

From biodiversity to biotechnological applications for sustainable development goals

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The United Nations Sustainable Development Goals (SDGs) aim to eradicate poverty, protect the environment, and advance equitable prosperity through an inclusive and sustainable way by 2030. This requires the integration of a wide range of strategies to overcome challenges and foster synergies among the various SDG targets, facilitating the achievement of these ambitious goals. The sustainable exploration and utilization of biodiversity through modern biotechnological approaches present significant opportunities to meet these goals while ensuring the conservation and restoration of natural resources. The exploration, preservation, and sustainable use of biodiversity are made possible by contemporary biotechnological techniques, such as genomics, synthetic biology, and bioinformatics. Ultimately, the synergy between biodiversity conservation and biotechnology not only promotes ecological balance but also accelerates progress toward achieving multiple SDGs, including zero hunger, good health, clean water and sanitation, clean energy, responsible consumption and production, climate action, life below water, and life on land. To preserve ecosystem health, assure long-term sustainability, and ensure a prosperous future for coming generations, it is imperative that the great diversity of life on Earth be preserved. This editorial advocates for integrative policies and multidisciplinary research to ensure that biodiversity-driven biotechnology remains a cornerstone of global sustainability efforts.

Biodiversity represents the living library of our planet, encompassing the immense variety of genes, species, and ecosystems that form the foundation of life. It is not merely a measure of the number of species but a reflection of the intricate interdependence and resilience of life forms across terrestrial, freshwater, and marine environments [1]. From the genetic diversity within a single crop variety to the vast ecological networks sustaining rainforests and coral reefs, biodiversity is the backbone of ecosystem services that regulate climate, cycle nutrients, purify water, and support human livelihoods. However, in the 21st century, biodiversity is under unprecedented threat from habitat destruction, overexploitation, pollution, invasive species, and climate

change [2]. As these pressures intensify, the urgency to preserve biodiversity while utilizing its potential for sustainable development becomes paramount.

The United Nations SDGs, adopted in 2015, provide a global blueprint for peace, prosperity, and environmental integrity by 2030. Biodiversity and biotechnology together hold transformative power to advance these goals, particularly in domains, such as food security, health, clean water, renewable energy, sustainable production, climate resilience, and ecosystem restoration [Figure 1] [3]. Biotechnology is the use of living systems and organisms to develop or modify products and processes has evolved far beyond traditional fermentation and breeding techniques [4]. In a broader context, modern biotechnology encompasses a merge of various technological paradigms, including molecular biology, modern genetics, computer technology, engineering, synthetic biology, clustered regularly interspaced short palindromic repeats (CRISPR-Cas), omics tools, and nanotechnology enable scientists to harness biodiversity's genetic wealth with unprecedented precision. This fusion of biodiversity and biotechnology creates a powerful pathway to address complex global challenges in a sustainable, equitable, and innovative manner.

Food deprivation, hunger, and malnutrition cannot be tolerated under any ethical principles. In this regard, SDG 2 is a multidimensional goal that aims to eliminate all forms of hunger by ensuring food security, improving nutrition, and promoting sustainable agriculture [5]. Research suggests that the problem is not the food insufficiency to feed the world population, but the actual dilemma is its unequal distribution. Technological advancements can increase wireless communications in rural areas and can allow small farmers to increase their productivity and equity with minimum costs and inputs [6]. In the past 20 years, biotechnology has worked in increasing the food resources of the world. By tapping into biodiversity through biotechnology, we can move toward a future where hunger is eradicated while preserving soil health and ecological balance, directly supporting Zero Hunger (SDG 2) [7].

Good physical and mental health, coupled with improved quality of life, serve as the keystones in achieving sustainable development. It enables individuals and communities to thrive, contribute to society, and achieve their full potential. Therefore, prioritization of health and well-being (SDG3) is vital to accomplish other SDGs. Achieving good health does not rely merely on the consumption of healthy and nutritious food, but also depends on the availability of adequate medicines to combat various illnesses [8]. In this regard, biotechnology offers powerful methods that are beyond increasing crop yields and synthesizing drugs for a range of diseases.

