chloroflexi, Proteobacteria, Cyanobacteria, Firmicutes, Mucoromycota, Verrucomicrobia, Nitrospirae, Planctomycetes, Spirochaetes, Thaumarchaeota, and Euryarchaeota [Figure 1]. The microbiomes of cold habitats including the subglacial lakes, Antarctic, Arctic glacier, permanently ice-covered sea, permafrost, and Himalayan and Mountain lakes have been investigated for the diversity of psychrotrophic, psychrophilic, and psychrotolerant microbes [52-56,19,57-62].

The biodiversity of cold-adapted bacteria was deciphered from northern hills zone of India. A total of 247 culturable bacteria have been isolated using serial dilution and spread plate methods from different sites in Indian Himalayan regions. The bacteria have been identified using 16S rRNA gene sequencing and BLAST analysis. All sequences have been analyzed for phylogenetic profiling and revealed that the sequences are affiliated to four phyla, namely Firmicutes, Proteobacteria, Bacteroidetes, and Actinobacteria. The selected strains have been found to be PGP attributes, which included phosphorus, K, and Zn solubilization; NH_3, HCN, indole-3-acetic acid ($C_{10}H_9NO_2$), and Fe-chelating compounds production; and the activity of 1-aminocyclopropane-1-carboxylate (ACC) deaminase and biological nitrogen fixation. The psychrotrophic bacteria also possess biological control against the different pathogens such as *Macrophomina phaseolina, Rhizoctonia solani,* and *Fusarium graminearum.* These PGP psychrotrophic and psychrotolerant bacteria could be applicable as biofertilizers and biocontrol agents for crops cultivated under the low-temperature conditions and hilly regions [2].

The Indian cold deserts are suitable for the selection of psychrotrophic and psychrotolerant bacteria, archaea, and fungi with potential biotechnological application in diverse sectors, microbes. Yadav *et al.* [63] investigated microbiome of the cold deserts of Northwestern Himalayas, India, using culture-dependent and culture-independent

