

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,400

Open access books available

174,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Chapter

Extremophiles and Limits of Life in a Cosmic Perspective

Nawab Ali, Muhammad Nughman and Syed Majid Shah

Abstract

Extremophiles are one of the most extreme entity on planet earth which can withstand many harsh conditions considered lethal for other life form of terrestrial life. From an evolutionary prospective, extremophiles are considered to be primitive cells that used to live in the early earths harsh environment living on this planet since billions of years, it can be found in almost in any environmental conditions on our planet. There are many established valuable uses of these extremophiles and particularly their bioactive compounds. The enzymes produced by extremophiles have significant applications in different industries like detergent, food, feed, starch, textile, leather, pulp and paper, and pharmaceuticals This chapter discuss extremophile, their survival mechanism and astrobiology, discussing life in a cosmic prospective.

Keywords: extremophiles, bioactive compounds, limits of life, astrobiology

1. Introduction

Over the period of the last century, the conditions at which life is able to flourish have been pushed in every possible direction, expanding to include wider range of temperature, pH, pressure, radiation, salinity, energy, and nutrient limitation. This has allowed for the discovery of life in previously unimaginable environments. Microorganisms have the ability to thrive in different harsh conditions on earth and in space, which include microgravity, high radiation, vacuum pressure, and extremely diverse temperature [1, 2]. Extremophiles are those organisms which can withstand many harsh conditions which are considered lethal for other life form of terrestrial life. They are able to flourish in extremely higher and lower temperature, as well as acidic and alkaline environments. Many extremophiles can also thrive in different organic solvents, heavy metals and hazardous waste [3]. Space has been often called “The Final Frontier,” where most of the universe’s conditions are hazardous for human habitation [4]. Extremophiles are essential for discovering biosignatures that can be used to find habitable environments beyond the earth. Different ecological habitat of earth has similarity to that of other planets in term of nutrient composition and biogeochemistry [5]. The aim of this chapter is to discuss extremophiles, importance of their bioactive compounds. Later on, the chapter is focused on life in extreme conditions, limits of life and astrobiology, discussing life in a cosmic prospective.

2. Extremophilic microorganisms

The term extremophile was first coined by McElroy in the year 1974 [6]. Most extremophiles are classified within the archaea, bacterial, and eukaryotic kingdoms [7]. Around a decade ago extremophiles were considered exotic organisms that were only investigated by few researchers around the world. Now, it has become a promising field for enzymologists to explore and utilize these microorganisms in a variety of industrial applications [8]. Studies on extremophiles have advanced substantially over the past twenty years where first international congress on extremophiles was held in Portugal (1996) and the peer-reviewed scientific journal “Extremophiles” was launched in 1997. In addition, in 2002, the “Worldwide Society for Extremophiles” (ISE) was established as an international organization for the purpose of facilitating the sharing of knowledge and expertise in the rapidly expanding field of study on extremophiles [9].

Extremophilic organisms have the ability to grow in such environments which are considered inhospitable to other life forms. These conditions include extreme hot and cold environments, and highly alkaline and acidic environments. Several extremophiles can also thrive in different hazardous waste, organic solvents and heavy metals. It's been discovered that extremophiles can also live in more than ten kilometers deep in the ocean and 6.7 kilometers deep in the earth's crust; in conditions ranging from 0 to 12.8 pH, in temperatures from 122°C to 20°C; and at pressures of up to 110 megapascals (MPa) [10]. Some organisms are not only stable at harsh conditions, but they need them to survive. Extremophiles are classified into different classes based on the conditions in which they thrive, they are thermophiles, which can withstand extreme temperature, psychrophiles, which can withstand extreme low temperature, acidophiles and alkaliphiles, which can withstand extreme higher and lower pH, barophiles, which can withstand higher pressure and halophiles which can withstand higher salt concentration [11]. Extremophiles are sometimes considered as polyextremophiles which mean that they can withstand multiple harsh conditions. Some hot springs have diverse harsh conditions i.e., they are alkaline and basic at the same time and also have higher amount of heavy metals. Different hypersaline lakes are extremely alkaline, and the deep oceans have also diverse harsh condition like cold, oligotrophic and high pressure [12].

Extremophiles have attracted a lot of attention because they are able to catalyze reactions despite harsh conditions and also have significant applications in industries [13–15]. Now researchers are focusing more on genetic engineering of enzymes to improve their activity and to make them interesting candidate in industrial and biotechnological processes. This is because extremozymes are more difficult to isolate than other types of enzymes. Microbes with desirable industrial traits are genetically engineered by a large number of research organizations and companies across the world, and these microorganisms has been used in different industrial processes [16]. Industrial enzymes had a market value of more than one billion dollars in 2010, and it was projected that this value will increase to five billion dollars in 2021 at 4% growth per year [17]. This was achieved earlier, as they hit \$5.5 billion in 2018, and various research associations now estimate that they will reach \$7.0 billion by 2023 [18, 19]. Extremozymes are the most promising options to take into consideration to meet the ever-increasing demand on the global market [14]. Extremophiles can produce different industrially important enzymes which are stable at different harsh conditions. We have reviewed different extremophiles, there habitat, growth characteristics, bioactive compounds and their industrial importance as shown in the **Table 1**.

Extremophile	Habitat	Growth characteristics	Bioactive compounds	Species	Application	Reference
Thermophiles	Hydrothermal vents, Hot springs	Growth temperature of more than 80°C	Amylase	<i>Bacillus mojavensis</i>	Glucose fructose for sweetness	[20]
			DNA polymerase	<i>Thermus aquaticus (Taq)</i>	PCR, Diagnostics, molecular biology	[21]
			Xylanases	<i>Bacillus tequilensis</i>	Biorefinery, food	[22]
Halophiles	Salt mines, marine, soil	High salt Concentration i.e., more than 5 M	α- amylase	<i>Halothermorthrix orenii</i>	Bio catalysis	[23]
			Protease	<i>Pseudoalteromonas Sp.</i>	Detergent, Peptide synthesis	[24]
Psychrophiles	Antarctica soil, deep ocean, Mariana trench	Low temperature i.e., below 15°C	β- Galactosidase	<i>Arthrobacter species C2</i>	Biorefinery, ethanol production	[25]
			Lipase	<i>Psychrobacter okhotskensis</i>	Food, cosmetics	[26]
Alkaliphiles	Salt mines, soil, soda lakes	Higher pH i.e., above 9	Protease	<i>Bacillus firmus</i>	Detergent, food and feed	[27]
			Cellulase	<i>Bacillus subtilis</i>	Fermentation of wine	[28]
Acidophiles	Man-made niches, hot springs	Lower pH i.e., lower than 3	Endocellulase	<i>Thermomonospora (Actinomycetes)</i>	Leather industries	[29]
Piezophiles	Deep seam, Mariana trench	Pressure above 110 MPa	Lipase	<i>Cohwellia hadaliensis BNL-1</i>	Food processing	[30]
			Chymotrypsin	<i>Shewanella benthica strains</i>	Pharmaceutical industry	[31]
Radiophiles	High UVR altitudes, Mountains	UVR above 110 nm	Mycosporine-like amino acids (MAAs)	<i>Deinococcus radiodurans</i>	Diagnostics, bioremediation and therapeutics	[32]

Table 1. Overview of different extremophiles, their habitat and application of their bioactive compounds.