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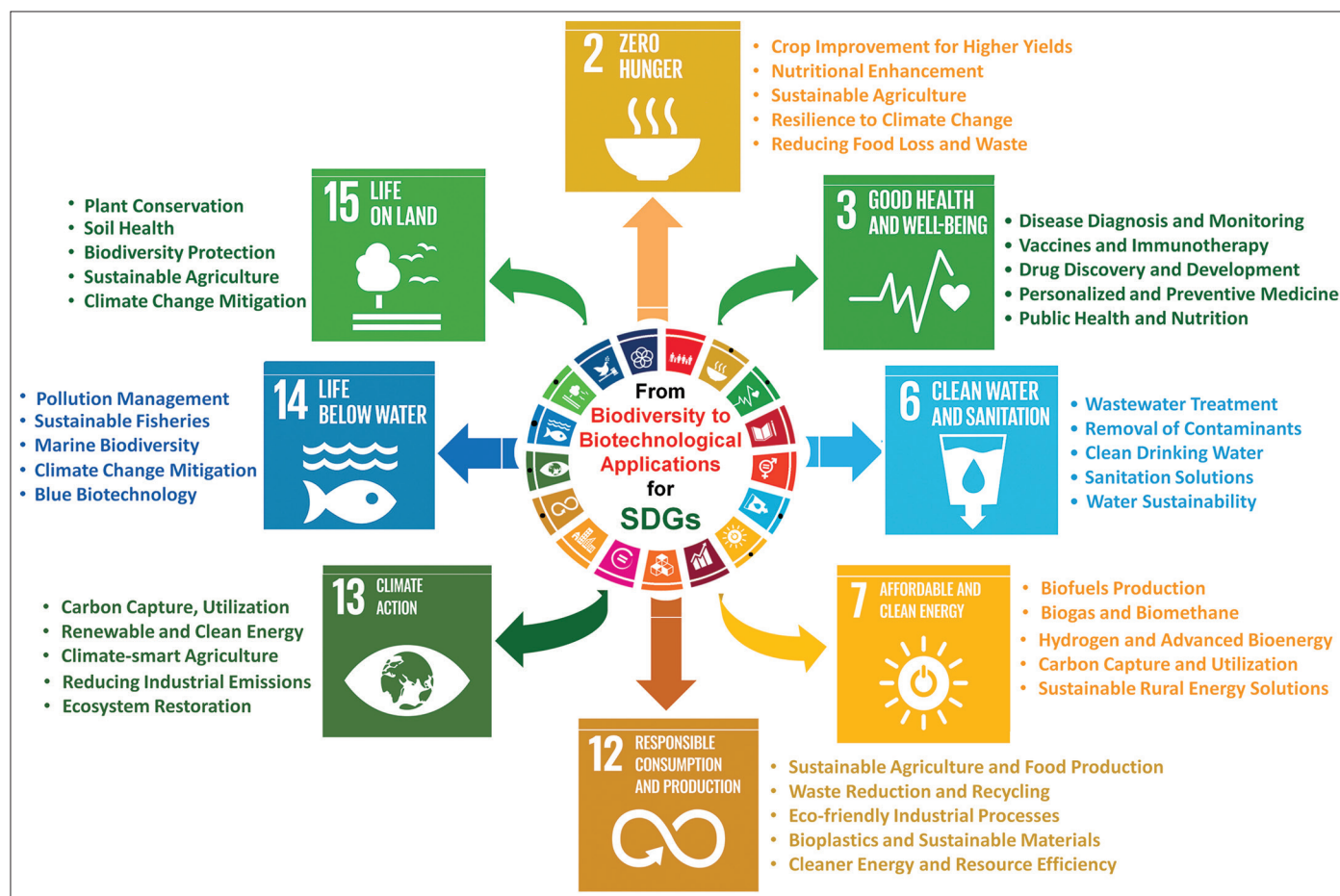


Figure 1: Biodiversity to biotechnological applications for sustainable development goals.

Access to safe water is fundamental to health and development, yet billions still lack it. Biodiversity offers a spectrum of microbial and plant species capable of degrading pollutants, removing pathogens, and restoring water quality [2]. Bioremediation is the use of microorganisms to detoxify polluted environments, has proven effective in treating industrial effluents, oil spills, and heavy metal contamination [9]. Wetland plants and algae play a vital role in natural and constructed wetlands for wastewater treatment, while biofilters employing microbial communities can efficiently remove contaminants at both household and industrial scales [10]. Advances in environmental biotechnology enable the design of microbial consortia tailored for specific pollutants, ensuring efficient and cost-effective solutions. By integrating biodiversity-based water purification systems, communities can achieve safe water access while minimizing environmental impact, thereby advancing clean water and sanitation (SDG 6) [11].

The availability and sufficiency of energy resources have always been the essential requirements of humankind and necessary for economic progress. Humans depend on fossil fuels (oil, gas, and coal) for energy production, which is now linked to the surge in greenhouse gas emissions, air pollution, and significantly increased global warming [12]. SDG 7 aims to provide inexpensive, steady, and sustainable energy to everyone by 2030. In recent years, the demand for energy has significantly risen due to our dependence on technology and a growing population [13]. To bridge the energy gap by 2030, scientists are striving to develop renewable energy sources

instead of fossil fuels. Across genetic engineering and bioprocessing, various feedstocks, such as crops, agricultural waste, and algae have been utilized to develop biofuels. Biogas is an outstanding renewable energy source, which is generated by anaerobic digestion of biomass, including agricultural wastes, animal manure, kitchen and green wastes [14]. These innovations not only reduce greenhouse gas emissions but also create decentralized energy solutions, empowering rural and off-grid communities, thereby contributing to affordable and clean energy (SDG 7) [15].

Biodiversity is also a key driver of the circular bioeconomy, which promotes responsible consumption and production (SDG 12) by ensuring that biological resources are used, reused, and recycled sustainably [16]. Biotechnology transforms agricultural waste, food waste, and industrial by-products into valuable commodities, such as bio-based plastics, biodegradable packaging, biofertilizers, and bio-based chemicals [17-19]. The valorization of waste streams through fermentation and microbial conversion not only reduces environmental pollution but also creates economic value, closing the loop in production cycles and shifting industries toward regenerative, resource-efficient systems [20].

