From Waste to Best: Biotechnological Approaches for Sustainable Development

ABSTRACT

An essential element required for the existence of man and other biotic species is the environment. The survival and well-being of all its constituent parts are measured by the physical environment's degree of sustainability. Furthermore, using any recognized way to dispose of poisonous or harmful compounds is insufficient.Increasing demand of human population results in utilization of many chemical based products like pesticides and synthetic fertilizers. But, these processes harm ecosystem and environment with increasing toxicity and pollutant.Excess mining with acids to recover metals also cause pH imbalance and change of natural microbial community. Waste is generated from routine life which comprising food wastes, animal wastes or agricultural wastes. These waste material contain cellulose, ligninand starch components. Waste material can be decomposed by microorganisms for their own growth. Microorganisms can synthesize different type of bioplastics by decomposing waste material. They can also fix nutrition in soil and can be used as a biofertilizers. Antagonistic nature of microbes can be used as a pesticide to kill pests in agricultural sector. Besides these enormous benefits of microbes, they can even recover metals from raw ore. Biobased products can even be degraded easily without any posing any toxicity.The greatest way to manage the environment is to recycle all of its constituent parts, or wastes, making them usable and assisting the biotic and abiotic relationships in maintaining the aesthetically pleasing and physiologically sound balance that distinguishes an ideal environment. Thus, this review comprises screening of utilization of microbes to produce bio based products from waste material to sustain the environment from chemical based products.Cooperation between nations and organizations is essential for knowledge exchange and for giving developing countries financial and technical support.

Key words:*Biopesticide, Biofetilizers,Biofuel, Sustainable environment, Wastes,Sustainable resource management and Ecosystem restoration*

Introduction

Natural ecosystem provides food, shelter, protection and mostly other needful things to live life. Ecosystem consists of biotic and abiotic factorsthatare required to balance natural system through different interactions patterns. But, rapid development by expanding human population which is the result of requirements satisfaction and distribution cause disturbance and negative effect to this balanced system [1]. Use of chemical fertilizers, synthetic pesticides, petroplastics, hazardous chemicals and xenobiotics cause harm and create toxicity to the environment. Chemical fertilizers are widely and routinely used to increase agricultural crop yield. Pesticides like organophosphate, orgnochloride, carbamate are also applied in farm sector to control various types of pest which are responsible to harm crop. Uncontrolled use of synthetic fertilizers and pesticides is causing soil and aquatic environment poisoning. Biomagnification and bioaccumulation of these compounds and their residues cause disease to living beings and also disrupt food chain and food web. For example, quinalphos and carbosulfan belongs to class II toxicity level and cause toxicity by inhibiting acetyl cholinesterase enzyme of nervous system. Endosufanhas LD50 value 80 mg/kg in Rat [2].If this imbalance goes in continuity, it can potentially pollute and destruct natural ecosystem in nearest timeline. To prevent this environmental damage and make it sustainable one should focus on options which can fulfil of human demands with less pollution causing tendency during and also after use. So, these optional materials should be recyclable, reusable but not recalcitrant (Fig.1).

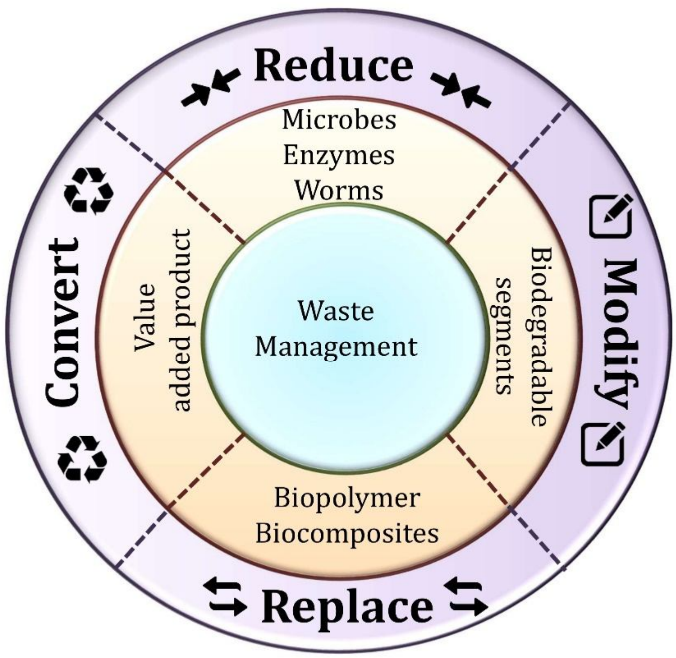

Fig:1. Overview of Waste management process for sustainable environment

Environmental sustainability can be achieved through use of products which are degradable and mostly non-xenobiotic. Biotechnology offers various products which are based on biological system. For example, bioplastic, biopesticides and biofertilizers mainly contain biological material or biological system originating compounds. These biological based products create less pollution during manufacturing and also while getting degraded. Bio based products degrade naturally in soil and water by microbial activity and enzyme secretion. Degradation of these products also replenishes nutrients in the ecosystem. Thus, these bioproducts are very helpful to maintain and regulate natural nutrient cycling without much efforts. Environmental Sustainability Index (ESI) provides performance quantification of environment to detect pollution level and progress of nation for sustainability of the environment [3].According to United Nations Environment Programme sustainable development is the development which should provide needs of living beings without compromising future aspects. For example, Stockholm convention was established to control Persistent Organic Pollutants (POPs) applications and manufacturing. Initially it has 12 different compounds with 3 of categories elimination, restriction and unintentional production [4] .