2.1 Thermophilic microorganisms and their importance

Researchers have shown a lot of interest in extremophiles specifically thermophilic bacteria, due to its ability of growing at above 50°C and producing thermostable enzymes [33]. Thermophiles are categorized into 3 classes: moderate thermophiles which have the ability to withstand 50–60°C, extreme thermophiles which can withstand 60–80°C and hyperthermophiles which have the ability to withstand 80–110°C. Thermophiles have been found in different environments, from hot springs to the deep ocean. Members of *Ascomycete*, *Zygomycete* families of fungi and archaean genera *Pyrobaculum*, *Pyrodictium*, *Pyrococcus*, and *Melanopyrus* are the organisms that are capable of growing at temperatures ranging from 103 to 110°C [34], whereas *Thermotoga maritima* and *Aquifex pyrophilus* bacterial species have the ability to grow at extremely high temperature ranging from 90 to 95°C [35, 36]. Utilizing enzymes that are both stable and active at higher temperatures is important for a number of purposes, the primary one is that these enzymes are better suited for conducting biotechnological activities at higher temperatures [8].

Many polymer-degrading enzymes (such as amylases, cellulases, chitinases, pectinases, pullulanases, and xylanases), as well as proteases, isomerases, esterases, lysases, phytases, dehydrogenases, and DNA-modifying enzymes, have been characterized from extremely thermophilic and hyperthermophilic microorganisms [37]. Because of their ability to amplify DNA in the polymerase chain reaction (PCR), thermostable DNA polymerases that were isolated from hyperthermophiles have been responsible for a significant breakthrough in the field of molecular biology. Taq polymerase, which originated from the bacterium *Thermus aquaticus*, is the best-known success story in this regard [38]. The enzymes that are produced by thermophiles have significant applications in the industries of detergent, food, feed, starch, textile, leather, pulp and paper, and pharmaceuticals [39, 40].

2.2 Halophilic microorganisms

Halophiles are organisms which have the ability to grow at higher salt concentration. They can survive in both moderate and extreme saline environment like salt mines and dead sea. Halophiles can thrive at 0.3–5.1 M NaCl concentrations [41]. Halophiles can also be discovered in ordinary habitats such as certain food products. For example, halophilic archaea are believed to play a key role in the fermentation process of kimchi, which is a popular dish in Korea [42]. Halophilic bacteria produce negatively charged enzymes which have promising applications in biotechnology due to their unique properties. The high concentration of halophiles and the lack of non-halophilic pollutants in hypersaline brines make them suited for a wide variety of biotechnological applications. In addition to their potential use in bioremediation and bio fermentation, halophiles may be a good source for obtaining a wide variety of other novel biomolecules, such as stable enzymes and biopolymers. Different studies are conducted on the conversion of plant and animal polymers in high salt environments, including the production of biofuels. Cellulolytic activity was detected in *Haloarcula* isolated from a Turkish salt mine at high salinities [43]. A strain from a Chinese salt lake showed cellulolytic activity in non-polar solvents, and it can ferment bioethanol from alkali-pretreated rice straw [44]. A species of *Halolactibacillus* was found able to convert raw maize starch into compounds that could be then processed into bioethanol [45]. It was discovered that an extremely halophilic green alga known as *Dunaliella salina* produces a high lipid content that is ideal for the production of

biodiesel [46]. Other halophilic lipases have also been reported, some of which have potential in biodiesel production [47, 48].

2.3 Psychrophilic microorganisms

Psychrotolerant or psychrophilic are organisms that can thrive at temperatures of 15°C or lower. These microorganisms can live in a variety of cold habitats on earth, such as the polar regions, glaciers, ocean depths, shallow underground regions, upper atmosphere and refrigerated equipment [49]. The majority of these microorganisms are classified as members of the bacterial family such as *Pseudoalteromonas*, *Vibrio*, *Pseudomonas*, *Arthrobacter*, and *Bacillus*, [50], *Methanogenium*, *Halorubrum*, *penicillium*, an *Cladosporium* are examples of archaea, fungi, and yeast [51]. Psychrophilic enzymes are those that are produced by microorganisms that are adapted to colder environments and having high catalytic efficiency at low temperatures. These characteristics offers a significant opportunity in the industries of detergent, textile, food, pharmaceutical, leather, brewing and wine, and paper and pulp. Psychrophiles and their enzymes have been suggested as an alternative in bioremediation of polluted soils and waste water [52]. The structural properties of cold-active enzymes, such as a decrease in core hydrophobicity, a decrease in ionic interactions, an increase in surface charge, and longer surface loops, contribute to the flexibility required for optimal activity at low temperatures [53].

2.4 Alkaliphilic and acidophilic microorganisms

2.4.1 Alkaliphiles

Microorganisms which can withstand extreme alkaline conditions i.e., pH value greater than 9. One of the most common examples of naturally occurring alkaline environments are the soda lakes (with a pH between 10 and 12) or extremely saline [54]. Even though these conditions are extremely harsh, they can be home to a wide variety of bacteria and archaea and are among the most metabolically active marine ecosystems due to the presence of alkaphilic cyanobacteria [55].

The alkaliphiles offer a significant amount of potential for use in biotechnology. Alkaliphiles have the potential of producing different industrially important enzymes like proteases, amylases, cellulases, lipases, xylanases, pullulanases, pectinases, and chitinase [56]. The most important uses of these enzymes are in the production of detergents, the dehairing of hides, the production of pulp and paper, the hydrolysis of starch, and the preparation of food [57].

2.4.2 Acidophiles

Acidophiles are organisms which can withstand extreme lower pH, like hot springs and mine drainage systems. Acidophiles can be found in both natural and man-made environments. Acidophiles and thermophiles are frequently grouped together because thermophilic conditions are present in the majority of acidophilic habitats [58]. Bioleaching is the main application of acidophiles through which microorganisms decompose metal ores in order to remove the metal ions into solution. These metal ions may be then harvested, which enables economical metal extraction from low-grade ores. Among the most valuable properties of acidophiles is their ability to bioleach a variety of metal ions, including heavy metals, which are generally harmful

to other organisms [59]. Acidophiles also have the ability to break down other hazardous organic molecules (such as aliphatic compounds), and can be used to bioremediate acid mine drainage systems [60]. Enzymes isolated from acidophiles can be used in different industries like detergents and leather (**Table 1**).

