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Unleashing the potential of biotechnology for sustainable development

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Abstract. – The UN Sustainable Development Goals (SDGs) strive to eliminate poverty, preserve the planet, and promote shared prosperity through sustainable and inclusive means by 2030. This requires the implementation of a diverse set of strategies to overcome challenges and foster synergies among different SDG targets, facilitating the achievement of these ambitious goals. The aim of this review is to highlight the world's progress toward SDGs with the utilization of biotechnological advancements, including targets, strategies, synergies, and challenges. We scrutinized published research articles in peer-reviewed journals, UN reports, and scientific books that were relevant to the current topic. We identified some major challenges faced by the countries, especially developing ones, in the way of sustainable progress. These include inadequate governance, fragile states, armed conflicts, rising inequality, limited economic progress, climate change, environmental degradation, and food insecurity. Biotechnological advancements contribute to sustainable resource management, environmental conservation, and ecosystem restoration. Collaboration among countries and organizations is crucial for sharing knowledge and providing technical and financial assistance to developing nations.

Key Words:
Sustainable Development, Biotechnology, Sustainable Development Goals, SDGs, Sustainable resource management, Environmental conservation, Ecosystem restoration.

Introduction

Rapid advances in scientific research and the bioconvergence of life sciences and technology have synergistically revolutionized the world with highly efficient scientific methods critical to attaining sustainable development. Genetically modified species of microbes, plants, and animals, have opened new perspectives, including for plants that are resistant to diseases and harsh conditions, enabling improved yields with reduced costs, thus ensuring food security and health of the environment. Environmentally and economically sound management of natural resources is the basis of 'biotechnology', essential for the achievement of the 2030 Agenda of 17 sustainable development goals[1,2]. By leveraging biotechnology, we can strive towards eradicating

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poverty, ensuring zero hunger, promoting good health and well-being, providing clean water and sanitation, facilitating affordable industries for transforming raw materials, and fostering overall economic growth strategies that do not cause persistent environmental damages (Table I)[3].

The collective success of all SDGs is crucial for the prosperity of future generations and can be achieved by strengthening global governance mechanisms and linking interdependent individual sectors to create an effective 'bioeconomy web'. Constructing this network would be helpful in driving a change from a fuel-based economy to a more sustainable bio-based economy while simultaneously ensuring food security and the preservation of a healthy environment[1,4]. For this purpose, there is a need for a transformative socio-technical system in which renewable biomass is converted and transformed into a variety of bio-based products necessary to produce food, feed, bio-fuel, and energy[2,4,5]. Thus, the bioeconomy relies on the sustainable utilization of biological products that end in reducing waste and also contribute to mitigating climate change. For maximum advantage, these practices can be engineered with biotechnological advances to give fruitful results[4].

In a broader context, modern biotechnology encompasses a merge of various technological paradigms, including molecular biology, modern genetics, computer technology, engineering, chemistry, physics, and nanotechnology. Advancements in all these paradigms are equally important because they are interconnected, and we cannot proceed without collectively studying them[6]. For instance, sequencing of complex genomes and their manipulations are impossible without the use of sophisticated computers. Likewise, nanotechnology is an emerging field that deals with the study of atoms and their minute clusters and advocates that the world's necessities could be fulfilled by utilizing a never-ending supply of atoms to manufacture vital tailored molecules[7]. Nanoscale construction of organic and inorganic matter is giving promising results in the fields of medicine, environmental monitoring, electronics, information technology and so on (Figure 1)[6,7].

In this review, we aim to present the frontiers in biotechnology that can significantly contribute at multiple levels towards the global pursuit of sustainability. We conducted research regarding the demands of each SDG and how biotechnological manipulations can contribute to fulfilling those demands. This manuscript analyses the great potential of biotechnology for sustainable development that can be beneficial for the scientific community to overcome global challenges.

Role of Biotechnology in the Pursuit of SDG 1: Eradicating Poverty

'Eradication of poverty' is the first goal among 17 SDGs, representing its importance in achieving global resilience. Thus, poverty reduction is a fundamental prerequisite for achieving sustainable development. The notion of poverty comprehends more than just income poverty and food scarcity. Certainly, it also extends to multidimensional aspects, including education, public health, access to clean drinking water, sanitation facilities, and sufficient access to new technologies[8]. The lack of these facilities in a population increases their vulnerability to famine, climatic disasters, and economic and environmental adversities.

Thus, the best way to address poverty diminution is the utilization of biotechnology to raise the living standards in developing countries. Innovative technologies have the capacity to amplify agricultural yields by offering bio-fertilizers and bio-pesticides[9], enhance the nutritional value of food[10], improve overall health conditions by increasing the availability of low-cost therapeutics to impoverished population[11], and increase affordability to energy production by decreasing the reliance on fossil fuels[11-13]. By using biotechnological processes, it becomes possible to convert biomass or biowaste into biofuels through biorefineries that reduce the dependency on fossil fuels and improve energy access in underserved areas[12].

