Review Paper:

Extremophiles: Potential Sources of Valuable Biomolecules

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Abstract

Extremophiles are a large group of organisms with the ability to thrive under extreme environmental conditions such as high and low temperatures, high salt levels, radiation and high antibiotic concentrations. Extremophilic microorganisms have established a diversity of molecular strategies in order to survive in extreme conditions and hence they are able to produces new and novel biomolecules. They have been the center of attention due to the remarkable benefits to the human society.

The knowledge of various novel biomolecules isolated from extremophiles and their application is essential for chemists, biochemists, chemical/biochemical/ bioprocess engineers, genetic engineers, biotechnologists, molecular biologists as well as computational biologists. This study discusses the classification of extremophiles, their survival mechanism and applications of various biomolecules isolated from extremophiles.

Keywords: Extremophiles, Microorganisms, Valuable Biomolecules, Thermopiles, Halophiles.

Introduction

The term extremophile was coined over a quarter of a century ago by MacElroy in 1974. The word has been interpreted in a number of ways and perhaps has become associated with those microorganisms that inhabit environments unsuitable to mammals. Conditions that are ‘extreme’ to one organism may be essential for another’s survival, so the concept of extremophily is a relative one. Extremophiles span all three domains of life: bacteria, archaea and eukaryotes[11].

The extremophilic microorganisms live in extreme conditions and also adopt in ranges of environmental variables such as temperature (55°C to 121°C and -2°C to 20°C), pressure (>500 atmospheres), alkalinity or acidity pH (pH > , pH < 4), salinity (2-5 M NaCl or KCl), geological scale/barriers, radiation (UVR resistance >600 J/m), chemical extremes of heavy metals (arsenic, cadmium, copper and zinc), lack of nutrients (e.g. water, ice, air, rock, or soil), osmotic barriers, or polyextremity[15,33,42].

They are characterized by efficient growth and enzymes products that led them to be potential candidate in industrial productions as detergents, brewing, cosmetics, dairy products, bakery, textiles, medicine, agriculture, biofuel production and as degradation materials.[17,44]

Farlow was the pioneer, first extremophile species isolated from salted fish described as a salt-loving organisms (halophilic)[17]. In 1936, up to 34% salt concentration resistance strains have been isolated from the Dead-sea by Eleazari Volcani[45]. Volcani is considered as historical leader due to his efforts since he got the starting point in extremophilic field and focused in halophilic microbes.

During that decade, hyperthermophilic and thermophilic microbes were isolated at 60 to 80ºC. Furthermore, in 1969, *Thermus aquaticus* thermophilic bacterium was isolated by Thomas Brock from Yellowstone National Park hot spring in the United States[7]. After one year, *Sulfolobus acidocaldarius* was the first hyperthermophile isolated able to survive in low pH (1-5) and up to 85ºC[8]. Accordingly, this was a great discovery for biologists because it changed all the previous concepts that used to state that there are no organisms which can resist higher than 80ºC[31].

These discoveries were fully focused on the diversity of microbiology. Extremophiles are important not only because of what they can teach us about the fundamentals of biochemical and structural biodiversity but also, because of their enormous potential as sources of enzymes and other biomolecules with applications in biotechnology, veterinary, agriculture, industry and medicine for the benefit of human. Their unusual properties make them key targets for exploitation by biotech companies around the world.

Classification of Extremophiles

Extremophile organisms are classified as living organisms able to survive and proliferate in environments with extreme physical (temperature, pressure, radiation) and geochemical parameters (salinity, pH, redox potential). Polyextremophile microorganisms are those that can survive in more than one of these extreme conditions. The vast majority of extremophile organisms belong to the prokaryotes and are therefore, microorganisms belonging to the Archaea and Bacteria domains. Extremophile microorganisms are classified according to the extreme environments in which they grow and the major types are summarized in table 1.

Different structural and metabolic characteristics are acquired by these organisms so that they can survive in these environments.

Survival and defensive strategies of Extremophiles: It is vital for extremophiles to cope with their environments making them viable to withstand under harsh environmental conditions. Extremophiles are known to adopt to the changes in their environment and surroundings that enable them to stabilize the changes in their homeostasis. The adaptability of extremophiles arrives from alteration of varying genes and proteins. Extremophiles produce extremolytes which help them to maintain their homeostasis such as ectoine mediated mechanism, which is produced by halophiles and organisms alike.

Evolutionary diversity, increased catalytic activity, amino acid accumulation, aggregation resistance strategies, resistance to cell death, activation of the nuclear factor, the use of heat shock proteins and cellular compartmentalization, are all vital tools that extremophiles take on in order to conserve their genes[35]. Table 2 provides an overview of the survival and defensive strategies of selected extremophiles.