2.5 Piezophilic microorganisms

Piezophiles and barophiles refer to organisms that are able to adapt to high levels of barometric pressure. Several different piezophiles have been successfully cultivated, however this process requires the utilization of complex apparatus to maintain necessary pressures, such as hydraulic pumps and complex gas systems, which are able to keep up pressures up to 38 MPa [61]. Since many laboratories lack the resources and expertise to obtain and safely operate the specialized equipment required to culture these organisms, an increasing number of researchers are relying on non-culturing methods, such as genomics, to learn more about them. Hydrothermal vents in the deep sea are well-studied examples of a high-pressure niche. Hydrothermal vents in the deep ocean are a prominent example of a high-pressure niche that has been extensively researched [62]. Piezophilic enzymes have the ability to withstand extreme pressure without requiring any pressure-related modifications. Enzymes extracted from piezophiles are resistant to high pressure and do not require any specialized modifications related to pressure. Enzymes isolated from piezophilic microbes have great potential in biotechnology (**Table 1**), especially in the food industry where high pressure is used to process and sterilize food [63]. Another enzyme, chymotrypsin, isolated from piezophilic microorganisms can function at high pressure and temperature and is used in many industrial processes [64].

2.6 Radiophilic microorganisms

Radiation-resistant or radioresistant extremophiles are microorganisms that can survive at extremely high levels of radiation. They have been discovered at high UVR altitudes (mountain ranges) and in broad fields. Continuous ozone depletion had a significant impact on global biosphere exposure to ultraviolet radiation. In addition, radioactive wastes have been released into the environment due to the widespread utilization of radioactive compounds and elements for energy, medicine, research, and in industries [65]. Nuclear disasters like Fukushima Daiichi in 2011 and Chernobyl in 1986 have increased radionuclides and radioisotopes in the environment. X-rays and Gamma radiation are two more kinds of environmental radiation that can cause harm to humans. Different kinds of microbes have found strategies to survive in high radiation environments despite the damaging effects of radiation on humans. The bacterium *Deinococcus radiodurans* is resistant to extremely high levels of radiation, both ionizing and ultraviolet ($> 1000 \text{ J/m}^2$) [66]. A number of bacteria, including *Rhodanobacter sp.* and *Desulfuromonas ferrireducens*, have been found to thrive in environments with elevated radioactive concentrations [67]. Researchers have found a correlation between the DNA repair mechanisms and the production of protective primary and secondary metabolic products of radioresistant organisms and their ability to withstand high doses of radiation [68]. Biotechnological techniques can stimulate or trigger the production of radiation-responsive metabolites, pigments, and enzymes, which can be used to create pharmaceuticals, particularly anticancer treatments, antibiotics, and commercially important agricultural products [69].

3. Limits of life and extremophiles

Searching for life beyond earth is linked to our understanding of life on earth. In order to detect possible extraterrestrial habitats, it is essential to know the conditions that can sustain earth life. This does not mean that other planets and moons cannot support life similar to that on earth. Although different types of life may have different origins and biochemistry, it is possible that studying life on earth can help us understand life elsewhere. It is also possible for life to exist in environments completely different from those on earth (for example, the bacterium *Deinococcus radiodurans* has been shown to withstand radiation levels far exceeding our natural environment, and *Escherichia coli* has been shown to be able to withstand pressures ten times higher than those found in the deepest ocean trenches) [70, 71]. Life as we know it depends on water, light source or chemical energy, nutrients like nitrogen, phosphorus, sulfur, iron, are just few of the 70 elements on earth that either need or interact with life [72]. Currently, the search for extraterrestrial life focuses on planets and moons that had liquid water, geological and geophysical factors that encourage the synthesis and polymerization of organic molecules, as well as energy sources and nutrients necessary to sustain life on these planets. Once life start on a planet, then evolution will work to fill every possible niche, even if some niches have environments substantially different from where life originated. Since our understanding of life is based on what we can observe and measure, it can only be applied to earth-based life. Based on the universal laws of chemistry and physics, we can extrapolate the conditions for life on other planets. This suggests that life requires a solvent, an energy source, and building blocks in order to survive [73].

Considering the fact that everything requires energy for their chemical reactions, redox chemistry seems to be universal. The emergence, evolution, and diversity of life has often been influenced by physicochemical gradients that create non-equilibrium redox conditions [74]. A proton gradient and redox gradient were likely the two main mechanisms involved in the origin of life, driving metabolism and growth [75]. As a result, the search for life's limits has expanded beyond temperature, pH, pressure, salinity, and radiation gradients to include energy and nutrient limits which can be considered as well [76, 77]. Temperature, pH, pressure, salinity, and radiation are all related and can affect nutrient and energy availability. There are some parameters that affect microbial diversity more than others, like temperature in geothermal waters [78], pH in soil communities [79], salinity in saline lakes [80], and water content in dry climates [11].

Some organisms can thrive under conditions that limit their growth or prove lethal to other organisms. Majority of earth's organisms are killed by extreme temperatures, pH levels, salt concentrations, toxic metals and radiation levels. However, organisms in all three domains have adapted to many extremes on earth [5]. As a result of the emergence of life on earth, microbes have colonized habitats encompassing almost every conceivable physicochemical factor. It was previously believed that terrestrial environments are not suitable for growth because of high temperatures and low water activity (desiccation). It is now known that environments with MgCl_2 above 2.3 M also inhibit life, and this is due to MgCl_2 denaturing macromolecules in biological systems [81]. These conditions aren't necessarily sterile; many organisms have adapted mechanisms to survive at temperatures above 100°C , or even in a desiccated environment. Very few environments that claim to be sterile are genuinely free of all life forms. The Atacama Desert in Chile has been found to contain a small amount of viable microbes despite it being one of the driest environments on earth and believed

to be similar to the environment on Mars [82]. Some liquid water environments do not support life, like the high-brine liquid in sea-ice inclusions at -30°C and the water above 40°C in submarine hydrothermal vents [83]. However, microbes have been observed to be able to survive in many extreme conditions outside their normal growth range, which still indicates their survival ability [84].