In order to improve the World's economic status, global agriculture is expected to rely heavily on the scientific breakthroughs provided by biotechnology at the local level. Genetically modified crops not only increase farm yields and income, but also raise health status by offering functional foods or 'nutraceuticals' (rich in essential micronutrients) that also act as biotherapeutics[10]. Such crop varieties are resistant to drought, herbicides, and pests, resulting in crop resiliency to climate change and more stable farm incomes[14]. For instance, insect-resistant Bt cotton is able to increase the profit of farmers by 50% and increase their household income by 18.3%[15]. Similarly, transgenic eggplant variety called Bt

Table I. Role of biotechnology in achieving sustainable development goals.

Name of SDG	Basic target	Role of biotechnologies in achieving the goal	Ref.
SDG 1: No Poverty	Eradication of poverty and improvement of living standards	Biotechnology can amplify agricultural yields through bio-fertilizers and bio-pesticides, enhance nutritional value of food, improve health conditions by providing low-cost therapeutics, and increase affordability of energy production through biofuels. Genetically modified crops and biotechnology-driven innovations can increase farm yields, income, and crop resiliency to climate change. Microalgae biofertilizers offer eco-friendly alternatives to synthetic fertilizers. Biotechnology can focus on poverty alleviation and combating climate change impacts.	8, 9, 10, 11, 12, 13, 14, 15, 16
SDG 2: Zero Hunger	Eliminate all forms of hunger, improve nutrition, promote sustainable agriculture	Biotechnology plays a crucial role in addressing hunger challenges through various avenues. Genetic modification of crops (GM crops) enhances disease resistance, nutritional content, and yields while reducing pesticide use. Biofortification creates nutrient-rich crops to fight malnutrition. Genetically improved animals contribute to increased food production. Biodegradable packaging extends shelf life and reduces food waste. Biotechnology aids in aquaculture for seafood production and conservation. DNA vaccines protect aquatic animals from diseases.	17, 18, 19, 20, 21, 22, 23, 24
SDG 3:g Good Health and Well-bein	Ensure healthy lives and promote well-being for all	Biotechnology plays a crucial role in improving health and well-being through various approaches. Food and nutritional technology enhance the functionality and health benefits of food. Genetic modification of foods increases essential micronutrients. Encapsulation preserves functional ingredients in food. Adding microorganisms and nutrients improves food's nutritional value. Medicinal biotechnology develops drugs, vaccines, and diagnostics. Precision medicine tailors therapies based on individual genetic markers. High-tech clinical diagnostics and imaging techniques advance disease identification.	25, 26, 27, 28, 29, 30, 31,32
SDG 6: Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all	Biotechnology contributes to clean water and sanitation through various methods. Recycling wastewater using bio-membrane reactors and anaerobic ammonium oxidation improves water quality. Cellulosic fibers with polyelectrolytes adsorb bacteria for water purification. Oil-eating bacteria are used for water treatment. Electrolyzed water with germ-killing properties removes pathogens. Chitin and chitosan are plant-based polymers for water purification. Nitrogen use efficient genetically modified crops reduce the environmental impact of fertilizers.	33, 34, 35, 36, 37, 38, 39, 40
SDG 7: Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all	Biotechnology contributes to clean and affordable energy through the development of biofuels as renewable alternatives to fossil fuels. Genetic engineering and bioprocessing are used to create biofuels from feedstocks such as crops, agricultural residues, and algae. Bioethanol derived from sugarcane and other sources serves as a low-carbon alternative to gasoline. Biogas generated from biomass through anaerobic digestion provides cleaner energy for cooking and vehicles, while reducing organic waste.	41, 42, 43,44, 45, 46, 47, 48
SDG 8: Decent Work and Economic Growth	Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all	Biotechnology contributes to economic growth and decent work by enhancing agricultural productivity, boosting industry, skill development, and healthcare improvement. GM crops have enabled increased yields for farmers and raised income for small farmers. Policies that encourage innovation attract investors and enhance product and service value. Microbial biotechnology offers opportunities in diverse fields like therapies, plant growth promotion, bio-catalysis, bioenergy, clean water provision, and more.	49, 50, 51
SDG 9: Industry, Innovation, and Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation	Biotechnology plays a significant role in achieving SDG 9 by driving innovation, fostering entrepreneurship, and building infrastructure. Collaboration between academic institutions and industry accelerates innovation. Biotechnology parks, incubation centers, and resources like BiotechTown, BioPark, and OneBio provide spaces for R&D and support startups. Investment in biotechnology encourages economic growth and technology transfer.	52, 53, 54

Continued

Table I *(Continued)*. Role of biotechnology in achieving sustainable development goals.

