

Unlocking the Power of Extremophiles: Nanobiotechnological Applications and Future Directions

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ABSTRACT

Extremophile-driven microorganisms thrive in the toughest adverse environmental conditions. Extremophilic microbes have exhibited greater endurance than their mesophilic counterparts. Thus, extremophiles demonstrate the survival of the fittest among other microbes. Extremophiles possess a unique richness of metabolites, enzymes, and bioactive compounds that provides a competitive edge over normal microbes. These extremophilic organisms and their derived enzymes have revolutionized biotechnology, particularly recombinant DNA technology. The discovery of thermostable catalytic proteins, such as Taq polymerase from *Thermus aquaticus* and Pfu enzyme sourced from *Pyrococcus furiosus*, has had a tremendous impact on the development of PCR technology which is employed for diverse applications. Advancements in sequencing technology, particularly the emergence of Next-Generation sequencing techniques, have accelerated the discovery process of the extremophilic microbes. Furthermore, bioinformatics tools provide insights into the genomics dissection of extremophilic catalytic proteins for a better understanding of the sequence-structure-function relationship. The explosion of genomic data, big data biology, has led to an expansion of bioinformatic tools, providing further direction for exploring the potential of the extremophile microbial genomic data. Thus, extremophiles offer the greatest avenues for expanding research and development in biotechnological processes. Robust extremozymes with heat stability, solvent stability, and shelf-life stability are in high demand for many industrial bioprocesses. For example, thermophile, a variant of extremophile are often employed in the biofuel industry to produce carbon-neutral, non-fossilized biofuels. To make these processes cost-effective, nanotechnology is enhancing enzyme biotechnological processes through advanced enzyme immobilization technology. Nanotechnology revolves around the synthesis and applications of nanoscale materials, including nanoparticles, nanofibers, nanotubes, and nanocomposites, which are used as nanocarriers for extremophilic biomolecules. The reusability of nanomaterial-bound biomolecules makes the process more cost-effective, and easy separation of products using



magnetic nanocarrier-bound biomolecules is feasible. Thus, in addition to stability, quick separation of products and biomolecules is achievable through nanotechnological intervention. In conclusion, the integration of extremophile biology, recombinant DNA technology, bioinformatic mining, bioprocess technology, and nanotechnology may offer sustainable processes and products.

Keywords: Extremophiles, Extremozymes, Gene Engineering, In Silico mining, Nanotechnology, Biotechnology application.

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