The limits of life, extremophile characteristics, and astrobiology implications are discussed in different studies [7]. Many discussions about the limits of life concentrate on extremes of one physical or chemical condition, such as temperature, salinity, heavy metal concentrations, desiccation, and pH [85]. To survive in nutrient-poor conditions, organisms have evolved a variety of metabolic and physiological strategies. Researchers found that *Pelagibacter ubique* a cosmopolitan microorganism in oligotrophic oceans, grew only at in situ micromolar concentrations of organic carbon. Despite its small genome, *P. ubique* has all the genes it needs to grow independently (without help from other organisms) [86]. The lowest concentrations of organic substances that can support heterotroph growth are set by *P. ubique* and related marine oligotrophs. *P. ubique* and similar marine oligotrophs could be used as models to develop detection strategies for organisms in the Lake Vostok, the subsurface of Mars, and Europa's ocean [87].

4. Survival mechanism of extremophiles under harsh conditions

Extremophiles have adapted a wide variety of strategies to survive in the inhospitable environments (**Figure 1**). Proteins are easily denatured and unfolded when exposed to temperatures over their normal range, as this breaks down intracellular bonds which is harmful to that particular organism. To prevent protein from degradation due to high temperature, thermophilic microbes produce chaperones or thermosomes, which allow them to recover their protein structure and function even in harsh environments [88]. Bacteria that thrive in high temperatures have evolved hydrogen bonds that interact with hydrophobicity to prevent protein unfolding. In contrast, the enzymes of thermophilic bacteria are structurally stable due to the abundance of salt and disulfide bridges. Additionally, structural compactness, oligomerization, glycosylation, and hydrophobic interactions between subunits all contribute to thermo-resistance and are therefore essential for stability [89]. The chaperones DnaK, GroEL, and GroES also assist protein folding in thermophiles through the role of heat shock proteins (HSPs). The DNA-repair system responds to DNA damage as well (**Figure 1**). Thermophiles use branched chain fatty acids and polyamines (such as spermidine) to stabilize their membranes [90]. In order to resist UV stress, ultraviolet resistant extremophiles have developed a variety of strategies (**Figure 1**). DNA repair, chaperone induction, and active defense against UV-induced oxidative stress (e.g., glutathione accumulation) are involved in these strategies [91]. Radiotolerance has been associated with the ability of these microorganisms to repair DNA damage because they accumulate a high level of intracellular manganese and a low level of iron, conferring UV resistance to them [92].

The cellular cold-adaptability mechanisms (**Figure 1**) of psychrophiles allow them to survive in extremely cold environments [93]. The presence of unsaturated fatty acids, cyclopropane-containing fatty acids, and short chain fatty acids in membranes prevents membrane fluidity loss [94]. Another mechanism is the high synthesis of cold-shock proteins (CSPs) and chaperones that protect RNA and protein synthesis [95]. The third mechanism involves the synthesis of antifreeze proteins (AFPs) that

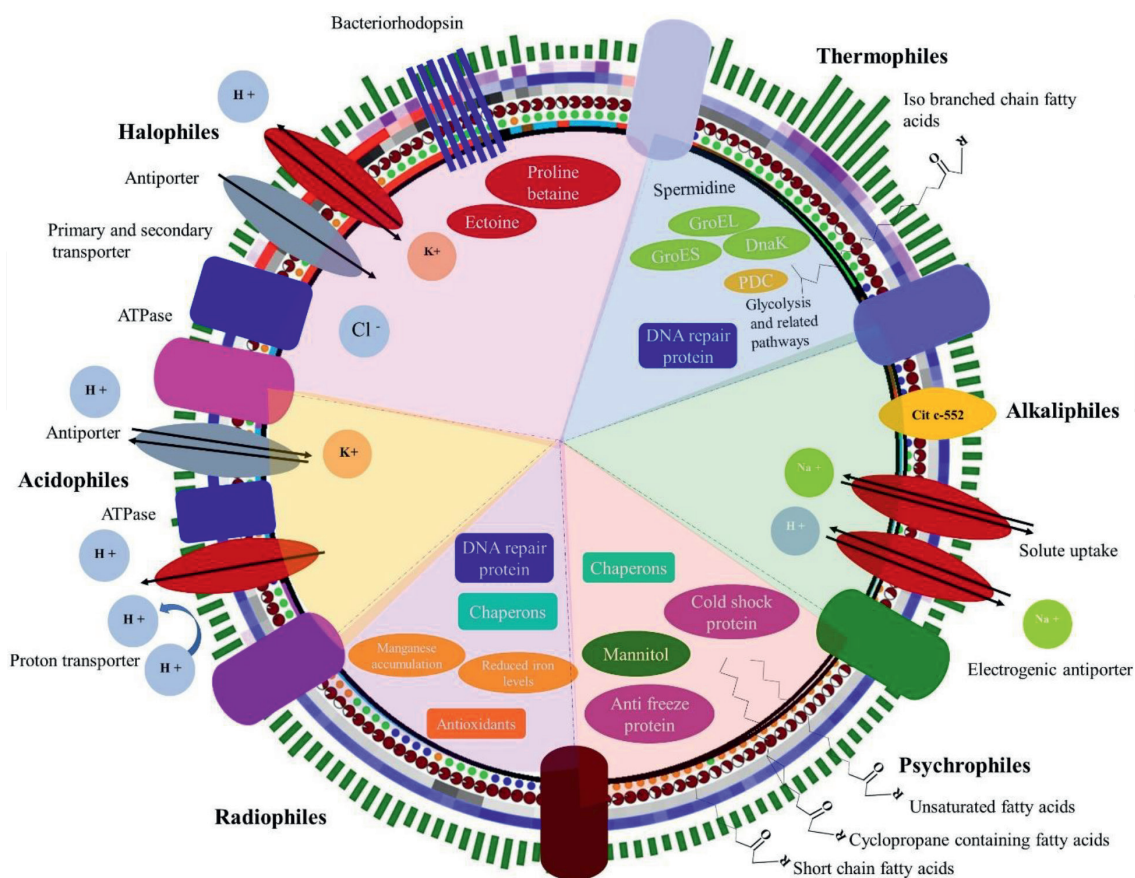


Figure 1. Strategies adopted by different extremophiles for their survival in different extreme environments.

bind to ice crystals and cause thermal hysteresis [96]. A fourth mechanism is the accumulation of mannitol as a cryo-protectant [97].