Name of SDG	Basic target	Role of biotechnologies in achieving the goal	Ref.
SDG 12: Responsible Consumption and Production	Ensure sustainable consumption and production patterns	Biotechnology contributes to responsible consumption and production through waste reutilization and recycling. Bioplastics made from microorganism-produced polyhydroxyalkanoates (PHAs) serve as eco-friendly alternatives. Plant-based bottles and converting municipal waste into energy precursors demonstrate biotech solutions.	55, 56, 57, 58
SDG 13: Climate Action	Take urgent action to combat climate change and its impacts	Biotechnology plays a significant role in climate action by providing solutions to combat climate change and promote sustainability. Biofuels and renewable energy sources reduce greenhouse gas emissions. Climate-resilient genetically engineered crops require fewer resources and contribute to mitigation.	18, 19, 44, 43, 59, 60
SDG 14: Life Below Water	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development	Biotechnology, specifically "blue biotechnology," contributes to SDG 14 by conserving marine species through genetic modification, using biosensors to monitor marine environments, and employing biotech approaches to manage nutrient inputs in aquatic environments.	61, 62, 63, 64, 65
SDG 15: Life on Land	Protect, restore, and promote ustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and biodiversity loss	Biotechnology plays a role in achieving SDG 15 by promoting sustainable land use through genetic engineering of crops that enhance agricultural productivity while minimizing land use. GM crops can resist pests, diseases, and herbicides, reducing the need for agricultural expansion and deforestation.	65, 66, 68, 67, 69, 70
SDG 17: Global Partnerships for Sustainable Development	Strengthen the means of implementation and revitalize the global partnership for sustainable development	Biotechnology supports SDG 17 by fostering global partnerships between countries, research institutions, and biotech companies. Collaborations enable knowledge sharing, technology transfer, health and disease management, and collaborations between sectors to achieve sustainable development goals.	71, 72

eggplant has enabled a raise in the farmer's net income as it is resistant to fruit and shoot infecting insects, and thus permits the reduction of the cost of insecticides[16]. Certain microalgae species have been also employed to serve as biofertilizers instead of synthetic chemical fertilizers for rice cultivation. Such organic fertilizers are cost-effective, eco-friendly and sidestep water and soil pollution, leading to more sustainable and inexpensive farming practices[9].

Jansen et al[13] quoted a term called 'biotechnology for poor' in their research and emphasized on focusing biotechnological revolution for the alleviation of poverty. Additionally, combating climate change and its impacts are crucial to improve resiliency of earth's geography for future generations. This can be done by implementing biotechnology in defined arenas to create an era with positive changes and a better life[8,13].