Many methods for removing and handling waste products used during the ancient times involve activated sludge, biosorption, bioreactor, and composting. Many carbon-based waste is decomposed into organic, inorganic, and xenobiotic waste.Organic waste contains cellulose, lignocelluloses and hydrocarbon while inorganic waste contains salts and heavy metals. Xenobiotic compounds are foreign to the earth's environment and some are mostly persistent. Sources of these waste materials are agriculture, domestic, mining, industries, laboratories, municipalities and hospitals[5].Microorganisms can use this different waste material to obtain nutrition by degrading them. Microbes synthesize and release various enzymes to convert complex nutritional sources to simpler one. By catabolism process microbes generate CO_2, H_2O and other by-products. These by products are sometimes bioplastics or biofuels. Some microbes have antagonistic and competitive effect of other microbes. This characteristic of microbes can be used as biopesticides[6].

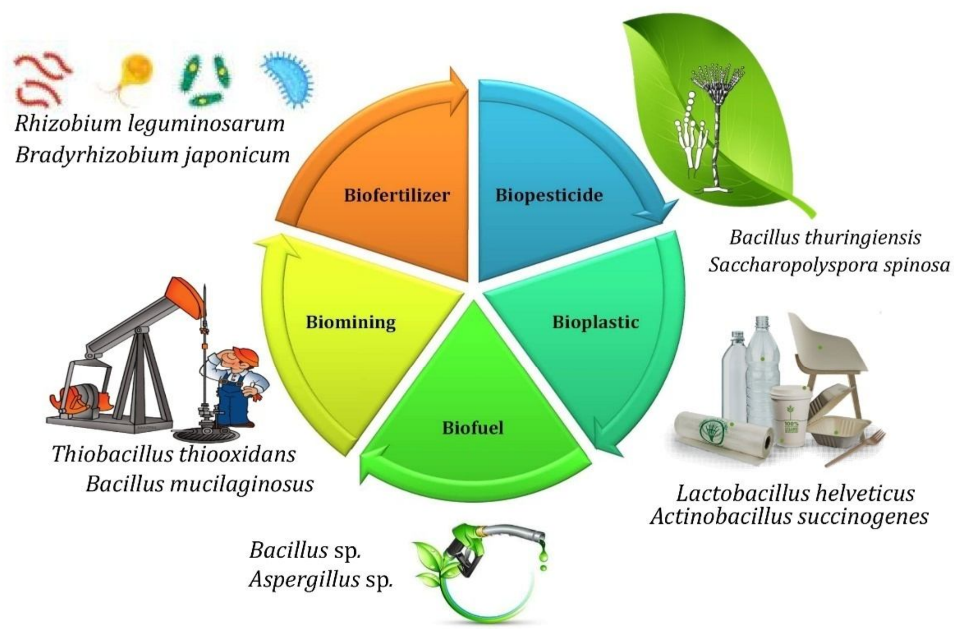

Fig. 2: Different process involved in sustainable environment management

Some organisms and their cellular constituents have an impact of environmental change. These organisms or their constituent molecules can be used to detect environmental change and toxicity. These are known as biomarkers [7]. Biomarkers indicate pollution level either by direct measurement through physiological changes or screening of change at intracellular level. Biobased products create no or negligible harmful effect on ecosystem compared to chemical or petroleum based products. Thus, this chapter mainly emphasizes on utilization of various waste material and microorganisms to manufacture human utilization bio based products which lead to development with fulfilment of needs without compromising environment sustainability (Fig. 2).

2 Various Biotechnological approaches for Sustainable Development:

2.1 Bioplastic

Bioplastic is a type of plastic which is biodegradable, synthesized from various renewable biological sources and from by-products of agricultural materials like starchy portion of potato, from biomass of sugarcane, from straw or starch of cotton. Bioplastic is a type of plastic which is bio based[8].Unlike petroplastic plastics, bioplastics can be recycled and metabolised by microbes, contributing to the production of H_2O , CO^2 and other compounds in the presence of oxygen, whereas CH_4 production occurs in the lack of oxygen.[9]. Different types of bio plastics are(1) Polylactide (PLA) (2) Polyhydroxyalkanoates (PHAs) (3) Poly (butylene succinate) (PBS) (4) Poly (*p*-dioxanone) (PPDO) and (5) Poly (ε- caprolactone) (PCL) [10]Microbes have ability to produce bioplastic. Following Table: 1enlisted bioplastic producing microbes.

Table 1: List of various Bioplastic productions in quantity by microbes

Sr. no.	Type of Bioplastic	Producing Microbes	Rate of Production	References
1.	PHA	*Enterococcus* sp. NAP 11 *Brevundimonas*sp. NAC1	79.27 % 77.63 %	[11]
		Pseudomonas sp. strain P(16)	90.9 %, 82.6 %, 91.6 % for rice bran, dates and molasses respectively	[12]
		*Azotobactervinelandii*UWD	-	
2.	PLA	*Bacillus* sp. X2L4 (Thermophilic)	1.86 g/L/hr	[13]
		Lactobacillus helveticus	35 g/L/hr	[14]
3.	PBS	*Actinobacillussuccinogenes*	53.2 g/L	[15]
		Saccharomyces cerevisiae	12.97 g/L	[16]

PHA bioplastic is polymerized form of approximately 104 monomers. Biopolymers synthesized in microbial cells as a result of excess amount of nutrients. Excess nutrients remain stored in microbial cell and released when environmental condition is favourable. PHA is classified into small chain length PHA, intermediate chain length PHA and large chain length PHA, based on carbon number. The addition of such chemical modifiers influences the different mechanical , chemical and functional characteristics of bioplastics. The effect of sorbitol on bioplastics derived from soy protein has been studied byFelix et al.[17].