In acidophiles, the cytoplasmic pH is maintained near neutrality in order to safeguard acid-labile cellular components. Adaptation to an acidic environment involves different mechanisms (**Figure 1**). In the first mechanism, protons are actively pumped to maintain a pH to 1 by proton flux systems. Several bacteria have been reported to efflux protons via transport pumps in the electron transport chain, as well as influx protons via FOF1-type ATP synthases [98]. Proton flux systems include primary proton pumps (symporters) and secondary proton pumps (e.g., cation/H⁺ antiporters). A second mechanism suppresses the entry of protons into the cytoplasm by lowering the permeability of the cell membrane. Inside the membrane, K⁺ ions form a positive potential that inhibits proton influx [99]. Thirdly, acidophiles possess a more advanced protein synthesis and DNA repair system than neutrophils. Acidophiles are induced by an external pH shift from 3.5 to 1.5 to produce proteins like chaperons involved in the heat shock response [100]. To survive in a saline environment, microorganisms have adapted different strategies (**Figure 1**). A first strategy involves maintaining a salt concentration within the cell equal to that in the environment. As a result, all intracellular systems have been adapted to the new environment. It is done by chloride and potassium transporters conjugated to bacteriorhodopsin and ATP synthase. Betaine and ectoine balance osmotic pressure by keeping intracellular salts low [101]. Another example of a microbial adaptation is the overexpression of a protein complex involved in DNA repair, replication, and recombination in two *Halobacterium sp. NRC-1* mutants that are capable of withstanding extremely high radiation levels

(LD50 > 11 kGy) [102]. To deal with high pH, alkaliphile bacteria use both symporters and antiporters (**Figure 1**). Symporters allow Na⁺ and other solutes into cells, and electrogenic antiporters produce a gradient of Na⁺ and H⁺ [103]. The respiratory system uses cytochrome C-552 to store electrons and hydrogen. By altering the distribution of ions (e.g., Na⁺), these systems allow protons and solutes to enter the cell, maintaining hydrosaline homeostasis and thermodynamic stability [104].

5. Relationship between extremophilic microorganism and astrobiology

Astrobiology studies how life evolved, distributed, and might continue in the universe in the future. Among other things, astrobiology brings a common biological perspective to astronomy, astrophysics, biochemistry, chemistry, extreme ecology, geology, molecular biology, microbiology, paleontology, physiology, planetary sciences, space exploration, technology, without omitting law and philosophy [105]. A major focus of astrobiology is finding evidence of life on other planets. This objective requires a clear understanding of the biophysical properties of life and the physical and chemical boundaries of earth's life [106]. Despite the fact that there are numerous definitions of life, none of them are widely accepted. Considering the gradual transition between abiotic structures and indisputable biological forms, any boundary between them must be based on a questionable standard. There is widespread agreement among biologists that the existence of DNA or RNA is a necessary condition for life to exist [107]. Mars and Jupiter's moon Europa are the best candidates for supporting life [108]. Several authors also proposed habitable environments on Venus and Saturn's moon Titan [105].

Different planetary bodies have similar environments like earth, having diverse range of each parameter. In order to discover habitable environments outside the earth, it is important to study extremophiles on earth to discover novel biosignatures. As far as biogeochemistry, nutrient composition, or topological similarities are concerned, extremophile habitats on earth share many similarities with those on other planetary bodies [109]. Based on this different (poly)extremophiles may persist in different planets depending on the planetary body. Halopsychrophiles may be able to survive on Titan, Ceres, and Europa because of their salty underground oceans [110], and on Mars because of its chlorine-rich brines [111, 112]. In addition, these living forms would have to withstand intense pressure, because the hydrostatic pressure in Titan's subterranean ocean varies between 140 and 800 MPa [113]. Despite the fact that these conditions are well outside the range of even the most extreme cultured piezophile (*Thermococcus piezophilus*, P_{max} = 125 MPa) [114], microorganisms have successfully been exposed to pressures up to 2000 MPa and found to be metabolically active in fluid inclusions within type-IV ice [115]. Based on these observation it is possible that life may exist on other planets, such as Enceladus (P_{max} = 50 MPa) and Europa (P_{max} = 30 MPa) [5].

6. Conclusions

Extremophiles produce numerous extremozymes having different industrial applications, including agricultural, chemical, and medicinal. They are found in almost any habitat. Due to these advantages, extremozymes will be increasingly used in a wide range of consumer products. Extremophiles improve our understanding of

macromolecular stability and physiochemical requirements for life. According to new research adaptations that enable survival under one stress, may also enable survival under other stress conditions. Finally, the study of extreme organisms contributes greatly to astrobiology's ongoing development. Understanding how life can thrive on earth may help astrobiologist better understand and locate potential life in other planetary bodies.

IntechOpen

Author details


Nawab Ali^{1*}, Muhammad Nughman¹ and Syed Majid Shah²

1 Department of Biotechnology and Genetic Engineering, Kohat University of Science and Technology, Kohat, Khyber Pakhtunkhwa, Pakistan

2 Department of Pharmacy, Kohat University of Science and Technology, Kohat, Khyber Pakhtunkhwa, Pakistan

*Address all correspondence to: nawabali_1857@yahoo.com

IntechOpen

© 2023 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

References

- [1] Horneck G, Klaus DM, Mancinelli RL. Space microbiology. *Microbiology and Molecular Biology Reviews*. 2010;**74**(1):121-156
- [2] Yamagishi A et al. Environmental data and survival data of *Deinococcus aetherius* from the exposure facility of the Japan experimental module of the international space station obtained by the Tanpopo mission. *Astrobiology*. 2018;**18**(11):1369-1374
- [3] Rampelotto PH. Extremophiles and extreme environments. *Life*. 2013;**3**(3):482-485
- [4] Capece MC et al. Polyextremophiles and the constraints for terrestrial habitability. In: *Polyextremophiles*. Springer; 2013. pp. 3-59
- [5] Ramirez J. Extremophiles: Defining the physical limits at which life can exist. *Extremophiles*. 2021
- [6] MacElroy RD. Some comments on the evolution of extremophiles. *Biosystems*. 1974;**6**(1):74-75
- [7] Rothschild LJ, Mancinelli RL. Life in extreme environments. *Nature*. 2001;**409**(6823):1092-1101
- [8] Van Den Burg B. Extremophiles as a source for novel enzymes. *Current Opinion in Microbiology*. 2003;**6**(3):213-218
- [9] Horikoshi K. Past, Present and Future of Extremophiles. Springer; 2008. pp. 1-2
- [10] Seckbach J et al. Biodiversity and extremophiles. In: *Life as We Know It*. Springer; 2006. pp. 3-143
- [11] Pikuta EV, Hoover RB, Tang J. Microbial extremophiles at the limits of life. *Critical Reviews in Microbiology*. 2007;**33**(3):183-209
- [12] Bowers KJ, Mesbah NM, Wiegel J. Biodiversity of poly-extremophilic Bacteria: Does combining the extremes of high salt, alkaline pH and elevated temperature approach a physico-chemical boundary for life? *Saline Systems*. 2009;**5**(1):1-8
- [13] Gupta G et al. Extremophiles: An overview of microorganism from extreme environment. *International Journal of Agriculture, Environment and Biotechnology*. 2014;**7**(2):371
- [14] Dumorné K et al., *Extremozymes: A Potential Source for Industrial Applications*. 2017
- [15] Shrestha N et al. Extremophiles for microbial-electrochemistry applications: A critical review. *Bioresource Technology*. 2018;**255**:318-330
- [16] Zhu D et al. Recent development of extremophilic bacteria and their application in biorefinery. *Frontiers in Bioengineering and Biotechnology*. 2020;**2020**:483
- [17] Sharma S, Kuila A, Sharma V. Enzymatic hydrolysis of thermochemically pretreated biomass using a mixture of cellulolytic enzymes produced from different fungal sources. *Clean Technologies and Environmental Policy*. 2017;**19**(5):1577-1584
- [18] Mehta PK, Sehgal S. Microbial enzymes in food processing. In: *Biocatalysis*. Springer; 2019. pp. 255-275
- [19] Lokko Y et al. Biotechnology and the bioeconomy—Towards inclusive and sustainable industrial development. *New Biotechnology*. 2018;**40**:5-10
- [20] Ozdemir S et al. A novel raw starch hydrolyzing thermostable α -amylase

