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Microbial biotechnological trends for future sustainability

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ABSTRACT

A shift towards the sustainability is an urge of the society nowadays as current earth environment is deteriorated. The anthropogenic activities including industrialization, afforestation, utilization of chemicals and release of pollutants without treatment into the water and land are the major reason for deteriorated health of the earth. Due to the deteriorated health, required resources such as agricultural productivity, pharmaceutical and food products is majorly affected. The depleted production of the resources end up using synthetic fertilizers in various fields which helps in the increased the production but on the other hand it effects the environment. The past two decades extensive surge in publications have been published. Despite huge research for the sustainability, still this concept remained open with myriad interpretations. Microbial biotechnology, the multidisciplinary area is rapidly growing sector for diversified applications in the agriculture, environment and pharmaceutical sectors. In agricultural sector, microbial biotechnology sectors helps in the production of the sustainable crops. Using the microbial biotechnological techniques different biofertilizers and biopesticides which could substitute the chemical fertilizers and pesticides. Biofertilizers and biopesticides could be developed by the plant growth promoting microbes which exhibits various beneficial traits such as fixation and solubilization of essential macro- and micronutrients (nitrogen, phosphorus, potassium, and zinc), chelation of nutrients (iron), production of hydrolytic enzymes, hydrogen cyanides, antibiotics, and secondary metabolites. In environment, microbial biotechnology helps in the sustaining the deteriorated environment.

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Biofertilizers and biopesticides could be developed by the plant growth promoting microbes with fewer side effects on human health and the environment which exhibits various beneficial traits such as fixation and solubilization of essential macro- and micronutrients (nitrogen, phosphorus, potassium, and zinc), chelation of nutrients (iron), production of hydrolytic enzymes, hydrogen cyanides, antibiotics, and secondary metabolites. In environment, microbial biotechnology helps in the sustaining the deteriorated environment. The environment has been severally polluted with various pollutants including heavy metals, polyaromatic hydrocarbons, oil sludge, synthetic dyes, and other xenobiotics. Microbes with the biotechnological techniques help in the bioremoval and bioremediation of the pollutants present in the water and land by bioaccumulation and biosorption methods.

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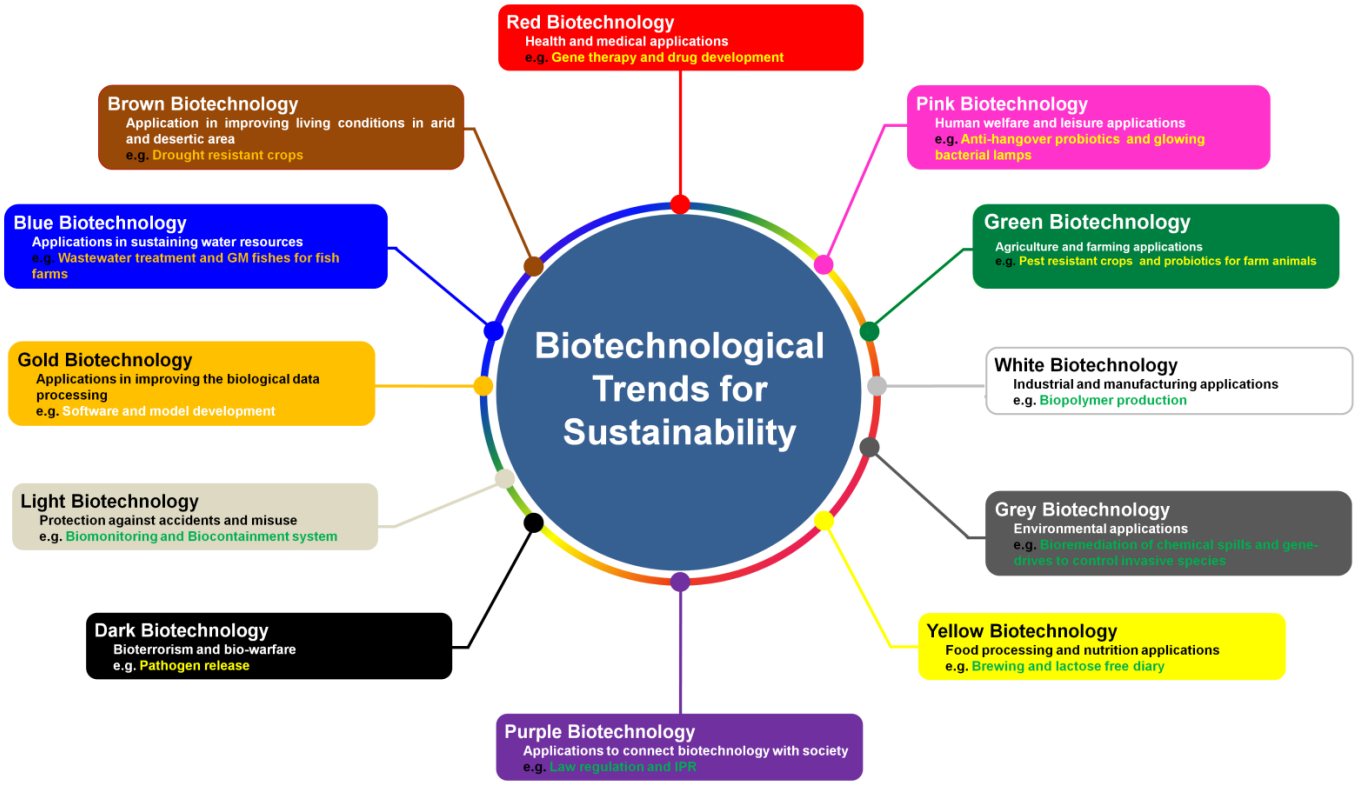