There are various application aspects of bioplastic. a-Puyana et al.[18] studied antimicrobial property of bioplastic which is pea plant based. In the presence of nisin which is polycyclic peptide and produced by *Lactococcuslactis*, bioplastic showed inhibition towards *Staphylococusaureus* with inhibition zone of 1 mm and 3 mm for at 20 g/kg and 40g/kg of nisin respectively. Contradictory to this, combination of both nisin and bioplastic could not inhibit gram negative bacterium *Escherichia coli* even at higher concentration.Due to the easy degradation of bioplastics, PLA and PGA are used in manufacturing of medical device, orthopaedic surgeries to replace metallic implant which also prevent secondary surgery [19]. First synthetic bioplastic was PGA, which is nowadays applicable for packaging, in gas oil industrial unit as it is mostly organic solvent insoluble. PGA only dissolves in hexafluoroisopropanol[20]

As biopolymers have great advantage of biodegradation, attribute for sustainable environment various microbes have been isolated and studied for degradation. Microbes degrade bioplastics to produce biomass.Degradation of bioplastic takes in to two steps of (1) hydrolytic degradation and (2) enzymatic degradation [21]. *Pseudonocardia* sp. RM432, *Thermopolysporaflexuosa* FTPLA, *Actinomadura keratinolytic* T16-1, *Saccharothrixwayanadensis*and*NonomuraeaFastidiosa* T9-1 were isolated for PLA bioplastic degradation. Serine proteases were screened out from *Amycolatopsis* sp. with screening of *sspA* and *blasé* genes responsible for PLA bioplastic degradation [22].Polycaprolactone can be degraded can be degraded through polycaprolactone depolymerase enzyme produced by *Alcaligenes faecalis* [23]Bioplastic can be used for transport of pesticides and drugs[24]. PLA can be used for packaging bags and drinking cups [25]. Thus, bioplastic is great alternative tool of petrochemical based plastic for pollution free environment.

2.2 Biopesticides

Biological materialssuch as microbes, plant or animal derived natural products and mineral substances which areapplied for pest control to achieve disease free crop with high amount of yield are known as biopesticides.Microbial pesticides are mainly based on bacteria, fungi and viruses. Bacterial biopesticides are mainly of four types. These are spore producing, pathogens which are obligate, potential pathogens and pathogens which One of the most studied and well defined entomopathogenic bacterium is gram positive *Bacillus thuringiensis*. During sporulation stage of *B. thuringiensis* crystal toxin also known as cry protein or δ endotoxin is produced with other virulence factors. These toxins are released during bacterial vegetative phase and kill larvae of *Diptera*, *Lepidoptera* and *Coleopteran*insects upon ingestion. Cry toxin specifically bind to the cadherins receptor of the mid gut and cause insect death due to cell lysis and septicaemia [26,27].Cry toxin resistance among insects can be developed upon mutation or dysfunction of cadherin genes 017[28].Subspecies of *B. thuringiensis* such as *B.thuringiensistenebrionis, B. thuringiensiskurstaki*, *B. thuringiensisaizawai*and *B. thuringiensissphaericus* are also used as anentomopathogens to control warms, nematodes, mites and insects. *Bacillus firmus* which has main target of nematodes was commercialized under name of Bionemagon[29].*Streptomyces* sp. and *Saccharopolysporaspinosa* produce macrocyclic lactone and spinosinswhich consequently having insecticidal activity [30,31].*Bacillus sphaericus* was isolated from grasshoppers, can produce toxic protein which is intracellular SSII-1 at the time of sporulation used for mosquito control. From *mtx* gene toxic protein having molecular weight of 100kDa is encoded[6]. Plant probiotics can also be produced by bacteria such as *Pseudomonaschloraphis*[32].

Entomopathogenic nematodes enter to the host and release bacteria which are symbiotic to nematodes. These bacteria release various insecticidal toxins complex and metabolites for reproduction facility of nematodes. *Steinernemafeltiae* used to control *Bradysia* sp., *Phytomyzavitalbae* and sciarids.*Phasmarhabditishermaphrodita* and *Heterorhabditisdownesi* are applied to prevent disease from molluscs and Black Vine Weevil[33].

Plants itself produce and secrete some chemicals which protect themselves from pathogens and insects. For example, neem oil is present in *Azadirachtaindica* having insecticidal activity. *Chrysanthemum cinerariaefolium* produce pyrathrin with ability of insect killing. Abamectin and spinosad are macrolide chemicals produced from actinomycetes of *Streptomyces avermitilis* and *Saccharopolysporaspinosa*with biopesticide activity [34].In plant incorporated biopesticide plants are genetically modified or engineered so that they can produce insecticidal substances by their own.For illustration, genetically modified plant was created with *B.thuringiensis*to prevent against insects and ballworms[35].According to Environmental Protection Agency (EPA) risk of genetically modified crops an be associated with humans and animals, due to some allergic reactions.