produced by newly isolated *Bacillus mojavensis* SO-10: Purification, characterization and usage in starch industries. *Brazilian Archives of Biology and Technology*. 2018;**61**

[21] Saiki RK et al. Primer-directed enzymatic amplification of DNA with a thermostable DNA polymerase. *Science*. 1988;**239**(4839):487-491

[22] Khusro A et al. Statistical optimization of thermo-alkali stable xylanase production from *Bacillus tequilensis* strain ARMATI. *Electronic Journal of Biotechnology*. 2016;**22**:16-25

[23] Mijts BN, Patel BK. Cloning, sequencing and expression of an α -amylase gene, *amyA*, from the thermophilic halophile *Halothermothrix orenii* and purification and biochemical characterization of the recombinant enzyme. The GenBank accession number for the sequence reported in this paper is AF442961. *Microbiology*. 2002;**148**(8):2343-2349

[24] Sanchez-Porro C et al. Screening and characterization of the protease CP1 produced by the moderately halophilic bacterium *Pseudoalteromonas* sp. strain CP76. *Extremophiles*. 2003;**7**(3):221-228

[25] Karasová-Lipovová P et al. The cloning, purification and characterisation of a cold-active β -galactosidase from the psychrotolerant Antarctic bacterium *Arthrobacter* sp. C2-2. *Enzyme and Microbial Technology*. 2003;**33**(6):836-844

[26] Zeng R et al. Cold-active serine alkaline protease from the psychrophilic bacterium *Pseudomonas* strain DY-A: Enzyme purification and characterization. *Extremophiles*. 2003;**7**(4):335-337

[27] Chang P et al. Cloning and characterization of two thermostable

xylanases from an alkaliphilic *Bacillus firmus*. *Biochemical and Biophysical Research Communications*. 2004;**319**(3):1017-1025

[28] Rai SK, Konwarh R, Mukherjee AK. Purification, characterization and biotechnological application of an alkaline β -keratinase produced by *Bacillus subtilis* RM-01 in solid-state fermentation using chicken-feather as substrate. *Biochemical Engineering Journal*. 2009;**45**(3):218-225

[29] George SP, Ahmad A, Rao MB. Studies on carboxymethyl cellulase produced by an alkalothermophilic actinomycete. *Bioresource Technology*. 2001;**77**(2):171-175

[30] Deming JW et al. Isolation of an obligately barophilic bacterium and description of a new genus, *Colwellia* gen. nov. *Systematic and Applied Microbiology*. 1988;**10**(2):152-160

[31] Nogi Y, Masui N, Kato C. *Photobacterium profundum* sp. nov., a new, moderately barophilic bacterial species isolated from a deep-sea sediment. *Extremophiles*. 1998;**2**(1):1-8

[32] Llewellyn CA, Airs RL. Distribution and abundance of MAAs in 33 species of microalgae across 13 classes. *Marine Drugs*. 2010;**8**(4):1273-1291

[33] Singh B, Satyanarayana T. Production of phytate-hydrolyzing enzymes by thermophilic moulds. *African Journal of Biotechnology*. 2012;**11**(59):12314-12324

[34] Busk PK, Lange L. Cellulolytic potential of thermophilic species from four fungal orders. *AMB Express*. 2013;**3**(1):1-10

[35] Haki G, Rakshit S. Developments in industrially important thermostable enzymes: A review. *Bioresource Technology*. 2003;**89**(1):17-34

- [36] Bhalla A et al. Improved lignocellulose conversion to biofuels with thermophilic bacteria and thermostable enzymes. *Bioresource Technology*. 2013;**128**:751-759
- [37] Bertoldo C, Antranikian G. Starch-hydrolyzing enzymes from thermophilic archaea and bacteria. *Current Opinion in Chemical Biology*. 2002;**6**(2):151-160
- [38] Chien A, Edgar DB, Trela JM. Deoxyribonucleic acid polymerase from the extreme thermophile *Thermus aquaticus*. *Journal of Bacteriology*. 1976;**127**(3):1550-1557
- [39] Fujiwara S. Extremophiles: Developments of their special functions and potential resources. *Journal of Bioscience and Bioengineering*. 2002;**94**(6):518-525
- [40] Kumar S, Nussinov R. How do thermophilic proteins deal with heat? *Cellular and Molecular Life Sciences CMLS*. 2001;**58**(9):1216-1233
- [41] Oren A et al. *Halobaculum gomorrense* gen. nov., sp. nov., a novel extremely halophilic archaeon from the Dead Sea. *International Journal of Systematic and Evolutionary Microbiology*. 1995;**45**(4):747-754
- [42] Chang H-W et al. Analysis of yeast and archaeal population dynamics in kimchi using denaturing gradient gel electrophoresis. *International Journal of Food Microbiology*. 2008;**126**(1-2):159-166
- [43] Yildiz E, Ozcan B, Caliskan M. Isolation, characterization and phylogenetic analysis of halophilic archaea from a salt mine in Central Anatolia (Turkey). *Polish Journal of Microbiology*. 2012;**61**(2):111-117
- [44] Yu HY, Li X. Characterization of an organic solvent-tolerant thermostable glucoamylase from a halophilic isolate, *Halolactibacillus* sp. SK 71 and its application in raw starch hydrolysis for bioethanol production. *Biotechnology Progress*. 2014;**30**(6):1262-1268
- [45] Gao Y, Yang M, Wang C. Nutrient deprivation enhances lipid content in marine microalgae. *Bioresource Technology*. 2013;**147**:484-491
- [46] Yilancioglu K et al. Oxidative stress is a mediator for increased lipid accumulation in a newly isolated *Dunaliella salina* strain. *PLoS One*. 2014;**9**(3):e91957
- [47] Li X, Yu H-Y. Characterization of an organic solvent-tolerant lipase from *Haloarcula* sp. G41 and its application for biodiesel production. *Folia Microbiologica*. 2014;**59**(6):455-463
- [48] Hou J et al. Characterization of genes for chitin catabolism in *Haloferax mediterranei*. *Applied Microbiology and Biotechnology*. 2014;**98**(3):1185-1194
- [49] Cavicchioli R et al. Biotechnological uses of enzymes from psychrophiles. *Microbial Biotechnology*. 2011;**4**(4):449-460
- [50] Collins G et al. Microbial community structure and methanogenic activity during start-up of psychrophilic anaerobic digesters treating synthetic industrial wastewaters. *FEMS Microbiology Ecology*. 2003;**46**(2):159-170
- [51] Inagaki F et al. Biogeographical distribution and diversity of microbes in methane hydrate-bearing deep marine sediments on the Pacific Ocean Margin. *Proceedings of the National Academy of Sciences*. 2006;**103**(8):2815-2820
- [52] Bhatia RK et al. Psychrophiles: A source of cold-adapted enzymes for energy