Climatic deviations have reached to critical thresholds, impacting our planet, ecosystems, and human well-being. These climate extremes call for urgent actions to reduce greenhouse gas emissions, mitigate climate risks, and lessen significant threats to sustainable development. SDG 13 highlights the importance of preserving and water ecosystems, as they play a crucial role in regulating the Earth's climate, conserving

biodiversity, and safeguarding human health. Biotechnology plays a significant role in achieving SDG 13 by offering innovative solutions to endure and combat climate change and promote sustainable practices. Production of cleaner fuel options, such as biofuels, biogas, and other biomass-utilizing renewable energy sources will reduce the reliance on fossil fuels, leading to less GHG emissions and less impact on the climate [21]. Marine environments harbor an immense diversity of life forms adapted to extreme conditions, and this biodiversity is a treasure trove of enzymes, bioactive compounds, and novel biomaterials. Blue biotechnology leverages marine organisms for pharmaceuticals, nutraceuticals, cosmetics, and environmentally friendly industrial processes. Cold-adapted enzymes from psychrophilic bacteria enable energy-efficient industrial reactions, while bioactive molecules from marine algae show potential in cancer therapy [22]. Marine biotechnology also supports sustainable aquaculture, reducing pressure on wild fish populations through alternative feeds, probiotics, and disease control measures, contributing to life below water (SDG 14) [23].

Covering almost 30% of the world's surface, forests accommodate about 80% of terrestrial species of plants, animals, and insects. Furthermore, forests are indispensable for the health of the ecosystem and biodiversity, which are crucial for food security, thriving of diverse species, and socio-economic well-being of populations [24]. SDG 15 is an impressive goal that aims to safeguard our terrestrial ecosystem by promoting sustainable land use, combating desertification and land degradation, leading to the preservation of biodiversity [25]. Biotechnology is significantly contributing to preserving life on land. Agricultural innovations, particularly the development of genetically modified crops as benchmarks of modern biotechnology, significantly contribute to land conservation efforts [26]. By improving agricultural productivity, promoting sustainable land management, and reducing environmental impacts, biotechnological advancements offer a valuable measure in the pursuit of SDG 15 and the conservation of terrestrial ecosystems.

Achieving SDGs through biodiversity-driven biotechnology requires a multidimensional approach that integrates scientific innovation, resource stewardship, and socio-economic inclusivity. For zero hunger (SDG 2), strategies include developing climate-resilient crop varieties through molecular breeding, microbial inoculants for nutrient solubilization, and biofortified foods to address micronutrient deficiencies. Good health and well-being (SDG 3) can be advanced by harnessing natural compounds from plants, microbes, and marine organisms for novel therapeutics, vaccines, and functional foods, alongside biotechnological disease diagnostics and preventive healthcare solutions. For clean water and sanitation (SDG 6), biofiltration systems, microbial bioremediation, and genetically engineered microbes for pollutant degradation can ensure safe and sustainable water access. Affordable and clean energy (SDG 7) can be supported by biofuel production from algae, lignocellulosic biomass conversion, and waste-to-energy technologies. Responsible consumption and production (SDG 12) can be addressed through biodegradable biomaterials, circular bioeconomy models, and waste valorization through industrial biotechnology. Climate action (SDG 13) benefits from carbon sequestration through afforestation, soil carbon enhancement through microbial consortia, and low-emission agricultural practices. Life below water (SDG 14) can be preserved by using biotechnology to restore coral reefs, monitor marine biodiversity, and manage aquaculture sustainably. Finally, Life on land (SDG 15) requires genomic tools for species conservation, habitat restoration using bio-based methods, and combating invasive species through targeted biocontrol strategies.

Biodiversity-driven biotechnology stands at the forefront of a transformative era where natural wealth converges with technological ingenuity to address humanity's most pressing challenges. The integration of diverse genetic, biochemical, and ecological resources into innovative biotechnological frameworks offers unparalleled opportunities to combat food insecurity, restore degraded ecosystems, develop sustainable energy sources, and mitigate climate change impacts. By channeling the unique properties of microbial, plant, and animal systems into tailored solutions, it becomes possible to design interventions that are both environmentally regenerative and socially equitable. However, the path forward demands vision, precision, and accountability. Achieving long-term impact requires not only scientific breakthroughs but also global solidarity, transparent governance, and ethical stewardship of natural resources. Strategic alliances between nations, industries, and communities must be strengthened to ensure that the benefits of biodiversity utilization are equitably distributed and that exploitation does not undermine the very ecosystems upon which innovation depends. In essence, the future of sustainable development hinges on our ability to value biodiversity as a strategic asset and harness biotechnology as a catalyst for systemic change. If guided by foresight and responsibility, this synergy has the potential to redefine human progress delivering solutions that sustain both people and the planet for generations to come.

1. AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

2. CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

3. USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that they have not used artificial intelligence (AI)-tools for writing and editing of the manuscript, and no images were manipulated using AI.

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