2.3 Biomining

Biomining is the extraction of metals which are very demanding and have economic implementations, using microorganisms like bacteria and fungi from mine waste or materials of rock ores. Biomining is one of the clean-upstrategy for making environment unpolluted. Stable as well as unstable both metals can be recovered through biomining[36]. Thermophilicmicrobes which can survive at high temperature, heterotrophic microbes which can utilize organic carbon, chemolithotrophic and acidophilic microbes which are survival of acidic pH are most commonly used for biomining of copper, uranium and gold metals. In bacterial genera *Leptospirillum* which can do both functions of bioleaching and biooxidation and *Thermobacillus* are most widely used [37]. *Thiobacillusferroxidans*which are moderate thermophiles can survive at optimum temperature range of 70 to 75 ˚C, oxidize Fe^{2+} to $Fe^{3+}$and sulphur also. *Thiobacillusferroxidans*and*Thiobacillusthiooxidans*both can effectively mine metals as consortium than single inoculants.

2.4 Biofuels

In the hierarchical organization of waste reduction management, the recycling of fuel from different waste products plays a crucial role in supporting the challenges of sanitation, climate and human health created by dumping.. Energy from waste (EfW) techniques provide the choice for a usually useful connection among one of a kind charges for the reusing of herbal waste, for example, wastewater slop, ranch squander , animal waste , meals squander and metropolitan sturdy waste for feasible strength use on this way lowering the degree of squanders created for the duration of the world. Such herbal waste ensures the accessibility of carbon belongings for strength advent as biofuels[38]

3 Various sources of generating Biofuels

(3.1) Wastewater sludge from various industries and urban area

Treatment or management of wastewater sludge is a serious hurdle given its broad scale , high water content, and lead to unhealthy (e.g., bacteria, heavy metals, etc.).Primary and secondary treated wastes are the primary sources of sludge considered for Biofuels. The primary treatment is primary removal or absorption of the dissolved particles The primary treatment is to concentrate organic substances and inorganic particles to a concentration of 2.5-7% where 30-70% of total dissolved solids are collected with an average solid output of 0.1 to 0.3 kg / m3 wastewater.The density of volatile suspended solids (VSS) is usually between 65% and 90%[39]Secondary treatment is based on biological treatment, which involves a combination of aeration, bacterial absorption, which secondary optimisation by sinking excess solids (i.e. secondary sediment).

(3.2) Animal manure decomposition

For enhanced soil enhancement, animal manure has been used as an important alternative. The agricultural requirements of crops and transportation costs, which limit the dangerous use of chemical fertilizers, are factors that affect the use of fertilizer. Alternatives include breaking down of the application of manure, reducing the nutrient content of manure, reducing the production of manure and/or finding alternative uses for manure as biofuels [40,41].

4 Biotechnologies approaches for biofuels as sustainable waste management

On account of significant farming practices, the number and varieties of homestead squander material are ascending to expand food creation. improper administration of farming waste materials is presently turning into a difficulty as ruined waste rural biomass radiates gas and debilitating, associated open intense by ranchers to clear the land creates carbonic acid gas and alternative natural toxins that result in an Earth-wide temperature boost, water and soil befoulment and ecological contamination. farming waste that's essentially dry like straw, which is filthy, is used creature slime. Eco-accommodating developments are expected to safeguard our reality to continue the present amount. during this activity, biotechnology assumes a basic job, but complete endeavors are needed internationally[42]

4.1 Biofertilizer

Plants supplements are fundamental for the creation of yields and solid nourishment for the world's consistently expanding populace. For the most portions, soil board systems rely mainly on manures based on inorganic substances that cause a real hazard to human and the environment. Organic fertilizers have been identified as prospective for expanding soil quality and harvesting to promote sustainability.The use of soil microbes as bio-fertilizers has become of major importance in the farming sector, considering their significant role in food safety and crop yield development.

Biofertilizer could be a key aspect of the chiefs' joint upgrades. Consolidate microorganisms usually used as bio-manure sections; solubilizers of nitrogen, potassium, phosphorus and zinc, advancing rhizobacteria, endo- and ecto-mycorrhizal growths, cyanobacteria, and various phytoplanktons. In the abiotic and biotic parts, the use of bio-manure activates advanced dietary supplements and water take-up, plant enhancement and plant protection.These potential natural fertilizers can play a key role in crop yield and configurability, as well as in soil sustainability as an environmentally sustainable and practical contribution for agriculture.[43]

4.2 Animal Manure

Livestock compost has been used worldwide for generations as an effective nutrient for agricultural production.The rise in organic manure and excretions in fields is due to the growing population of the world that needs bigger supplies of crop yields. These treated the manure area unit moneyed in natural issue and contain essential supplements, for instance, gas, and phosphorus that might be used as composts for high-profitability agricultural things and unequalled productivity. The board of those creature byproducts is big, as they will have long run unfriendly impacts on soil structure[44]. This is during this manner essential to determine the upsides of utilizing excretory product as a natural compost, and inquiries regarding the drawn out utilization of such natural plant food. Utilize skilful organisms or biofertilizers to develop crops on yard changes was likewise found to perform higher correlation than soils treated with designed manure following a three-month development amount.

Because of the nutritional assets in the manure which encourage bacterial growth in the soil environment, the use of solid pig and dairy waste also could boost microbial communities throughout growing period. The proliferation of these beneficial bacteria may respond to plant health and organic matter oxidation through the degradation of complex compound and the subsequent development of antibiotics somewhat as a-product.This demonstrates the ability of livestock dung to encourage the number of microorganisms communities to help plant production, pollutant destruction and biodiversity conservation[45]

4.3 Sewage Sludge Waste

For a living species, phosphorus is a considerable complement that will impact crop productivity by its lack of rural production. The phosphorus wellspring comes from phosphate rocks with non-renewable energy and that is the reason why phosphorus substances should be sufficiently reused to preserve the assets to survive an expanding total population. In comparison to a few other unfortunate substances, sewage ooze is among the natural waste which causes a big phosphorus concentration [46,47]. Sewage ooze has notable agribusiness characteristics with a higher nitrogen and phosphorus level that can boost soil microbial population, soil compounds, and soil humus due to degradation of natural content[48] .In addition, the application drawn up had the option of endorsing the chemical science and microbiological properties of rural soil, but nevertheless prompted conductor and Zn declarations in the soil while not upgrading them.