Role of Biotechnology in the Pursuit of SDG 2: Alleviating Hunger

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[17]. Howev-

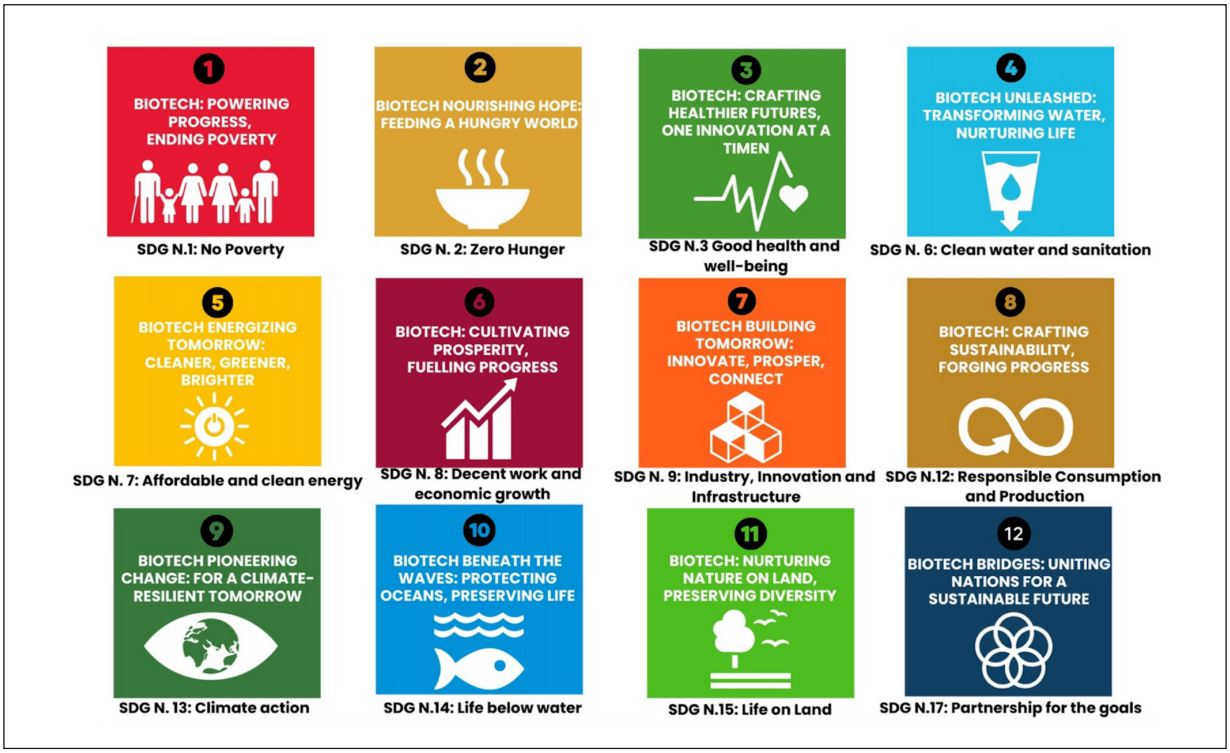

Figure 1. Biotechnology's contributions to attaining sustainable development goals.

er, it is facing significant challenges to achieve its desired targets. The current limitations include shortage of land and water resources, coupled with unexpected climate change that further complicate the already challenging endeavor of doubling food production within the next four decades[18]. 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[18].

Utilization of innovative technologies that can harness the productivity of agricultural yields serve as the foundation against hunger. The dissemination of agricultural biotechnology requires substantial initial investments in rural education, infrastructure, and extension services that do not only focus on increasing agricultural productivity, but also on raising small farmer's income, managing natural resources, improving livelihoods, stimulating economic growth, and improving food quality and health[18]. In the last 20 years, biotechnology has worked in increasing food resources of the world. Some examples are described below.

GM Crops

Genetic modification (GM) of crops has been utilized to generate useful traits in natural crops, such as disease resistance, enrichment of nutritious constituents, and amplified yields. Additionally, transgenic crop varieties also reduce the use of chemical pesticides, insecticides, and mechanical tilling leading to preservation of environment[18]. For instance, transgenic hybrids of cotton, maize, and potatoes manufactured through incorporation of bacterial genes (Bacillus thuringiensis) have been utilized commercially to minimize the cost of expansive insecticides. Similarly, certain herbicide-resistant crops of soybeans, sugar beet, wheat, and maize have been developed; they are cost effective and highly productive[19]. Additionally, some cereal varieties that can tolerate soil alkalinity, aluminum and iron toxicities have been made and can ward off soil degradation. Technologically engineered crops can also bear harsh climate conditions like drought, heat and cold that can increase the yield per unit area[19].

Biofortification

High-throughput technologies, including nano technology, have facilitated the breeding of micronutrients rich essential crops that contain ample

vitamin A, zinc, iron, and essential nutritional value. This biofortification is useful in a fight against malnutrition, undernourishment, and poverty, because it increases the accessibility of naturally fortified food to people of impoverished population who cannot afford commercially marketed fortified foods to meet their dietary requirements[19].

Genetically Improved Animals for Staple Food Production

Genetic engineering has also made phenomenal advancements in producing transgenic animals. Genetically modified salmon is the first FDA approved transgenic animal that can grow rapidly. Likewise, transgenic dairy cows that can tolerate tuberculosis have been created in China[20]. In addition, genetic improvement in lactating species have also led to three to four times augmented milk production. The genetic alterations, which require much investment and work, are luckily transferrable to next generations without additional costs[20].

Increase Shelf Life of Food Products

Biodegradable packaging has become essential in raising shelf-life of food products and reduce their wastage. Integration of nanomaterials and anti-microbial agents in bio-based packaging are helpful in protecting food from pathogens and preserving the health of environment[21]. By the use of biotechnology, edible films and coatings have been manufactured – they are ideal in preserving fresh and frozen food. Such biodegradable coatings slow down microbial growth, prevent moisture loss and have an edge over synthetic coatings, as they are edible and eco-friendly[22].

Protection and Fostering of Sea Food and Aquatic Life

Oceans comprise the largest ecosystem of the planet and sea food fulfils the 20% of dietary protein needs of people. Therefore, aquaculture provides essential food resources and employment to the people involved in processing and distribution of sea food[20].

For many reasons, protection of aquatic life is essential. Biotechnology offers efficient methods like 'cryopreservation' to conserve specific genetic traits of endangered aquatic species and has proved very helpful in fish farming[23]. Additionally, with the advent of biotech research, DNA vaccines have been developed against fish pathogens to protect economically important aquatic animals from infectious diseases[24].

All of these great endeavors of biotechnology increase the productivity of healthy food and contribute to attaining the goal of zero hunger in the world.

Biotechnology in the Pursuit of SDG 3: Good Health and Well-Being

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 (SDG 3) is vital to accomplish other SDGs[25].

