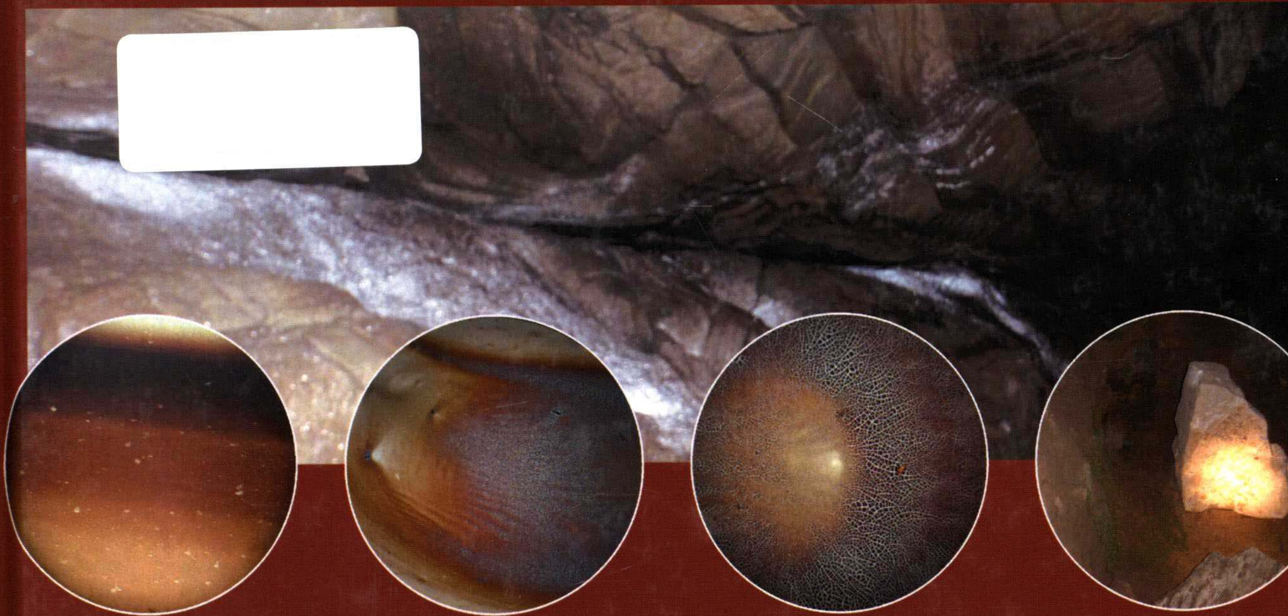
OM V. SINGH



EXTREMOPHILES

Sustainable Resources and Biotechnological Implications

WILEY-BLACKWELL

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Sustainable Resources and Biotechnological Implications

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INTRODUCTION

Om V. Singh

It has long been in the interest of science to explore mysterious events to establish scientific theories. In the fascinating world of microorganisms, extremophiles are the most mysterious category of life on planet Earth (Rothschild and Mancinelli, 2001) and perhaps on other planets as well (Navarro-González et al., 2003, 2009). Nature, of course, offers abundant opportunities to life forms that can consume or produce sufficient energy for their survival. However, normal survival may not be possible in environments that experience extreme conditions (e.g., temperature, pressure, pH, salinity, geological scale and barriers, radiation, chemical extremes, lack of nutrition, osmotic barriers, or polyextremity). Due to extraordinary properties, certain organisms (mostly bacteria and archaea, and a few eukaryotes) can thrive in such extreme habitats; they are called *extremophiles*.

It would benefit human society to learn from extremophiles; they have the potential to assist us in dealing with emerging diseases, due to their ingenious adaptations and the metabolic strategies they use to survive under extreme environmental conditions. The products of extremophilic microbial metabolisms are referred to as *extremolytes*: in the form of enzymes, proteins, and primary and secondary metabolic products, they have proven their importance to biotechnology. There has been some success in producing a variety of extremolytes on an industrial scale. Recent reports have covered various aspects of the current state of technologies involving metabolic products from extremophiles (Hammon et al., 2009; Brito-Echeverría et al., 2011; Burg et al., 2011). This book continues to bridge the technology gap and focus on aspects of extremolytes and the respective mechanisms regulating their biosynthesis that are relevant to human health, energy, and value-added products of commercial significance.