4.4 Food Waste Composting

The expansion of the world network has contributed to the expansion of food admission and food squandering. Better living standards in non-industrial nations also lead to more squandered food being processed to address food security challenges. Disposal of transient agricultural goods, homegrown food waste and waste from food processing companies dumped in landfills provided the vast majority of the food squandering.Compost has been utilized as manures, reused soil natural upgrades and numerous other farming exercises. Fertilizing the soil olive waste as natural compost will improve the nature of the dirt and furthermore limit ozone harming substance outflows. These results indicate that the agronomic expertise of fertiliser updated soil demonstrates additional soil benefits and can increase crop production and yield. In view of the fact that it can turn biodegradable waste into useful manure goods and can be used as a feasible recovery of recyclable waste, natural-based rural compost developments are highly intriguing[49].

4.5 Environmental Impact of Fertilizers and Biofertilizers

In view of their guarantee, different forms of biofertilizers are being supplied as a considerably more biologically manageable, open and safe alternative for inorganic composts. Biofertilizers play a major role in enhancing the protection of the soil and the effectiveness of the crop. Mycorrhiza, for example, a form of organism occurring in soils much of the time, may assist in the entry of plant phosphorus, enhance the opposition of root microorganisms and improve crop safety from ecological and natural pressures. This fungal system has the ability to propagate nutritional collection across a large area and withstand harsh environments [50].

4.6 Economic Potential of Biowaste Conversion to Fertilizer

An economic study found that the energy intake of chemical fertilizers is the largest portion of total energy intakes due to the ineffective usage of the fertilizer in such a way that farmers prefer to consume more fertilizers than required [51]. To resolve the health and environmental issues associated with the improper use of these Developing more effective processing methods is crucial to allowing the valuable substances that can be extracted from such biomass waste to be used properly and understanding the economic feasibility of bio-products through biowaste.

4.7 Biomarker

Increase in human population day by day also increases their demand and facility. To meet their requirement development needs more progress in less time. To fulfil these criteria various chemical based things take place in daily routine. Use of various chemicals and chemicals based products increase amount of xenobiotic compounds. Presence of various chemicals above their acceptance level creates pollution and toxicity to both living beings and environment.

Other biomarkers are also used at field level. For example, chlorophyll content of *Zeamays* L. is used to quantifyhydrocarbon in agricultural sectors [52]. Oil spilling can be detected by *Azotobacter* sp. in aquatic bodies [53].Various omics approaches like genomics, transcriptomics, proteomics and metabolomics can also be used to detect presence and effect of various pollutants in environment. Presence of pollutant affects microbes present in soil, water and air. Affected microbes shows different type of pattern of nucleic acid, different quality and quantity of proteins and metabolites. Different fingerprint expression pattern of genes and RNA can also be used for monitoring of environmental risks [54].

A number of significant obstacles stand in the way of sustainable development for nations, particularly developing ones. Inadequate governance, unstable regimes, military wars, growing inequality, slow economic growth, environmental degradation, climate change, and food insecurity are a few of these. Developments in biotechnology support ecological restoration, environmental preservation, and sustainable resource management. Cooperation between nations and organizations is essential for knowledge exchange and giving emerging countries technical and financial support[55,56,57].

Zero hunger, excellent health and well-being, gender equality, clean water and sanitation, affordable and clean energy, sustainable and green industry, innovation and infrastructure, responsible consumption and production, climate action, life below water, life on land, and partnerships for the goals are just a few of the sustainable development goals (SDG) targets that biotechnology can help achieve. Of course, this will have a beneficial indirect effect on the other aims. Thus, the continued application and improvement of green biotechnology techniques is crucial to the survival of the human race on Earth[58].

5 Conclusion

As chemical based products are harmful and pollution creating to the environment and living system, biobased products are proven to be successful as an alternate option which can also full fill demand without compromising development process. By screening of microbial ability, their characteristics and application criteria one can apply selected and identified microbes to produce bioplastic, to recover metal, to generate electricity, as biopesticide or as biofertilizer. There are some limitations and challenges are still associated with bio based products. For example, toxins related to biopesticides have different effect from species to species of insects. Bioplastics have limitation of thermal resistance. Successful commercialization with proper knowledge of application should be counted with bio based products research. Bio based generated products should be of high quality, should not prove to be toxic for living beings, should not create pollution for environment, must be cost effective and should be efficient to withstand with environmental changes. By overcoming limitations and through regulation guidelines one can select and apply biobased products without compromising environment sustainability. The international community, which consists of nations, governments, and organizations, should work together to share best practices, expertise, and experiences while also offering developing nations financial and technical support. At the moment, The SDGs must be deeply incorporated into strategies and policies for national growth, to make substantial progress in reaching the SDGs, tackling world issues and promoting an inclusive, sustainable future for all.