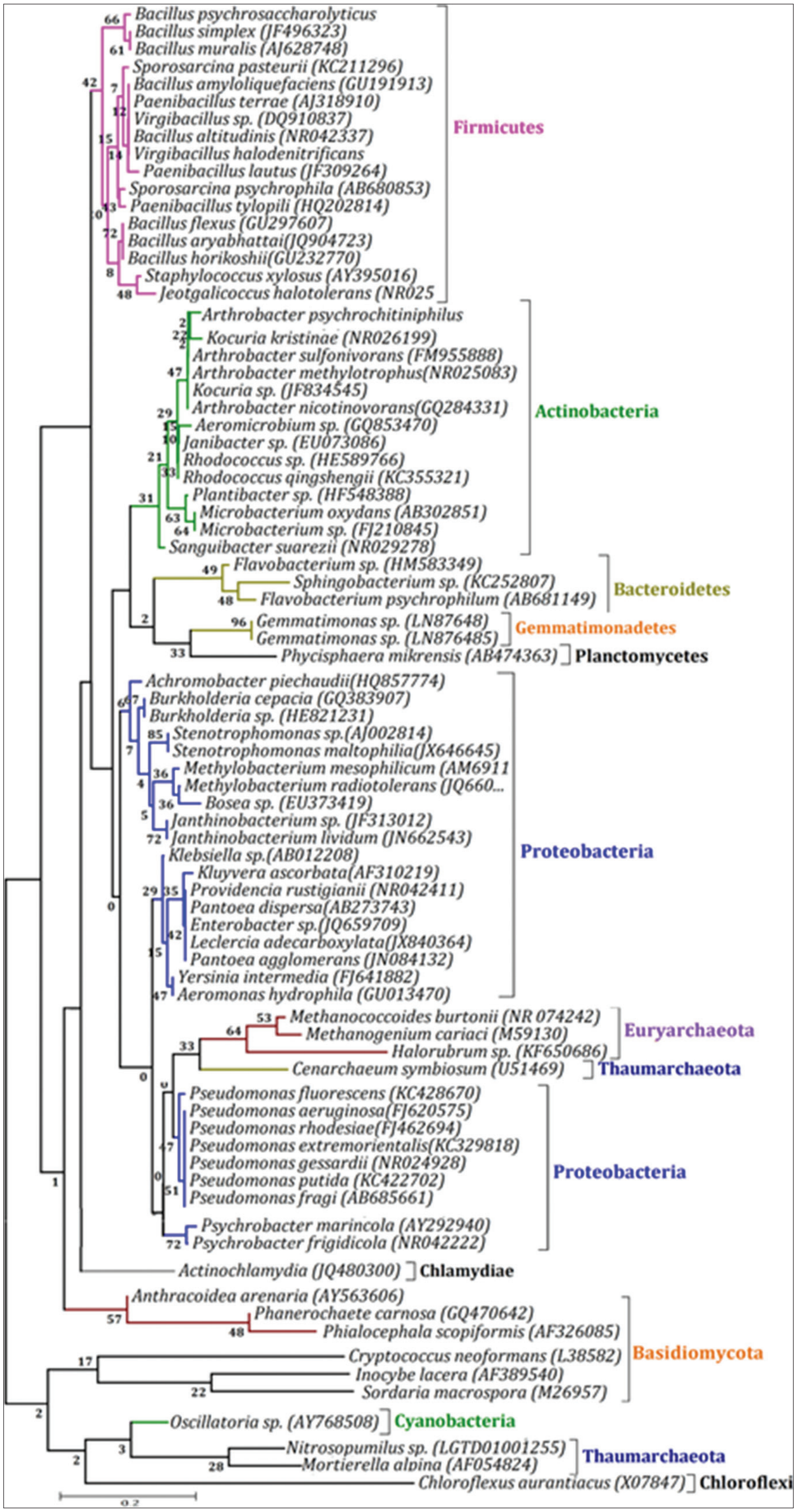

Figure 1: Phylogenetic tree showed the relationship among psychrotrophic, isolated from diverse cold habitats worldwide

method and reported different genera, belonging to different phyla, namely Bacteroidetes, Firmicutes, Actinobacteria, and Proteobacteria. The selected microbe showed PGP attributes of the production of NH_3, HCN, gibberellic acid, Fe-chelating compounds (catecholates [phenolates], hydroxamates, and carboxylates), and indole acetic acids; P, K, and Zn solubilization and ACC deaminase activity. The microbiomes with psychrotrophic ability with different PGP traits may be used as biofertilizers/bioinoculants and biocontrol agents for hilly crops. The report by Yadav *et al.* [63] shows the presence of *Pseudomonas cedrina, Brevundimonas terrae, Arthrobacter nicotianae,* and *Paenibacillus tylopili* in cold habitats for the 1st time and exhibits multifarious PGP attributes at low-temperature conditions. In another investigation by Yadav *et al.* [64], the culturable biodiversity of microbiomes in Leh Ladakh region and found that bacteria belong to four phyla, namely Proteobacteria, Firmicutes, Bacteroidetes, and Actinobacteria which included different genera *Bacillus, Desemzia, Pseudomonas, Sporosarcina, Arthrobacter, Psychrobacter, Exiguobacterium, Flavobacterium, Alishewanella, Staphylococcus, Brachybacterium, Klebsiella, Providencia, Paracoccus, Planococcus, Sinobaca, Janthinobacterium, Sphingobacterium, Kocuria, Aurantimonas, Citricoccus, Cellulosimicrobium, Brevundimonas, Stenotrophomonas, Vibrio,* and *Sanguibacter.* These microbes possess PGP attributes and may be applicable as bioinoculants and biocontrol for crops in hilly area.

The subglacial lakes are also hot spots of microbial diversity of psychrotrophic and psychrotolerant bacteria with functional attributes of cold-adapted and cold stable active extracellular hydrolytic enzymes productions [65]. On the basis of DNA isolation, polymerase chain reaction amplification of 16S rRNA gene and their sequencing using universal primers reveled that isolated bacilli belong to different genera, namely *Exiguobacterium, Virgibacillus, Staphylococcus, Lysinibacillus, Jeotgalicoccus, Desemzia, Bacillus, Paenibacillus, Planococcus, Pontibacillus, Sinobaca,* and *Sporosarcina.* The identified genera affiliated to different families Bacillales incertae sedis, Carnobacteriaceae, Bacillaceae, Planococcaceae, Paenibacillaceae, Staphylococcaceae, and Sporolactobacillaceae. The selected isolates found to exhibit cold-active enzymes such as amylase, chitinase, pectinase, β-glucosidase, protease, cellulase, xylanase, β-galactosidase, laccase, and lipase by different genera, namely *P. terrae*, *Bacillus amyloliquefaciens*, *Exiguobacterium indicum*, *Bacillus marisflavi*, *Pontibacillus* sp., *Sporosarcina globispora,* and *Sporosarcina psychrophila.*