Extremophiles and Biomolecules

Extremophiles are able to produce various novel biomolecules because of their unusual behaviors in extreme conditions. It is difficult to overstate the success or impact the DNA polymerases from the thermophiles *Thermus aquaticus*, *Pyrococcus furiosus* and *Thermococcus litoralis*, otherwise known as Taq, Pfu and Vent[29,32,43] respectively have had in biotechnology.

Table 1
Extremophile microorganisms and their environments[22]

Extremophile Microorganism	Favorable Environment to Growth
Acidophile	Optimum pH for growth—Below 3
Alkaliphile	Optimum pH for growth—Above 10
Halophile	Requires at least 1M salt for growth
Hyperthermophile	Optimum growth at temperatures above 80 °C
Thermophile	Grows at temperatures between 60 °C and 85 °C
Eurypsychrophile (psychrotolerant)	Grows at temperatures above 25 °C, but also grow below 15 °C
Stenopsychrophile (psychrophile)	Grows at temperatures between 10 °C and 20 °C
Piezophile	Grows under high pressure—Above 400 atm (40 MPa)
Endolithic	Grows inside rocks
Hipolithic	Grows on rocks and cold deserts
Oligotrophs	Able to grow in environments of scarce nutrients
Radioresistant	Tolerance to high doses of radiation
Metallotolerant	Tolerance to high levels of heavy metals
Toxitolerant	Tolerates high concentrations of toxic agents (eg. Organic solvents)
Xerophile	Grows in low water availability, resistant to desiccation

Table 2
Survival and defensive strategies in major extremophiles to thrive under extreme environmental conditions.

Extremophiles	Survival and defensive strategies
Thermophiles	Stabilization of enzymes from stress and freeze drying; protection of oxidative protein damage[27]
Acidophiles/ alkaliphiles	Maintaining a circumneutral intracellular pH; constant pumping of protons in and out of cytoplasm; acidic polymers of the cell membrane; passive regulation of the cytoplasmic pools of polyamines and low membrane permeability[3,9,21]
Halophiles	Protection of skin immune cells from UV radiation; enzyme stabilization against heating, freezing anddrying; protection of the skin barrier against water loss and drying out; block of UV-A induced ceramide release in human keratinocytes[10,34,41]
Geophiles	Mucoidal layer enveloping cell colonies; biofilm formation as stress response to extreme environmental conditions[2,4,26]
Psychrophiles	Translation of cold-evolved enzymes; increased flexibility in the portions of protein structure; presence of cold shock proteins and nucleic acid binding proteins; reduction in the packing of acyl chains in the cell membranes[6,12,18.,28]
Barophiles	Homeoviscous adaptation, tight packing of their lipid membranes; and increased levels of unsaturated fatty acids; polyunsaturated fatty acids maintain the membrane fluidity; robust DNA repair systems; highly conserved pressure regulated operons; presence of heat shock proteins[28,36]

Without a doubt, the automated version of the PCR would not have been possible without these enzymes. Nowadays biodiesel can be produced with the help of extremophiles. Previously the production of hydrogen traditionally relies on a chemical/catalyst process[14]; however, larger-scale microorganism-based systems using the thermophiles *Caldicellulosiruptor saccharolyticus* and *Thermotoga elfii* have been developed recently[16]. In contrast to the other products, methane has always been produced using a consortium of microorganisms, which include methanogens (extremophiles that are the only known biologic producers of methane)[5].

Psychrophilic/mesophilic protease was generated that proved to improve the performance of detergent during cold water washing[24]. Lipases are a billion-dollar industry[25] and very attractive for use in industrial settings because of their broad range of substrates, high degree of specificity and stability[19]. Although their applications in laundry detergents (i.e. low temperatures and alkaline conditions) and organic synthesis (i.e. low water activity) require lipases to be active under extreme conditions, most lipases used are mesophilic. Many mesophilic lipases, which typically come from organisms like *Bacillus* and *Aspergillus* species, are active at high temperatures.

As a result, extremophilic lipases are often overlooked; however, lipases from thermophilic *Bacillus* species have been shown to be more efficient than currently used enzymes[23]. Many industrial processes involved in hydrolyzing starch require high temperatures (95°C for one step and 60°C for the other) and high pH, polyextremophilic (thermophilic and alkaliphilic) enzymes would be ideal. Currently, α-amylase from *Bacillus acidicola*[37], glucoamylases from *Picrophilus*[38] and a pullulanase from *Thermococcus kodakarensis*[20] show great promise in replacing their mesophilic counterparts.