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6 References

1. Ezeonu, C.S., Tagbo, R., Anike, E.N., Oje, O.A., Onwurah, I.N.. Biotechnological tools for environmental sustainability: prospects and challenges for environments in Nigeria—a standard review. *Biotechnology research international*, 2012. https://doi.org/10.1155/2012/450802
2. Dawson, A.H., Eddleston, M., Senarathna, L., Mohamed, F., Gawarammana, I., Bowe, S.J., Manuweera, G., Buckley, N.A. . Acute human lethal toxicity of agricultural pesticides: a prospective cohort study. *PLoS Med*,2010: 7(10), e1000357. https://doi.org/10.1371/journal.pmed.1000357
3. Saha, D. A Comparative Analysis of Global Environmental State with Special Reference to Indian Performance. *International Journal of Research in Social Sciences*, 2018:8(12), 1.https://doi.org/10.1016/j.sbspro.2012.03.282

4. Fiedler, H. Stockholm convention on POPs: obligations and implementation. in: *The Fate of Persistent Organic Pollutants in the Environment*, Springer, 2008:pp. 3-12.https://doi.org/10.1007/978-1-4020-6642-9_1
5. Singh, M.P., Agrawal, A. and Sharma, B. *Biotechnology in hazardous waste management*. Nova Science Publishers, New York (USA). 2010:pp. 45-82.https://doi.org/10.1016/0734-9750(84)90255-6
6. Opender, K. Microbial biopesticides: opportunities and challenges. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 2011:6(056), 1-26.https://doi.org/10.1079/pavsnnr20116056
7. Peakall, D., Walker, C. The role of biomarkers in environmental assessment (3). Vertebrates. *Ecotoxicology*, 1994:3(3), 173-179.https://doi.org/10.1007/bf00117082
8. Saharan, B., Ankita, S.D. Bioplastics-for sustainable development: a review. *Int J Microbial Res Technol*,2012: 1, 11-23.https://doi.org/10.4314/afrrev.v13i4.1
9. Witholt, B., Kessler, B. Perspectives of medium chain length poly (hydroxyalkanoates), a versatile set of bacterial bioplastics. *Current opinion in biotechnology*, 1999: 10(3), 279-285. https://doi.org/10.1016/s0958-1669(99)80049-4
10. Aljuraifani, A.A., Berekaa, M.M., Ghazwani, A.A. Bacterial biopolymer (polyhydroxyalkanoate) production from low□cost sustainable sources. *MicrobiologyOpen*, 2019:8(6), e00755. https://doi.org/10.1002/mbo3.755
11. John, R.P., Nampoothiri, K.M., Pandey, A. Fermentative production of lactic acid from biomass: an overview on process developments and future perspectives. *Applied microbiology and biotechnology*, 2007:74(3), 524-534. https://doi.org/10.1007/s00253-006-0779-6
12. Zhou, S., Shanmugam, K., Ingram, L. Functional replacement of the Escherichia coli D-(−)-lactate dehydrogenase gene (ldhA) with the L-(+)-lactate dehydrogenase gene (ldhL) from Pediococcus acidilactici. *Applied and Environmental Microbiology*, 2003:69(4), 2237-2244. https://doi.org/10.1128/aem.69.4.2237-2244.2003
13. Yang, T.H., Kim, T.W., Kang, H.O., Lee, S.H., Lee, E.J., Lim, S.C., Oh, S.O., Song, A.J., Park, S.J., Lee, S.Y. Biosynthesis of polylactic acid and its copolymers using evolved propionate CoA transferase and PHA synthase. *Biotechnology and bioengineering*, 2010:105(1), 150-160. https://doi.org/10.1002/bit.22547
14. Felix, M., Carpintero, V., Romero, A., Guerrero, A. Influence of sorbitol on mechanical and physico-chemical properties of soy protein-based bioplastics processed by injection molding. *Polímeros*, 2016:26(4), 277-281.https://doi.org/10.1590/0104-1428.0044
15. Bubpachat, T., Sombatsompop, N., Prapagdee, B. Isolation and role of polylactic acid-degrading bacteria on degrading enzymes productions and PLA biodegradability at mesophilic conditions. *Polymer Degradation and Stability*, 2018: 152, 75-85.https://doi.org/10.1016/j.polymdegradstab.2018.03.023