Fig 1. Biotechnological trends for sustainability, Adapted with permission from Yadav et al. (2025).

Microbial biotechnological techniques can also produce the biofuels which is another sustainable solution to the petroleum which are extracted from the fossil fuels. In industrial sector, microbial biotechnological techniques can be used to produce products in the food, pharmaceutical industries. In food industries, microbes can be used for the production of fermented products such as cheese, yogurts, brewery products (wine and beer). On the other hand, in pharmaceutical industries, microbes can be used for the production of medicines instead of synthetic chemicals. Microbes are known to release the secondary metabolites which may have antimicrobial, anti-cancer, anti-diabetic and anti-inflammatory activities. In the present editorial basic and applied aspects of the microbial biotechnological applications in various fields have been discussed.

Microbes inhabit the various habitats including soil, air, water, animals, and plants which can be beneficial or pathogenic. Many beneficial microbes are reported which belongs to genus, *Alternaria, Aspergillus, Acinetobacter, Aureobasidium, Azotobacter, Bacillus*, *Beijerinckia, Bipolaris, Camelliae, Cercospora, Cladosporium, Dioszegia, Enterobacter, Gluconacetobacter, Herbaspirillum, Hyphomicrobium, Klebsiella, Kocuria, Methylibium, Lactobacillus, Brevibacillus, Methylobacterium, Moesziomyces, Mucor, Nostoc, Phoma, Pantoea, Penicillium, Pseudomonas, Rhizobium, Stenotrophomonas, Venturia*, and *Wardomyces* can be used in the agricultural, bioremedical, industry and environmental sector (Yadav et al. 2020, Angelini et al. 2022, Razaghi & Abdel-Azeem 2024).

Biotechnology is the rapidly growing field with diversified applications in sustainable agriculture (Umesha et al. 2018). The genetic resources of human, animals, microbes and the plants consist of the basic raw materials for all biotechnology based research, innovations and technology development (Figure 1). Microbial biotechnology is an emerging field with a range of applications in sustainable agriculture, health, industry and environment (Hesham et al. 2021). Agricultural sector forms the basis of the global economies and make a significant contribution towards the major challenges and priorities of recent times including poverty eradication, economic diversification, rapid industrialization and environmental management and health field. Agricultural microbiology is an important segment to swap knowledge from general microbiology to agricultural biotechnology. The major

focus of the present times is achieving the target of sustainability. In this regard, beneficial microbial communities play a fundamental role in the sustainable production of the crops and meet the major challenges of zero hunger, Diseases caused by poor agricultural products and poverty. The beneficial microbes in soil and in association with the plants such as rhizospheric microbes, endophytes and the phyllospheric microbes possess unique capabilities of promoting plant growth, maintaining soil health as well as fertility and producing healthy food for the growing population (Hirsch et al. 2013). Plant growth promoting microbes such as the macro and micronutrient fixers and solubilizers, IAA, hydrolytic enzymes, antibiotics and siderophores producers could be developed as bioinoculants for enhancing the productivity in a sustainable manner while reducing the application of the harmful chemicals and without leading to any imbalance in the ecosystem ultimately preserving the healthy biosphere (Barea 2015; Yadav et al. 2020). Thus, the use of the biofertilizers is an important low input and eco-friendly constituent of integrated nutrient management (Gosal et al. 2020).