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. In this regard, biotechnology offers powerful methods that are beyond increasing the crop yields, and synthesizing drugs for a range of diseases. Modern nutritional food technology and curative science (dealing with medicine & therapy) are the two sides of the same coin, both of which are indispensable for leading an active life and attaining longevity[26]. Here, we will separately discuss these two aspects of healthcare biotechnology and explore their innovations.

Food and Nutritional Technology for Health

A healthy lifestyle benefits good health. Wholesome food combined with physical and mental fitness practices maintain cellular homeostasis that further controls metabolic activities of body. Biotechnology can integrate naturally available potential ingredients in our daily food as nutraceuticals, cosmeceuticals, and pharmaceuticals through bio-processing[27].

Recently established innovative technologies have transformed the way food is processed. Traditional methods like fermentation, fat replacement, and modification of food components have now been manipulated with biotechnologies to make the food more specific, functional, and enriched with desirable flavors and textures. Discoveries in genetic field and advent of nanotechnology have enabled the scientists to develop personalized food with additional health

benefits[26,27]. Here, we are discussing just some food technologies that are making food healthy enough to achieve wellness and good health.

Genetic Modification

It is possible to genetically modify foods in a way that they will be richer of specific essential micronutrients. Golden rice represents an excellent example of nutritionally improved crop, in which levels of beta carotene (vitamin A) are augmented through genetic manipulation. Similarly, we can harness the bioavailability of essential micro and macro nutrients, eliminate allergens, and alter starch and fatty acid profiles of different foods through biotechnological methods[26].

Encapsulation of Food Materials

Encapsulation of Food Materials is the conventional method to protect the functionally active ingredient (vitamins, anti-oxidants, and probiotic living organisms) from moisture, heat and other harsh conditions. Encapsulation of fish oil is very popular to conserve the benefits of polyunsaturated fatty acids (PUFA) beneficial against coronary heart disease[26].

Use of Micro-Organisms or Adding Valuable Nutrients to the Food

Micro-organisms are introduced in a variety of food products to enhance its functionality. For instance, microbial fertilizers which increase soil fertility and also provide essential nutrients to plants have been developed. Moreover, various amino acids, vitamins, and enzymes are also added to animal feeds to enhance its nutritional value[28]

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Medicinal Biotechnology for Maintaining Health

The use and development of biotherapeutics are at the greatest pace to improve life expectancy and upgrade the quality of life of the growing global population. Recent breakthroughs in research and development (R & D) in the health sectors have significantly improved healthcare infrastructure and survival rates from serious ailments.

Medicines and Vaccines

Biotech companies are on their way to design drugs and vaccines that are potent against lethal diseases, like cancer and HIV, which provide the patient with greater life expectancy. Moreover, vaccines against devastating viral and bacterial outbreaks (such as polio, typhoid, mumps, Ebola etc.) have greatly improved prevention and treatment of infectious diseases to avoid epidemics and pandemics. Research suggests that almost 10.5 million infectious illnesses cases can be avoided by the administration of vaccines. A British company developed a genetically modified insect – *Aedes aegypti* – to control the outbreaks of dengue, chikungunya, and Zika virus[29].

High-tech Clinical Diagnostics

Novel diagnostics methods have been developed to identify and categorize the diseases and different stages of disease. Considerable progress has been done in Next Generation Sequencing (NGS) method, which is a rapid and cost-effective method to analyze entire genome and help to identify genetic variations and mutations in various diseases[30]. As biotechnology continues to advance, the healthcare sector is utilizing the power of sophisticated computers and computational tools that enhance the accuracy and efficiency of diagnostic processes. Imaging techniques, like MRI and PET, along with high-resolution imaging techniques like ultrasound and CT, scan have seen significant advancements in recent years.

Precision Medicine

Advances in omics sciences with biotechnology, psychosocial, clinical, and genetic data of patients, have enabled the scientists to design personalized therapies for individual patients. By discovering disease-causing and drug-sensitive genes and biomarkers in one's genome, targeted therapies have been tailored. Applications of precision medicine are widespread, such as in the fields of oncology, CVD, pulmonary, renal diseases, and certain endocrine disorders (such as Multiple endocrine neoplasia type 2)[31]. Moreover, this approach has also revolutionized genetic testing, therapies, and disease classification. Such as molecular testing done for cancers and genetic disorders to identify genetic markers and optimize care for individual patients[32].

Role of Biotechnology in the Pursuit of SDG 6: Clean Water and Sanitation

Water is the fluid of life on this planet, and public health strongly requires cheap and clean drinking water to survive. Thus, access to clean water and safe sanitation are indispensable for popula-

tion health globally. SDG 6 is primarily targeted to guarantee universal access to water and sanitation in a sustainable manner, while also improving the health and quality of life of global population[33].