While attempting to learn from extremophiles, ignorance of extreme conditions is unjustifiable. Since the "deep time," there have been extreme environments on Earth. With the wide-ranging ingredients of life in the atmosphere, it is inconceivable that life did not exist in geological time (i.e., 4.6 billion years ago). Little evidence of this time remains in Earth's rocks; however, the existence of methanogens about 2.7 Gya (gigayears ago) has been proven by isotopic records, as stated by Chakravorty et al. in Chapter 1. The modern era allows for genetic adaptations, including horizontal and lateral gene transfer, among a variety of extremophiles, and the possibility of natural selection and/or spontaneous evolution remains. This chapter details the biochemical aspects and major events of molecular evolution, including the genomes and proteomes of various extremophiles, suggesting that modern technology can predict accurate evolutionary links among extremophiles.

In extreme environmental niches, uncultivable microorganisms can be found (Deppe et al., 2005). These microorganisms draw on unknown sources of energy, and modern science has yet to discover a supporting growth medium that can be used with them. However, advancements in metagenomics may assist in exploration of the unique properties of such uncultivable microorganisms (B.K. Singh, 2010; Singh and MacDonald, 2010). If appropriate sources to grow uncultivable microorganisms can be found, it could open new doors to the fascinating microbial world and its unique characteristics. In Chapter 2, Chakravorty and Patra discuss the unique features of growth strategies for a wide variety of extremophiles, highlighting the methodologies and limitations.

The ocean covers 75% of the planet and is a diverse environment for life. Rasmussen (2000) presented evidence of deep-sea microfossils of threadlike microorganisms in 3,235-million-year-old volcanogenic sulfide deposits, representing the first fossil evidence for microbial life in a Precambrian submarine thermal spring system. Other studies have presented the facts of appropriate environment for all life forms due to the one significant element of life, water, which astrobiologists are exploring on other planets. After the discovery of hydrothermal vents in 1979, an entirely different ecosystem was observed there with a variety of prokaryotic and eukaryotic microorganisms that had adapted themselves to the hostile environment and the lack of energy from sunlight. The limited information and technology galvanized researchers to investigate microbial life under extremes of temperature, pressure, oxygen, pH, and so on. In Chapter 3, Aharon Oren presents facts and strategies for the isolation and cultivation of halophilic microorganisms. Arakawa et al. in Chapter 4 present unique properties of halophilic microorganisms and their manipulation toward aimed biotechnological applications. Then, in Chapter 5, Ximena C. Abrevaya presents the diverse features and applications of halophilic archaea.

Including the ocean, cold environments make up the majority of the biosphere on Earth and other planets. In Chapter 6, Garcia-Descalzo et al. present the facts that 90% of the ocean's volume is below 5°C and that sea ice (13% of the Earth's surface), glaciers (10% of the Earth's surface), and permafrost (24% of the Earth's surface) are full of living microorganisms. Other sites, such as lakes, deserts, caves, and the upper atmosphere (upper troposphere and lower stratosphere), are being considered as permanent cold environments for living organisms. The authors of this chapter also interpret the facts of molecular events and microbial modifications that allow them to survive in extremely cold environments.

Anoxia is another type of extreme condition in which microbes can live. Anoxic sites in the environment (i.e., deep underground, sedimented bottoms of water bodies, deep sea, higher altitudes, and industrial effluent sites) and gut microbial flora in animal systems reveal a vast variety of anaerobic bacteria that have long histories in chemical and fuel production (Zeikus, 1980). Francesco Cangenella in Chapter 7 discusses the ecological aspects of selective anaerobic extremophiles—thermophiles—and interprets the biotechnological implications of their thermal resistance.

Food is necessary for organisms to maintain the required energy levels for life. Regardless of the abundance of food on Earth, there are always concerns about food safety and security in human society. The advanced technologies of modern genetic engineering (GE) have potential to ensure food security, but food safety remains a topic of discussion (Singh et al., 2006). Food regulations imposed by government agencies (O.V. Singh, 2010) rely on data provided by food growers. The limited research efforts hamper our understanding of the impact of GE food on the living world. On the other hand, extremophiles, with their broad range of biotechnological implications, could prove suitable for food processing and production. Since ancient times, a variety of microorganisms have been used to produce fermented alcoholic beverages and other food products. Most organisms used in food processing are mesophiles, but in some applications, extreme conditions are required. Microorganisms thriving in environments that are hostile to other organisms provide a source of novel bioproducts (extremozymes), products of primary and secondary metabolites. A broad category of these novel bioproducts is presented in Chapter 8 by Jane A. Irwin, who describes the unique roles of extremophiles and their bioproducts in food processing and production. This chapter adds to our understanding of whether extremophiles are able to fill the gaps in food safety that arise from GE food.