efficient biotechnological industrial processes. *Journal of Environmental Chemical Engineering*. 2021;**9**(1):104607

[53] Sarmiento F, Peralta R, Blamey JM. Cold and hot extremozymes: Industrial relevance and current trends. *Frontiers in Bioengineering and Biotechnology*. 2015;**3**:148

[54] Fujinami S, Fujisawa M. Industrial applications of alkaliphiles and their enzymes—Past, present and future. *Environmental Technology*. 2010;**31**(8-9):845-856

[55] Duckworth A et al. Phylogenetic diversity of soda lake alkaliphiles. *FEMS Microbiology Ecology*. 1996;**19**(3):181-191

[56] Wiegel J, Kevbrin V. *Alkalithermophiles*. Portland Press Ltd.; 2004

[57] Hasan F et al. Enzymes used in detergents: Lipases. *African Journal of Biotechnology*. 2010;**9**(31):4836-4844

[58] Elleuche S et al. Extremozymes—Biocatalysts with unique properties from extremophilic microorganisms. *Current Opinion in Biotechnology*. 2014;**29**:116-123

[59] Dopson M et al. Growth in sulfidic mineral environments: Metal resistance mechanisms in acidophilic micro-organisms. *Microbiology*. 2003;**149**(8):1959-1970

[60] Rani A, Souche YS, Goel R. Comparative assessment of in situ bioremediation potential of cadmium resistant acidophilic *Pseudomonas putida* 62BN and alkaliphilic *Pseudomonas monteilli* 97AN strains on soybean. *International Biodeterioration & Biodegradation*. 2009;**63**(1):62-66

[61] Zhang Y et al. Current developments in marine microbiology:

High-pressure biotechnology and the genetic engineering of piezophiles. *Current Opinion in Biotechnology*. 2015;**33**:157-164

[62] Jebbar M et al. Microbial diversity and adaptation to high hydrostatic pressure in deep-sea hydrothermal vents prokaryotes. *Extremophiles*. 2015;**19**(4):721-740

[63] Smedile F et al. Adaptations to high pressure of *Nautilia* sp. strain PV-1, a piezophilic campylobacterium (aka Epsilonproteobacterium) isolated from a deep-sea hydrothermal vent. *Environmental Microbiology*. 2022;**24**(12):6164-6183

[64] Leanwala AP. Application of Extremophiles in Food Industries, in Physiology, Genomics, and Biotechnological Applications of Extremophiles. IGI Global; 2022. pp. 251-259

[65] Gabani P, Singh OV. Radiation-resistant extremophiles and their potential in biotechnology and therapeutics. *Applied Microbiology and Biotechnology*. 2013;**97**(3):993-1004

[66] Yuan M et al. *Deinococcus gobiensis* sp. nov., an extremely radiation-resistant bacterium. *International Journal of Systematic and Evolutionary Microbiology*. 2009;**59**(6):1513-1517

[67] Green SJ et al. Denitrifying bacteria from the genus *Rhodanobacter* dominate bacterial communities in the highly contaminated subsurface of a nuclear legacy waste site. *Applied and Environmental Microbiology*. 2012;**78**(4):1039-1047

[68] Singh OV, Gabani P. Extremophiles: Radiation resistance microbial reserves and therapeutic implications. *Journal of Applied Microbiology*. 2011;**110**(4):851-861

- [69] Murthy PS et al. Extremophiles as a source of biotechnological products, in *Physiology, Genomics, and Biotechnological Applications of Extremophiles*. IGI Global; 2022. pp. 308-333
- [70] Cox MM, Battista JR. Deinococcus radiodurans—The consummate survivor. *Nature Reviews Microbiology*. 2005;**3**(11):882-892
- [71] Sharma A et al. Microbial activity at gigapascal pressures. *Science*. 2002;**295**(5559):1514-1516
- [72] Wackett LP, Dodge AG, Ellis LB. Microbial genomics and the periodic table. *Applied and Environmental Microbiology*. 2004;**70**(2):647-655
- [73] Schwieterman EW et al. Exoplanet biosignatures: A review of remotely detectable signs of life. *Astrobiology*. 2018;**18**(6):663-708
- [74] Covone G, Giovannelli D. Stellar Metallicity Is a Key Parameter for the Search of Life in the Universe. arXiv preprint arXiv:2207.03748. 2022
- [75] Herschy B et al. An origin-of-life reactor to simulate alkaline hydrothermal vents. *Journal of Molecular Evolution*. 2014;**79**(5):213-227
- [76] Hoehler TM, Jørgensen BB. Microbial life under extreme energy limitation. *Nature Reviews Microbiology*. 2013;**11**(2):83-94
- [77] LaRowe DE, Amend JP. Power limits for microbial life. *Frontiers in Microbiology*. 2015;**6**:718
- [78] Sharp CE et al. Distribution and diversity of *Verrucomicrobia* methanotrophs in geothermal and acidic environments. *Environmental Microbiology*. 2014;**16**(6):1867-1878
- [79] Rousk J et al. Soil bacterial and fungal communities across a pH gradient in an arable soil. *The ISME Journal*. 2010;**4**(10):1340-1351
- [80] Yang J et al. Salinity shapes microbial diversity and community structure in surface sediments of the Qinghai-Tibetan Lakes. *Scientific Reports*. 2016;**6**(1):1-6
- [81] Hallsworth JE et al. Limits of life in MgCl₂-containing environments: Chaotropicity defines the window. *Environmental Microbiology*. 2007;**9**(3):801-813
- [82] Navarro-González R et al. Mars-like soils in the Atacama Desert, Chile, and the dry limit of microbial life. *Science*. 2003;**302**(5647):1018-1021
- [83] Kelley DS, Baross JA, Delaney JR. Volcanoes, fluids, and life at mid-ocean ridge spreading centers. *Annual Review of Earth and Planetary Sciences*. 2002;**30**(1):385-491
- [84] Baross JA, Deming JW. Growth at high temperatures: Isolation and taxonomy, physiology, and ecology. In: *The Microbiology of Deep-sea Hydrothermal Vents*. 1995. pp. 169-217
- [85] Board SS, Council NR. *The Limits of Organic Life in Planetary Systems*. National Academies Press; 2007
- [86] Giovannoni SJ et al. Genome streamlining in a cosmopolitan oceanic bacterium. *Science*. 2005;**309**(5738):1242-1245
- [87] Belt G. Extremophiles, the physicochemical limits of life (growth and survival). In: *Complete Course in Astrobiology*. 2007
- [88] Annamalai N, Rajeswari MV, Balasubramanian T. Thermostable and alkaline cellulases from marine sources.