Biotechnological advancements are reinforcing the availability, quality, and sustainability of water resources and sanitation services. An increasing and alarming problem is the depletion of fresh water reserves due to climate change. To address this problem, scientists are discovering ways to recycle the wastewater in order to fulfill water demands. Bio-membrane reactors technology can efficiently remove solid wastes, micro-organisms and particles from wastewater, and further purification with anaerobic ammonium oxidation can make it drinkable. Moreover, biotech approaches enable the development of novel water treatment methods based on de-centralized sanitation and reuse (DESAR)[34].

Use of Cellulosic Fibers for Water Clean-Up

A study explored the use of cellulosic fibers specialized with polyelectrolytes for purifying water in portable purification systems. The adsorbed polyelectrolytes create a positive charge on the fiber surface, attracting and bonding with bacteria. This system can remove almost 99% bacteria from natural water making it an environmentally sustainable and cost-effective option for water purification[35].

Use of Bacteria to Clean Water

The role of oil-eating bacteria to clear oil spills is already well-known[36], some water treatment procedures utilize bacteria to purify and clean drinking water. Scientists grow the bacteria in bioreactors and harness them to remove harmful pollutants even other bacteria from water[37].

Use of Electrolyzed Water with Germ Killing Properties

A study[38] showed that acidic electrolyzed water is able to remove food-borne pathogen biofilms from water. Moreover, it is a cheap and eco-friendly water purification method that can destroy both Gram positive and Gram-negative bacteria found in water and has vast applications in food industry.

Chitin and Chitosan for Water Purification

These are low-cost, plant-based polymers, and renewable resources used in water purification systems. They can actively remove hazardous pollutants of water including phenols, dyes, pesticides, heavy metal ions, bacteria, and yeast. Chitin significantly boosts the functionality of filtration systems because it can capture fine particles and solved pollutants[39].

Nitrogen use Efficient (NUE) Genetically Modified Crops

Nitrogen (N), being the most favorable element for plant growth, have been excessively used in fertilizers. However, inefficient nitrogen fertilizers cause harm to soil and water resources. So, transgenic approaches are headed towards the emergence of nitrogen use efficient (NUE) genetically modified crops, that will use less nitrogen and will eventually cause less harm to waterways[40].

Role of Biotechnology in the Pursuit of SDG 7: Affordable and Clean Energy

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, that is now linked to the surge in greenhouse gas emissions, air pollution, and significantly increased global warming. Therefore, a transition in the way we produce and consume energy is needed. For this purpose, renewable energy sources were developed as they are cost-effective, dependable, and effective for routine usage. Some of the safe and sustainable energy production systems include hydropower, wind energy, solar energy, biomass energy, biofuels and geothermal energy, that are paving the way towards resilient ecosystem and natural life[41,42].

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 growing population. To bridge the energy gap by 2030, scientists are striving to develop renewable energy sources instead of fossil fuels. This is crucial to prevent long-term, large-scale consequences, particularly climate change, which poses severe risks to our planet[41].

By harnessing the power of biological systems and processes, biotechnology offers 'biofuels' that can serve as renewable alternatives to fossil fuels, reduce carbon emission and mitigate the

climate crisis. Through genetic engineering and bioprocessing, various feedstocks such as crops, agricultural waste, and algae have been utilized to develop biofuels[43]. There are two types of commercially available biofuels, ethanol used as a substitute to gasoline, and vegetable oils to be used as biodiesel instead of diesel fuel[44].

Bioethanol is an excellent alternative to petrol representing a viable solution to environmental pollution. Ethanol in its pure form (E 100) is a high-octane biofuel, largely obtained from sugarcane, that generates more power in high-compression engines. Countries like Brazil and India, major producers of sugarcane, are encouraging the use of ethanol for energy in transport sector due to its low carbon emission[45]. In Brazil, the majority (90%) of cars have flex-fuel engines that are exclusively operated with bioethanol. Blending of ethanol with gasoline (E25) provides cleaner option for energy, leading to reduced pollution[44].

Biogas is an outstanding renewable energy source, that is generated by anaerobic digestion of biomass including agricultural wastes, animal manure, kitchen and green wastes[46]. Biogas contains ample methane gas and serves as an ideal and cost-effective option for cooking and vehicle fuel. This not only provides cleaner energy to generate electricity and heat, but also contribute to reducing organic waste[47]. Companies like Audi, DuPont, and DSM have promised to adopt sustainable energy options to reduce carbon emission by 50%. Companies are striving to generate cleaner energy to replace charcoal-burning cookstoves[48].

Role of Biotechnology in the Pursuit of SDG 8: Decent Work and Economic Growth

The 2030 Agenda considers full employment and decent work as fundamental human rights. SDG 8 aims to foster long-lasting, equitable, and productive economic growth, while ensuring widespread access to employment opportunities and graceful work for everyone. Its main objective is to invest strategically in developing new businesses that can boost productivity, reduce waste, and promote sustainable economic growth on a global scale[49].