However, amylases have also been isolated from halophiles such as *Halomonas meridian* and *Natronococcus amylolyticus* that could be useful in the process of producing high-fructose corn syrup, which is produced by hydrolyzing corn starch[39]. Surprisingly, recently extremophiles, are good producers of a host of antibiotics, antifungals and antitumor molecules[30]. Diketopiperazines (also known as cyclic dipeptides) have been shown to affect blood-clotting functions as well as having antimicrobial, antifungal, antiviral and antitumor properties.

They are found in halophiles like *Naloterrigena hispanica* and *Natronococcus occultus*[13] and have been shown to activate and inhibit quorum-sensing pathways[1]. Finally, a very interesting extremophile contribution to the field of medicine comes in the form of an alternative vaccine delivery system[40]. Some extremophiles and biomolecules produced by them are mentioned in the fig. 1.

Conclusion

Due to the complex properties of extremophiles and extremolytes, research in this field will continue to expand. New extremozymes from extremophiles are being identified and developed relatively slowly, since pharmaceutical industries are driven by economic gains from their innovations. However, increased investment for research into the characteristics of the various proteins and substances from extremophiles can help in the process of sustainable development.

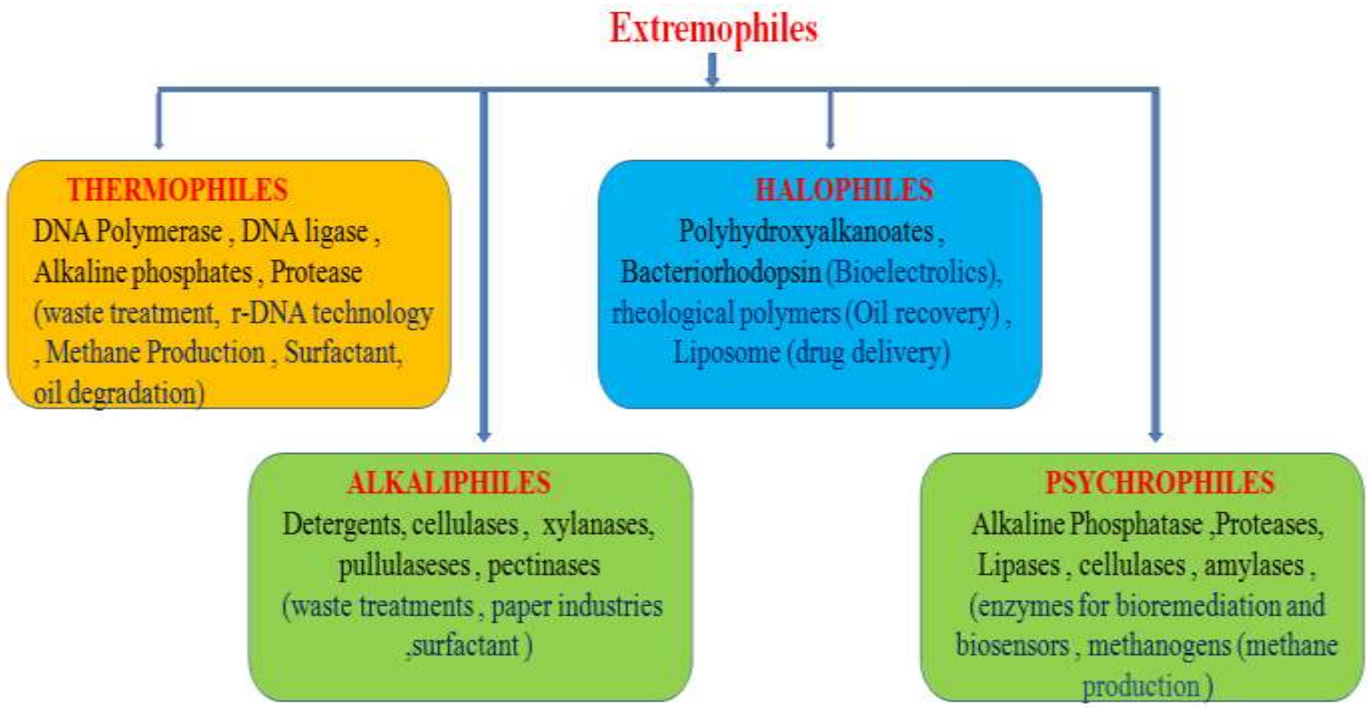

Fig. 1: Biotechnological applications of Biomolecules isolated from Extremophiles

Therefore, there is a need for collaborative efforts to study extremophiles to resolve various challenges in the field of agriculture, medical, renewable energy production, pharmaceutical, bioremediation, biomonitoring etc. Extremophiles have untapped potential and future research must investigate types of extremophiles that have not been previously studied for their possible new and novel application for the benefit of human society.

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