In: *New and Future Developments in Microbial Biotechnology and Bioengineering*. Elsevier; 2016. pp. 91-98

[89] Chakraborty A et al. Metabolic responses of thermophilic endospores to sudden heat-induced perturbation in marine sediment samples. *Frontiers in Microbiology*. 2022;**13**

[90] Orellana R et al. Living at the frontiers of life: Extremophiles in Chile and their potential for bioremediation. *Frontiers in Microbiology*. 2018;**9**:2309

[91] Pérez V et al. Bacterial survival under extreme UV radiation: A comparative proteomics study of *Rhodobacter* sp., isolated from high altitude wetlands in Chile. *Frontiers in Microbiology*. 2017;**8**:1173

[92] Paulino-Lima IG et al. Extremely high UV-C radiation resistant microorganisms from desert environments with different manganese concentrations. *Journal of Photochemistry and Photobiology B: Biology*. 2016;**163**:327-336

[93] Jin S, Wang Y, Zhao X. Cold-adaptive mechanism of psychrophilic bacteria in food and its application. *Microbial Pathogenesis*. 2022:105652

[94] Bradburn MJ et al. Survival analysis part III: Multivariate data analysis—choosing a model and assessing its adequacy and fit. *British Journal of Cancer*. 2003;**89**(4):605-611

[95] Godin-Roulling A et al. Functional adaptations of the bacterial chaperone trigger factor to extreme environmental temperatures. *Environmental Microbiology*. 2015;**17**(7):2407-2420

[96] Muñoz PA et al. Structure and application of antifreeze proteins from Antarctic bacteria. *Microbial Cell Factories*. 2017;**16**:1-13

[97] Baraúna RA et al. A proteomic perspective on the bacterial adaptation to cold: Integrating OMICs data of the psychrotrophic bacterium *Exiguobacterium antarcticum* B7. *Proteomes*. 2017;**5**(1):9

[98] Michels M, Bakker EP. Generation of a large, protonophore-sensitive proton motive force and pH difference in the acidophilic bacteria *Thermoplasma acidophilum* and *Bacillus acidocaldarius*. *Journal of Bacteriology*. 1985;**161**(1):231-237

[99] Christel S et al. Multi-omics reveals the lifestyle of the acidophilic, mineral-oxidizing model species *Leptospirillum ferriphilum* T. *Applied and Environmental Microbiology*. 2018;**84**(3):e02091-e02017

[100] Amaro A et al. Effect of external pH perturbations on in vivo protein synthesis by the acidophilic bacterium *Thiobacillus ferrooxidans*. *Journal of Bacteriology*. 1991;**173**(2):910-915

[101] Margesin R, Schinner F. Bioremediation (natural attenuation and biostimulation) of diesel-oil-contaminated soil in an alpine glacier skiing area. *Applied and Environmental Microbiology*. 2001;**67**(7):3127-3133

[102] Byrne RT et al. Evolution of extreme resistance to ionizing radiation via genetic adaptation of DNA repair. *eLife*. 2014;**3**:e01322

[103] Krulwich TA et al. pH homeostasis and ATP synthesis: Studies of two processes that necessitate inward proton translocation in extremely alkaliphilic *Bacillus* species. *Extremophiles*. 1998;**2**(3):217-222

[104] Matsuno T, Yumoto I. Bioenergetics and the role of soluble cytochromes c for alkaline adaptation in gram-negative

alkaliphilic *Pseudomonas*. *BioMed Research International*. 2015;**2015**

[105] Javaux EJ. Extreme life on earth—Past, present and possibly beyond. *Research in Microbiology*. 2006;**157**(1):37-48

[106] Trent JD. Extremophiles in astrobiology: Per Ardua ad Astra. *Gravitational and Space Biology*. 2000;**13**(2):5-12

[107] Van Loon A. The needless search for extraterrestrial fossils on earth. *Earth-Science Reviews*. 2005;**68**(3-4):335-346

[108] Seckbach J, Chela-Flores J. Frontiers of extremophilic microorganisms: from life on the edge to astrobiology. In: *Exo-/Astro-Biology*. 2001

[109] Merino N et al. Living at the extremes: Extremophiles and the limits of life in a planetary context. *Frontiers in Microbiology*. 2019;**10**:780

[110] Cavicchioli R. Extremophiles and the search for extraterrestrial life. *Astrobiology*. 2002;**2**(3):281-292

[111] Clifford SM et al. Depth of the Martian cryosphere: Revised estimates and implications for the existence and detection of subpermafrost groundwater. *Journal of Geophysical Research: Planets*. 2010;**115**(E7)

[112] Jones EG, Lineweaver CH, Clarke JD. An extensive phase space for the potential martian biosphere. *Astrobiology*. 2011;**11**(10):1017-1033

[113] Stevenson A et al. Multiplication of microbes below 0.690 water activity: Implications for terrestrial and extraterrestrial life. *Environmental Microbiology*. 2015;**17**(2):257-277

[114] Dalmaso C et al. *Thermococcus piezophilus* sp. nov., a novel

hyperthermophilic and piezophilic archaeon with a broad pressure range for growth, isolated from a deepest hydrothermal vent at the mid-Cayman rise. *Systematic and Applied Microbiology*. 2016;**39**(7):440-444

[115] Kish A et al. High-pressure tolerance in *Halobacterium salinarum* NRC-1 and other non-piezophilic prokaryotes. *Extremophiles*. 2012;**16**(2):355-361