16. Aznury, M. Mechanical Properties of Bioplastics Product from Musa Paradisica Formatypica Concentrate with Plasticizer Variables. *JPhCS*, 2019:1167(1), 012048.https://doi.org/10.1088/1742-6596/1167/1/012048
17. Lam, W., Wang, Y., Chan, P.L., Chan, S.W., Tsang, Y.F., Chua, H., Yu, P.H.F. Production of polyhydroxyalkanoates (PHA) using sludge from different wastewater treatment processes and the potential for medical and pharmaceutical applications. *Environmental technology*, 2017:38(13-14), 1779-1791.https://doi.org/10.1080/09593330.2017.1316316
18. Ahn, J., Jho, E.H., Nam, K. Effect of acid-digested rice straw waste feeding methods on the 3HV fraction of bacterial poly (3-hydroxybutyrate-co-3-hydroxyvalerate) production. *Process Biochemistry*, 2016:51(12), 2119-2126.https://doi.org/10.1016/j.procbio.2016.09.014
19. Vega, F.E., Meyling, N.V., Luangsa-ard, J.J., Blackwell, M. Fungal entomopathogens. *Insect pathology*, 2012: 2, 171-220. https://doi.org/10.1016/b978-0-12-384984-7.00006-3
20. Tay, S.B., Natarajan, G., bin Abdul Rahim, M.N., Tan, H.T., Chung, M.C.M., Ting, Y.P., Yew, W.S. Enhancing gold recovery from electronic waste via lixiviant metabolic engineering in Chromobacterium violaceum. *Scientific reports*, 2013: 3, 2236. https://doi.org/10.1038/srep02236
21. Wu, W., Liu, X., Zhang, X., Zhu, M., Tan, W.. Bioleaching of copper from waste printed circuit boards by bacteria-free cultural supernatant of iron–sulfur-oxidizing bacteria. *Bioresources and Bioprocessing*, 2018:5(1), 10.https://doi.org/10.1186/s40643-018-0196-6
22. Avanzi, I.R., Gracioso, L.H., dos Passos Baltazar, M.G., Veiga, M.N., Gimenes, L.J., Perpetuo, E.A., do Nascimento, C.A.O. Comparative study of microbial community from mining wastes-focus on future recovery of copper. *BMC proceedings*. 2014, Springer. pp. P182.https://doi.org/10.1186/1753-6561-8-s4-p182
23. Brierley, C. How will biomining be applied in future? *Transactions of nonferrous metals society of China*, 2008: 18(6), 1302-1310.https://doi.org/10.1016/s1003-6326(09)60002-9
24. Rehan, M., Nizami, A.-S., Rashid, U., Naqvi, M.R. Waste Biorefineries: Future Energy, Green Products and Waste Treatment. *Frontiers in Energy Research*, 2019: 7, 55.https://doi.org/10.3389/978-2-88945-993-3
25. Skaggs, R.L., Coleman, A.M., Seiple, T.E., Milbrandt, A.R. Waste-to-Energy biofuel production potential for selected feedstocks in the conterminous United States. *Renewable and Sustainable Energy Reviews*, 2018: 82, 2640-2651. https://doi.org/10.1016/j.rser.2017.09.107
26. Turovskiy, I.S., Mathai, P. *Wastewater sludge processing*. 2006: John Wiley & Sons. https://doi.org/10.1002/047179161x
27. Yin, S., Dolan, R., Harris, M., Tan, Z. Subcritical hydrothermal liquefaction of cattle manure to bio-oil: Effects of conversion parameters on bio-oil yield and characterization of bio-oil. *Bioresource Technology*, 2010: 101(10), 3657-3664.https://doi.org/10.1016/j.biortech.2009.12.058
28. MacDonald, J.M. *Manure use for fertilizer and for energy: report to congress*. DIANE Publishing. 2009, https://doi.org/10.13031/2013.24247

29. Singhania, R., Patel, A., Pandey, A. Biotechnology for Agricultural Waste Recycling. in: *Current Developments in Biotechnology and Bioengineering*, Elsevier, 2017: pp. 223-240.https://doi.org/10.1016/b978-0-444-63664-5.00010-1
30. Itelima, J., Bang, W., Onyimba, I., Oj, E. A review: biofertilizer; a key player in enhancing soil fertility and crop productivity. *J. Microbiol. Biotechnol. Rep*, 2018: 2, 22-28.https://doi.org/10.1007/978-981-10-6934-5_3
31. Vessey, J.K. Plant growth promoting rhizobacteria as biofertilizers. *Plant and soil*, 2003: 255(2), 571-586. https://doi.org/10.1023/a:1026037216893
32. Roubík, H., Mazancová, J., Banout, J. Current approach to manure management for small-scale Southeast Asian farmers-Using Vietnamese biogas and non-biogas farms as an example. *Renewable energy*, 2018: 115, 362-370. https://doi.org/10.1016/j.renene.2017.08.068
33. Sharara, M.A., Sadaka, S.S. Opportunities and Barriers to Bioenergy Conversion Techniques and Their Potential Implementation on Swine Manure. *Energies*, 2018: 11(4), 957.https://doi.org/10.3390/en11040957
34. Javaid, A. Effects of biofertilizers combined with different soil amendments on potted rice plants. *Chilean Journal of Agricultural Research*, 2011: 71(1), 157. https://doi.org/10.4067/s0718-58392011000100019
35. Chemura, A. The growth response of coffee (Coffea arabica L) plants to organic manure, inorganic fertilizers and integrated soil fertility management under different irrigation water supply levels. *International Journal of Recycling of Organic Waste in Agriculture*, 2014: 3(2), 59. https://doi.org/10.1007/s40093-014-0059-x
36. Steiner, C., Teixeira, W.G., Lehmann, J., Nehls, T., de Macêdo, J.L.V., Blum, W.E., Zech, W. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and soil*, 2007: 291(1-2), 275-290. https://doi.org/10.1007/s11104-007-9193-9
37. Hamm, A.C., Tenuta, M., Krause, D.O., Ominski, K.H., Tkachuk, V.L., Flaten, D.N. Bacterial communities of an agricultural soil amended with solid pig and dairy manures, and urea fertilizer. *Applied soil ecology*, 2016: 103, 61-71. https://doi.org/10.1016/j.apsoil.2016.02.015
38. Haiba, E., Nei, L., Herodes, K., Ivask, M., Lillenberg, M. On the degradation of metformin and carbamazepine residues in sewage sludge compost. *Agron. Res*, 2018: 16, 696-707. https://doi.org/10.1109/icbee.2010.5653590
39. Tiwari, P., Adholeya, A., Prakash, A., Arora, D. Commercialization of arbuscular mycorrhizal biofertilizer. *Fungal biotechnology in agricultural, food, and environmental applications*, 2003: 21, 195-204.https://doi.org/10.1201/9780203913369.ch17
40. Seghetta, M., Hou, X., Bastianoni, S., Bjerre, A.-B., Thomsen, M. Life cycle assessment of macroalgal biorefinery for the production of ethanol, proteins and fertilizers–a step towards a regenerative bioeconomy. *Journal of cleaner production*, 2016: 137, 1158-1169.https://doi.org/10.1016/j.jclepro.2016.07.195