The PGP psychrotrophic bacilli were investigated from different sites in NW Himalayas India [66] and bacteria have been reported from different genera, namely *Desemzia, Exiguobacterium, Lysinibacillus, Sporosarcina, Jeotgalicoccus, Planococcus, Paenibacillus, Sinobaca, Pontibacillus, Staphylococcus,* and *Virgibacillus.* Among all the identified bacterial strains, *Bacillus muralis, Bacillus licheniformis, Sporosarcina globispora, P. tylopili,* and *Desemzia incerta,* were found to be an important biofertilizers for Indian Himalayan agriculture.

Cold-adapted microbes are ubiquitous in nature and can be isolated from permanently ice-covered lakes, cloud glaciers, and hilly regions [8]. Microbes recovered using isolation techniques using different growth media as selective and complex and using 16S rRNA gene sequencing the bacteria were affiliated to genera *Stenotrophomonas, Virgibacillus, Citricoccus, Enterobacter, Brevundimonas, Providencia, Pseudomonas, Flavobacterium, Pantoea, Planococcus, Paenibacillus, Pontibacillus, Methylobacterium, Psychrobacter, Cellulosimicrobium, Exiguobacterium, Janthinobacterium, Lysinibacillus, Rhodococcus, Sanguibacter, Arthrobacter, Sphingobacterium, Bacillus, Staphylococcus,* and *Sporosarcina.* The identified bacteria affiliated to different phylum on the phylogenetic profiling using Actinobacteria, Proteobacteria, Basidiomycota, Chlamydiae, Chloroflexi, Bacteroidetes, Cyanobacteria, and Firmicutes using Mega 4 analysis.

Cold-adapted microbial communities can be studies using culture-dependent and culture-independent techniques. The microbiomes reported using both techniques culture dependent and culture independent revealed the occurrence of different and diverse major groups viz., Actinobacteria, Ascomycota, Bacteroidetes, Verrucomicrobia, Thaumarchaeota, Spirochaetes, Proteobacteria, Planctomycetes, Nitrospirae, Mucoromycota, Gemmatimonadetes, Firmicutes, Euryarchaeota, Cyanobacteria, Chloroflexi, Chlamydiae, and Basidiomycota. On review of isolated cold-adapted microbes, it was found that proteobacteria were most dominant phylum followed by Firmicutes and Actinobacteria [10].

3. BIOTECHNOLOGICAL APPLICATIONS

The psychrotrophic microbes exhibited multifarious PGP attributes such as ACC deaminase activity, potassium zinc and phosphorus solubilization, biological N_2 fixation, and production of different bioactive compounds such as gibberellic acids, ammonia, cytokinins, Fe-chelating compounds, hydrogen cyanide, and indole-3-acetic acid. The use of PGP microbes improves plant growth by supplying plant nutrients, which can help sustain environmental health and soil productivity [10]. Psychrotrophic PGP microbes were found in several genera, including *Arthrobacter, Bacillus, Burkholderia, Pseudomonas, Exiguobacterium, Janthinobacterium, Lysinibacillus, Methylobacterium, Microbacterium, Paenibacillus, Providencia,* and *Serratia* [67-70]. The microbes having ACC deaminase activity help plant to alleviate cold stress [Table 3] [2,66,71,72].

Sustainable agriculture requires the use of strategies to increase or maintain the current rate of crops and food production using eco-friendly manners. PGP microbe can affect plant growth directly under the low-temperature condition through nitrogen-fixing bacteria

Table 3: Psychrotrophic microbes with multifunctional plant growth promoting attributes