To meet the ever-increasing demand for energy, human society can rely on nature, which offers abundant renewable resources with the ability to replace fossil fuel. However, several issues, including economics and technological readiness, must still be resolved. Alternative fuel sources such as cellulosic ethanol or biodiesel are the most immediate and obvious target fuels. In Chapter 9, Taylor et al. discuss applications of extremophiles for biofuel research, and in Chapter 10, Chandel et al. examine how thermophiles are used in second-generation bioethanol production.

With the demand for ecofriendly bioproducts that can benefit biotechnology industries at the forefront, the exploration of microbial metabolic products has turned toward extremophiles. In Chapter 11, Agarwal and Mishra present ecofriendly applications of extremozymes in the textile industries. This chapter reveals that the use of extremozymes in everyday practical life may have additional applications that can fulfill biotechnology aims by reducing environmental pollution through toxic chemicals. In Chapter 12, Carlos A. Jerez discusses extremophilic applicability in the industrial recovery of metals.

Microbial metabolic products with unique characteristics, such as exopolysaccharides, represent a wide range of chemical structures with wide applications in the food, pharmaceutical, and other industrial fields. In Chapter 13, Barbara et al. present the fact that extremophiles are able to biosynthesize extracellular polymeric substances. These extremophiles could be another biofactory for exopolysaccharide biosynthesis. In continuation, Molina et al. in Chapter 14 present an overview of the biomedical applications of exopolysaccharides produced by microorganisms isolated from extreme environments.

Radiation in the form of particles or electromagnetic waves (i.e., ultraviolet radiation, gamma rays, x-rays, radio waves, etc.) causes serious oxidative damage to vital biomolecules, including proteins and nucleic acids. Historically, ultraviolet radiation and other radioactive substances have been linked to many harmful effects, including immune suppression, dermatitis, premature aging, neurodegeneration, and skin cancer. Extremolytes are unique organic compounds that are not directly involved in the normal growth, development, or reproduction of organisms; however, their absence does affect the long-term impairment of the organism's survivability, fecundity, or aesthetics. These microbial reserves have been widely explored for industrial significance; however, their therapeutic implications remain to be investigated. The exploration of strategic therapeutic applications of extremophiles in the area of defense and homeland security has credible potential. The potential for development of radioprotective drugs using radioresistant extremophiles has yet to be determined. In Chapter 15, Copeland et al. discuss the biosynthesis of extremolytes along with the concept of therapeutics utilizing the unique properties of radiation-resistant microorganisms. In Chapter 16, Kumar and Singh present smart therapeutics that can be produced from extremophiles. A brief description of the unexplored applications will provide industrial professionals with an opportunity to think outside the box by making investments in research and technology development.

Driven by increasing industrial demands for biocatalysts, enzymes, and metabolites that can cope with industrial process conditions, considerable effort has been made to search for such products. Because of their ability to thrive in extreme habitats that would kill other organisms almost instantly, extremophiles have a strong potential for future advancements in biotechnology, pharmaceuticals, and the extermination of certain toxic compounds from the environment. Extremozymes, such as thermostable amylase, are being incorporated into biochemical reactions that occur at high temperatures in water-based solutions, and could be substituted for high-cost reactants to lower the cost of the final product. Furthermore, the current nuclear arms race, instability in the environment due to ozone depletion, and solar flares reaching to the Earth's surface (M8.7 Solar flare and Earth Directed CME available at http://www.nasa.gov/mission_pages/sunearth/news/News012312-M8.7.html) make normal life vulnerable to natural and human-made radiation. Radiation-resistant microbes contain compounds that can potentially be harnessed as radioprotective drugs, which may be useful in space programs to prevent unwanted radiation exposure. In the years to come, the exploitation of extremophiles will indubitably advance to find the cures for diseases such as radiation-mediated cancer and meet other industrial demands.

This book is a collection of outstanding articles elucidating several broad-ranging areas of progress and challenges in the utilization of extremophiles as sustainable resources in the biomedical and biotechnological fields. The book will contribute to research efforts in the scientific community and commercially significant work for corporate businesses. The expectations are to establish long-term sustainable alternatives for adverse environmental conditions from microorganisms living under extreme conditions. Apart from therapeutics, this book also emphasizes the use of sustainable resources (i.e., extremolytes and extremozymes) for value-added products, which may help in revitalizing the biotechnology industry on a broader scale.

We believe that readers will find these articles interesting and informative for their research pursuits. It has been my pleasure to put this book together with Wiley-Blackwell. I would like to thank all of the contributing authors for sharing their outstanding research and ideas with the scientific community.

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