Biotechnology is helping in agricultural productivity and food security, industry boost, skills development, and improved healthcare; eventually upgrading global economy and fostering financial systems. Development of GM crops has enabled farmers to increase their yields with less input. An economic survey revealed that innovative crop biotechnology has enabled 26 countries to amplify their growth, by empowering farmers to achieve high yields. Moreover, it has also facilitated about 16.5 million population of small farmers to raise their net income[50].

Implementing policies that encourage the development of innovative solutions, attract investors, and increase the value of products and services would definitely contribute to global growth in a sustainable manner. In this context, the applications of 'microbial biotechnology' are widespread and provide plethora of opportunities for entrepreneurs and small stakeholders. The range of microbial biotech fields include microbial therapies, plant growth promotion and protection agents, bio-catalysis, bioenergy from renewable feedstocks, fossil fuel recovery and valorization, clean water provision, recycling technologies, wastewater treatment, bioremediation, and many more[51].

Role of Biotechnology in the Pursuit of SDG 9: Industry, Innovation, and Infrastructure

SDG 9 acknowledges the importance of industrialization, technological advancements, and infrastructure in driving economic growth, creating employment opportunities, and improving living standards while minimizing negative environmental impacts. Investment in creating a reliable framework of industries will facilitate public-private partnerships, technology transfer, knowledge sharing, capacity building, and innovation diffusion[52].

The emergence of biotechnology is an illustration of the dynamic evolution of a technology from life-sciences. While on the other hand, the interplay between academic institutions and industry influences the pace of innovation. So, countries and companies should take steps to bridge the gap between research and development (R&D) and industries. For this purpose, significant investment has been made, at country level and global level, in constructing biotechnology parks, and creating opportunities for investment and partnerships. In India, science, technology, and innovation (STI)-based incubation centers have been constructed to encourage entrepreneurship and meet societal goals[53].

In Brazil, development of BiotechTown is a demonstration of framework that encourages start-ups to expand that business and provide resources for it. Similarly, building of BioPark in Mauritius and OneBio in Cape Town depicts a convivial infrastructure to provide space and resources for R&D in the biotechnology field and foster biomedical research[54].

Role of Biotechnology in the Pursuit of SDG 12: Responsible Consumption and Production

SDG 12, for responsible consumption and production of global resources, seeks to foster a future that is both sustainable and fair; where economic growth is independent of environmental impacts and resources are utilized efficiently and responsibly. The consequences of SDG 12 visions demonstrate a perspective focused on business-friendly regulatory system, and places trust in new technologies as potential solutions[55].

Biotechnology is helping to achieve SDG 12 in a variety of ways by re-utilizing waste materials and their recycling. Bioplastics made from polyhydroxyalkanoates (PHAs) are eco-friendly alternatives to chemical plastics. They are synthesized by rich biomass concentration of microorganisms by the process of activated sludge (a system where microorganisms metabolize and consume organic matter in a tank). These biologically manufactured plastics have vast usage in food packaging, 3D painting, therapeutics and agriculture, and they are biodegradable[56].

Coca-Cola, one of the world's largest soft drink producing companies, firstly highlighted the use of plant bottle, made of polyethylene terephthalate (PET) which is a plant material[57]. Similarly, scientists at Berkeley National Laboratory converted Municipal solid waste (MSW) into precursor chemical compounds used for energy generation by waste-to-energy technologies[58].

Role of Biotechnology in the Pursuit of SDG 13: Climate Action

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. Climate action is crucial for achieving sustainable development in all its dimensions. Addressing climate change contributes to mitigation in climatic hazards and natural calamities, as well as integration of climate change strategies into national policies[59].

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 like biofuels, biogas, and other biomass-utilizing renewable energy sources will reduce the reliance on fossil fuels, leading to less GHG emissions and less impacts on climate[43,44].

Development of climate-resilient genetically engineered crops, that require fewer resources and are tolerant to drought, heat, pests, and diseases provide solutions to climatic challenges in agriculture. GM crops utilize less land and water, require less tilling of soil leading to preservation of ecosystem and natural resources[18,19]. In 2014, a study[60] showed that through conservation tillage and reduce fuel usage with GM crop crops, 5.2 billion pounds of atmospheric carbon dioxide emissions were decreased, that is almost equal to withdrawing 10 million cars from roads for one year.

Role of Biotechnology in the Pursuit of SDG 14: Life below Water

Oceans cover more than 70% of the earth's surface and provide valuable marine and coastal resources, significantly contributing in social, economic, and environmental realms. Transportation of goods, fisheries, and tourism are primary areas which provide employment and livelihood to many people and partake to local and international economies[61]. Sea water constitutes the largest ecosystem of the world but faces many challenges, such as pollution and climate change. SDG 14 primarily focuses on protecting and sustainably utilizing oceans for sustainable development. Steps forward for this SDG are closely connected to the overall framework of Agenda 2030, because it is concerned with balancing between various uses of water resources, main-

taining both the quality of water and the need to preserve diverse and healthy ecosystems[62]. The marine bioresources have been integrated with biotechnological applications in a field referred to as 'blue biotechnology'.