Psychrotrophic microbes	P	Sid	ACC	References
Aeromonas hydrophila	31.5±1.8	+	-	[63]
Arthrobacter methylotrophus	55.9±1.4	+	+	[2]
Arthrobacter sulfonivorans	25.6±1.2	+	-	[64]
Bacillus amyloliquefaciens	54.2±1.5	+	+	[123]
Bacillus firmus	35.2±3.3	+	+	[64]
Bacillus licheniformis	19.2±1.0	+		[66]
Bacillus pumilus	36.1±0.8	+	-	[64]
Bacillus subtilis	19.8±0.5	+	+	[64]
Cellulosimicrobium cellulans	15.5±1.1	-	+	[64]
Desemzia incerta	47.5±1.2	+	-	[64]
Paenibacillus tylopili	48.4±2.4	+	-	[66]
Pantoea dispersa	44.5±0.2	+	-	[124]
Pseudomonas fluorescens	768.3±0.2	-	-	[125]
Pseudomonas fluorescens	90.2±1.7	+	-	[126]
Pseudomonas fragi CS11RH1	514.9±0.2	-	-	[127]
Pseudomonas vancouverensis	66.3±0.2	+		[128]
Rahnella sp.	805.0±1.	+	+	[129]
Sanguibacter antarcticus	20.1±0.1	+	+	[64]
Sanguibacter suarezii	18.1±0.5	+	+	[63]
Stenotrophomonas maltophilia	55.7±0.5	+	+	[2]

P: Phosphorus, Sid: Siderophores, ACC: 1-aminocyclopropane-1-carboxylate such as *Arthrobacter*, *Azoarcus*, *Azospirillum*, *Azotobacter*, *Bacillus*, *Enterobacter*, *Gluconacetobacter, Herbaspirillum*, *Klebsiella*, *Pseudomonas*, and *Serratia* [1,2,69,73,74]; ACC deaminase activity by *Acinetobacter, Achromobacter, Agrobacterium, Alcaligenes, Azospirillum, Bacillus, Burkholderia, Enterobacter, Pseudomonas, Ralstonia, Serratia,* and *Rhizobium* [75-78] and through indirect mechanism by releasing siderophores, β-1, 3-glucanase, chitinases, antibiotics, and fluorescent pigment or by cyanide production by *Alcaligenes* sp., *Bacillus pumilus*, *B. subtilis*, *B. megaterium*, *Clavibacter michiganensis, Curtobacterium* sp., *Flavobacterium* sp., *Kluyvera* sp., *Microbacterium* sp., *Pseudomonas alcaligenes, P. putida,* and *P. fluorescens* [79-85].

The psychrophilic, psychrotolerant, and psychrotrophic microbes are important for many reasons, particularly because they exhibited antifreezing compounds, antibiotics, and bioactive compounds production [1] and production of extracellular hydrolytic enzymes with potential biotechnological applications in different processes. These enzymes included β-glucosidase, β-galactosidase, xylanase, protease, pectinase, laccase, lipase, chitinase, cellulase, and amylase [37,65,86]. Cold-active enzymes are produced by psychrophilic microbes, namely *Acinetobacter*, *Aquaspirillum*, *Arthrobacter*, *Moraxella*, *Bacillus*, *Moritella*, *Carnobacterium*, *Planococcus*, *Clostridium*, *Cytophaga*, *Shewanella*, *Vibrio, Flavobacterium*, *Marinomonas*, *Paenibacillus*, *Pseudoalteromonas*, *Pseudomonas*, *Psychrobacter*, and *Xanthomonas* [9,37,65,87-89]. Enzymes from psychrophilic and psychrotrophic microbes have become interesting for different processes in industry, pharmaceuticals, medicine, and food and feed industry. Antifreezing compounds from psychrophilic microbes are useful in cryosurgery and also in the cryopreservation of whole organisms, isolated organs, cell lines, and tissues [1,9,37].

4. CONCLUSION AND FUTURE VISION

The psychrophilic, psychrotolerant and psychrotrophic microbiomes have been isolated from different cold habitats worldwide. The microbial diversity of cold environments has attracted the consideration of the scientific community dues to production of cold active enzymes production, anti-freezing compounds, secondary metabolites and bioactive compounds by psychrotrophic microbes. The psychrotolerant/ psychrotrophic microbes have potential biotechnological applications in industry, pharmaceuticals, medicine, food and feed for human. The psychrotrophic microbes with multifarious

PGP attributes could be used as biofertilizers and biocontrol agents for crops growing in hilly and low temperature condition for enhance crops production and soil health for sustainable agriculture. The psychrotrophic microbes having biodegradation ability could be used for bioremediation, and waste water treatments for sustainable environments. These cold-adapted microbes may be used for biofuels and biodiesel production for future energy systems. The psychrotrophic microbiomes are widely distributed and have been reported to promote plant growth and alleviation of cold stress in plants. Although the most research work conducted so far has largely focused on psychrophilic and psychrotolerant microbes, it is a welcome sign that many agriculturally important resourceful microbes are being described from various parts of the earth.

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