41. Lalevic, B., Sivcev, B., Raicevic, V., Vasic, Z.R., Petrovic, N., Milinkovic, M. Environmental impact of viticulture: Biofertilizer influence on pruning and wine waste. *Bulgarian Journal of Agricultural Science*, 2013: 19(5), 1027-1032. https://doi.org/10.17660/actahortic.2004.652.39
42. Jara-Samaniego, J., Pérez-Murcia, M., Bustamante, M., Pérez-Espinosa, A., Paredes, C., López, M., López-Lluch, D., Gavilanes-Terán, I., Moral, R. Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production. *Journal of cleaner production*, 2017: 141, 1349-1358.https://doi.org/10.1016/j.jclepro.2016.09.178
43. Forte, A., Fagnano, M., Fierro, A. Potential role of compost and green manure amendment to mitigate soil GHGs emissions in Mediterranean drip irrigated maize production systems. *Journal of environmental management*, 2017: 192, 68-78. https://doi.org/10.1016/j.jenvman.2017.01.037
44. Yodkhum, S., Gheewala, S.H., Sampattagul, S. Life cycle GHG evaluation of organic rice production in northern Thailand. *Journal of environmental management*, 2017: 196, 217-223.https://doi.org/10.1016/j.jenvman.2017.03.004
45. Erdal, G., Esengün, K., Erdal, H., Gündüz, O. Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy*, 2007: 32(1), 35-41.https://doi.org/10.1016/j.energy.2006.01.007
46. Bratina, B., Šorgo, A., Kramberger, J., Ajdnik, U., Zemljič, L.F., Ekart, J., Šafarič, R. From municipal/industrial wastewater sludge and FOG to fertilizer: A proposal for economic sustainable sludge management. *Journal of environmental management*, 2016: 183, 1009-1025.https://doi.org/10.1016/j.jenvman.2016.09.063
47. Yetilmezsoy, K., Ilhan, F., Kocak, E., Akbin, H.M. Feasibility of struvite recovery process for fertilizer industry: A study of financial and economic analysis. *Journal of cleaner production*, 2017: 152, 88-102.https://doi.org/10.1016/j.jclepro.2017.03.106
48. Jilani, G., Akram, A., Ali, R.M., Hafeez, F.Y., Shamsi, I.H., Chaudhry, A.N., Chaudhry, A.G. Enhancing crop growth, nutrients availability, economics and beneficial rhizosphere microflora through organic and biofertilizers. *Annals of Microbiology*, 2007: 57(2), 177-184.https://doi.org/10.1007/bf03175204
49. Shen, Z., Ruan, Y., Wang, B., Zhong, S., Su, L., Li, R., Shen, Q. Effect of biofertilizer for suppressing Fusarium wilt disease of banana as well as enhancing microbial and chemical properties of soil under greenhouse trial. *Applied Soil Ecology*, 2015: 93, 111-119. https://doi.org/10.1016/j.apsoil.2015.04.013
50. Jara-Samaniego, J., Pérez-Murcia, M., Bustamante, M., Pérez-Espinosa, A., Paredes, C., López, M., López-Lluch, D., Gavilanes-Terán, I., Moral, R. Composting as sustainable strategy for municipal solid waste management in the Chimborazo Region, Ecuador: Suitability of the obtained composts for seedling production. *Journal of cleaner production*, 2017: 141, 1349-1358.https://doi.org/10.1016/j.jclepro.2016.09.178

51. Jilani, G., Akram, A., Ali, R.M., Hafeez, F.Y., Shamsi, I.H., Chaudhry, A.N., Chaudhry, A.G. Enhancing crop growth, nutrients availability, economics and beneficial rhizosphere microflora through organic and biofertilizers. *Annals of Microbiology*, 2007: 57(2), 177-184.https://doi.org/10.1007/bf03175204
52. Peakall, D., Walker, C. The role of biomarkers in environmental assessment (3). Vertebrates. *Ecotoxicology*, 1994: 3(3), 173-179.https://doi.org/10.1007/bf00117082
53. Munkittrick, K.R., Arens, C.J., Lowell, R.B., Kaminski, G.P. A review of potential methods of determining critical effect size for designing environmental monitoring programs. *Environmental Toxicology and Chemistry: An International Journal*, 2009: 28(7), 1361-1371. https://doi.org/10.1897/08-376.1
54. Lionetto, M.G., Caricato, R., Giordano, M.E. Pollution biomarkers in environmental and human biomonitoring. *The Open Biomarkers Journal*, 2019, 9(1).https://doi.org/10.2174/1875318301909010001
55. Donato, K.,Medori,M.C.,Stuppia,L.,Beccari,T.,Dundar,M.,Marks,R.S. et al. Unleashing the potential of biotechnology for sustainable development European Review for Medical and Pharmacological Sciences, 2023; 27: 100-113
56. Krauss JE. Unpacking SDG 15, its targets and indicators: tracing ideas of conservation. Globalization 2022; 19: 1179-1194.
57. Sutherland DL, McCauley J, Labeeuw L, Ray P, Kuzhiumparambil U, Hall C. How microalgal biotechnology can assist with the UN Sustainable Development Goals for natural resource management. Curr Res Environ Sustain 2021; 3: 100050.
58. Arora, N.K., Fatima, T. Environmental sustainability and biotechnology: opportunities and challenges. Environmental Sustainability,2024: 7, 115–119.https://doi.org/10.1007/s42398-024-00317-9