Microbial technologies have been providing solutions to all key challenges of our daily lives for over a century. The issues on health, energy and environmental challenges have become one of the largest challenges among UN sustainable development goals which need sustainable solutions to be dealt up with. The increasing environmental pollution has become a major concern which needs to be addressed now and even in the future (Liu 2020). Some of the organic pollutants persist in the environment for a longer period of time and becomes major threat to the human health (Zhuang et al. 2007).The tiny microbes, the most precious gift of the nature play a vital role in the remediation of the ecosystem by degrading and removing the major environmental pollutants such as recalcitrant compounds and heavy metals. Beneficial microbes clean up heavy metal contaminated sites by different approaches such as biodegradation, biosorption, biotransformation, chelation, bioaccumulation and precipitation (Gupta et al. 2024). A recent trend emerging in this direction is the use of the beneficial and compatible bacteria and fungi in combination as bioremediation agents to make the process more efficient as well as robust to the changing environmental condition. Thus, the use of the microbes represent a promising approach in overcoming environmental pollution by utilizing the natural metabolic abilities of the microbes to degrade and detoxify the pollutants.

Microbes form an integral part of food, textile, detergent and pharmaceutical industries. Microbes have been playing an amazing role in production of substances useful to mankind. Microbes have been used in preparation of the bread, yogurt, wine and many other fermented foods. The microbes when added to the food production impart color, texture, aroma and flavor to the foods as well as enhance the marketability of the products (Kv 2022). Microbes are the precious bioresources of the hydrolytic enzymes such as the pectinases for coffee industry, amylases for baking industry, proteases for dairy industry and cellulases for paper industry (Kour et al. 2019). Bacterial and fungal proteases are preferred in detergent industry (Niyonzima and More 2015). Thus, microbes are important bioresources of biotechnologically important enzymes of industrial importance. In recent years, there has been shift from synthetic to natural pigments due to increased consumer demand for natural products. The use of pigments from microbial sources in processed food is an area of promise with large economic potential (Malik et al. 2012).

Biomedical field is not an untouched field of microbial biotechnology. Microbial biotechnology has revolutionized diseases diagnosis as well as the disease treatment. The research on biosurfactants from microbes has increased in past few decades. The antimicrobial activities of biosurfactants make them significant molecules as therapeutic agents as well as for combating diseases. Biosurfactants can also be used as anti-adhesive coating agents for insertional materials which can prevent many nosocomial infections (Rodrigues et al. 2006). Microbial lectins are other biomedically important molecules. Lectins have many biologically significant properties such as capability to agglutinate red blood cells, lymphocytes, fibroblasts and spermatozoa (Singh and Bhari 2013). Lectins in oncology can be used as diagnostic probes. Lectins from *Aspergillus oryzae* was reported to induces mast cell activation and anaphylactoid reaction by cross linking IgE via binding to fucose residues in mice and human IgE *in vitro* (Yamaki and Yoshino 2011). *Clitocybe nebularis* lectins inhibited the growth of human leukemic T cells (Pohleven et al. 2009). Lectins from *Bryothamnion seaforthii* possess anti-nociceptive activity in rodents (Viana et al. 2002). Lectins have been also known to exhibit anti-inflammatory, anti-viral and anti-microbial activities. Biosensors have an important role in rapid and accurate detection of biomolecules. Bacterial cellulose is emerging as a versatile material for biosensors (Akki et al. 2024). Thus, microbial biotechnology is emerging area of research with vast

applications and has not left any sphere of planet untouched.

In conclusion, microbial biotechnological applications are in high demand as it can helps in the sustaining the environment and ease the life of the mankind. Sustainability is the core agenda of the every second person as it is current need of the mankind. Microbial biotechnological techniques are used in the various fields including agriculture, environment, health and industrial (food, and pharmaceutical) sectors which can substitute the products like fertilizers, pesticides, and synthetic chemicals used in the industries. In future times, microbial biotechnological can be more researched which can be used in the more sectors in order to attain the sustainability in agricultural, environmental, health and industrial sector.

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