Blue biotechnology is helping to conserve valuable marine species to avoid overfishing, known as 'blue revolution'. Techniques, like genomics and recombinant DNA technology, have been utilized to grow genetically modified salmon, trout, and tilapia in fish tanks to lessen overfishing and protect marine species[63].

Biosensors have been deployed in oceans to screen marine environments and detect for the presence of pollutants, nutrients, sediments, oil, and invasive micro-organisms in cost-effective manner[64].

The discharge of nutrients, particularly nitrogen (N) and phosphorus (P), into aquatic environments by agricultural runoff and stormwater, have been identified as major contributors to nutrient input in various countries. Filamentous algae have the ability to rapidly absorb nitrogen (N) and phosphorus (P) from the water above and incorporate them into their biomass. Through microalgal biotech approaches, filamentous microalgae are cultivated in a controlled flow-way, to allow the microalgae absorb the nutrients[65].

Role of Biotechnology in the Pursuit of SDG 15: Life on Land

Covering almost 30% of world's surface, forests accommodate about 80% of terrestrial species of plants, animals and insects. Also, forests are indispensable for the health of ecosystem and biodiversity, that are crucial for food security, thriving of diverse species, and socio-economic well-being of populations. However, unfortunately, ever increasing world's population, industrialization, and agricultural expansion has led to deforestation and loss of biodiversity. This in turn, can result in species extinction, increased carbon emission, and land degradation leading to more delicate ecosystem and devastating effects on rural population[66].

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 preservation of biodiversity. Biotechnology is significantly contributing to preserving life on land. Agricultural innovations, and development of genetically modified crops which are the benchmarks of modern biotechnology, that are the supporters of land conservation efforts[67].

Genetic engineering is a chief biotechnological advancement. GM crops can enhance agricultural productivity while minimizing land use. Through genetic engineering, resistance against pests, diseases and herbicides are induced in crops leading to conservation of topsoil (less tilling) and water, and long-term viability of agricultural landscape[68]. Therefore, reduced need of agricultural expansion into natural ecosystem, chemical inputs, and deforestation significantly saves the land for plant and animal species at risk of extinction.

Researcher was able, by using GM, to improve crop of ancient chestnut tree, developed at the State University of New York (SUNY), with the aim to prevent its depletion by a fungal infection[69]. Similarly, rainbow papaya was nearly wiped out in 1990s, due to the infection of ringspot virus. GM crops of rainbow papaya were developed to save this plant species resistant to ringspot virus[70].

In this way, biotechnology is helping the world to manage the competition between people and wildlife for land. 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[65,66].

Role of Biotechnology in the Pursuit of SDG 17: Global Partnerships for Sustainable Development

Strengthening global partnerships between countries, research institutions, and biotech companies are very important to address various social, economic, and environmental challenges collectively. SDG 17 is playing significant role in establishing firm relationship between different stakeholders across the globe, and biotechnology is underpinning the primary targets. Knowledge sharing and capacity building, technology transfer, health and disease management, environmental challenges, and collaborations between public and private sectors to drive innovation and achieve sustainable development goals, are essential to maintain a resilient global community[71].

For instance, The Centre for Tropical Livestock Genetics and Health (CTLGH) is an institute based in The University of Edinburgh, Scotland's Rural college, that is working in partnership with farmers of low-income countries to grow more productive animals through modern genetic engineering methods[72]. Merck is supporting BroadReach Institute for Training and Education (BRITE) in Zambia to train their healthcare workers for efficient and expert health related services, and they are performing well in their country[72].

Conclusions

Undoubtedly, biotechnological advancements offer solutions for sustainable resource management and environmental conservation. It enables the development of clean technologies, bio-based material utilization, and processes that reduce pollution, waste generation, and resource consumption. Bioremediation and biological control methods help restore ecosystems and minimize the impact of human activities on the environment.

Global community, including countries, governments, and organizations should collaborate to share knowledge, experiences, and best practices, as well as provide technical and financial assistance to developing countries. Currently, there is a strong need to integrate the SDGs into national development plans and policies, to make significant strides towards achieving the SDGs, addressing global challenges, and fostering a sustainable and inclusive future for all.

Conflict of Interest

The authors declare that they have no conflict of interests.

Ethics Approval

Not applicable.

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Authors' Contribution

Conceptualization, MB; Investigation, KD, MCM and DM; Writing – Original Draft, KD, MCM and LS; Writing – Review & Editing, TB, MD, RSM, SM, EB, CZ, HE, GS and DM; Supervision, MB; Funding acquisition, MB. Each author approved the final version of the manuscript.

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