UNVEILING THE ROLES OF MICROBES IN ENVIRONMENTAL MANAGEMENT AND SUSTAINABLE ECONOMIC DEVELOPMENT

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ABSTRACT: In spite of the environment producing everything it needs to ensure the survival and growth of its residents, man still continue to strive in ensuring that the natural environment becomes more suitable towards meeting up with his needs for survival. This has led to his engagement with series of manipulative activities such as agriculture, exploitation, exploration, innovations and urbanization that had left the environment with negative impacts. Attempts toward the mitigation of these impacts had led to the concept of environmental management and economic sustainability, whose principal aim is to ensure the needs of man are met but not at the expense of environmental damage. The ubiquitous and diverse nature of Microbes make them significant assets toward achieving sustainable development when used and exploited wisely. The scope of this paper is to explain the roles of microbes in agriculture, waste management, bioremediation, renewable energy production and climate change mitigation. However, more researches need to be done to have a better understanding on the interactions of microbes with the environment. Also, beneficial microbial processes should be built in industrial scale in order to fully achieve the benefits of microbial roles towards the actualization of environmental and economic sustainable development.

Keywords: microbes; environmental management; sustainable economic development; waste management; climate change mitigation

Introduction

The term Environment is defined as the complex of physical, chemical and biological factors, external to organisms and the effects that influence their growth and development (Edwards 2019). The environment includes land, water, air and the interrelationship which exist between these elements and human beings and other living creatures (EPA, 1986). The natural environment produces everything it needs to ensure the survival and growth of its residents. However, with the aim of ensuring the natural environment becomes more suitable towards meeting up with his needs for survival, man has engaged in series of manipulative activities which include agriculture, exploitation, exploration, innovations, urbanization etc. that had left the environment with negative impacts (Rey-Galindo and Melo, 2023). Attempts towards the mitigation of these impacts had led to the concept of environmental management and economic sustainability which when incorporated with social sustainability, lead to the actualization of sustainable development.

Environmental management is the practice of coordinating the activities of humans with the aim of limiting their impacts on the natural environment. It encompasses the protection of all components of the environment through the development, implementation, and monitoring of the environmental policies to checkmate the activities of man. On the other hand, sustainable economic development is the process in which the exploitation of natural resources, direction of investment, orientation of technological development and institutional change or reform are all in coordination and harmony in order to enhance both the current and future potentials for meeting human needs (Wang, 1996). Sustainable development requires that we find new approaches to economic life, in terms of both production and consumption. The principal aim of environmental management and sustainable economic development is to ensure the needs of man are met but not at the expense of environmental damage. Rather, they coordinate man's activities to protect the environment by preserving all forms of life, preventing and controlling the unlawful exploitation of natural resources, reduction of pollution and ensuring sustainability for future generations. (United Nations, 2016a).

The ubiquitous and diverse nature of Microbes makes them significant assets towards achieving environmental and economic sustainability if used and exploited wisely. They play imperative roles in the environment like the biogeochemical cycles of nutrients, breakdown of organic matters and recalcitrant pollutants as well as being vital in the production of greener energies and technologies (Akinsemolu, 2018; Shamsudeen and Murtala, 2023). In spite of their significance, these invisible giants are often trivialized leaving these advantageous roles underexplored in promoting environmental and economic sustainability. Hence, this paper aims at elucidating the vital contributions of microorganisms towards the promotion of effective environmental management and sustainable economic development.

Agriculture

The integral roles of agriculture towards the world's economy cannot be overlooked due to its contributions to realizing key continental priorities such as hunger and poverty eradication, economic diversification, swift industrialization, sustainable resources and environmental management. However, with the fast rise in worlds population that is expected to double by 2033, the demand for food and agricultural raw materials is expected to increase thereby increasing pressure on the agricultural system by forcing the system to increase productivity to match up with the demands (Yadav *et al.*, 2022). The efficiency in increasing agricultural productivity is not without some limits such as biotic (weeds, and pests) and abiotic stresses (depletion of soil nutrients), of which the agricultural sector depends on chemical pesticides, herbicides and fertilizers to tackle. The excess use of these chemicals results in soil pollution, affects soil fertility and eventually human health through bioaccumulation and biomagnifications along the food chain (Naik *et al.*, 2019).

Microorganisms can be used to develop biofertilizers, biopesticides and bioherbicides which are economically viable and environmentally friendly unlike the chemicals being used in agriculture (Martyniuk, 2010; Akinsemolu, 2018). *Rhizobium* is a bacterium that lives on the roots of Fabaceae in a collection of cells called "nodules," can take nitrogen from the air and convert it into organic forms, which can then be used by the plant (Gupta, 2021), *Penicillium bilaii* helps to release phosphate from the soil by releasing an organic acid, which then dissolves phosphates in the soil and makes them available to plants (Ramos-González *et al.*, 2013), *Bacillus thuringiensi*s subsp. *Tenebrionis* strain NB-176, has successfully been used as bacterial insecticide destroys *Leptinotarsa decemlineata* larvae (Egbuna *et al.*, 2020). Also, *Pseudomonas* Strains have been used to formulate bioherbicides that have recorded a 90% reduction in the emergence of an annual weedy grass, *Setaria viridis* (Daigl, 2002), while strains of *Fusarium* with seeds decaying potentials have been evaluated for their capacity to kill weeds (Muller-Stover, 2016). The use of biofertilizers and biocontrol has the potentials to reducing the use of chemical fertilizers and pesticides which helps to protect the environment for future generations.

Waste Management

The activities of man are often accompanied with the generation of wastes. Wastes, when not properly managed could lead to foul smells, breeding sites for disease vectors, clogged pipes, floods and spread of the water-borne diseases. Effective waste management is very vital to environmental and economic sustainability. According to Lee 2016, the disposal of organic waste is an expensive process, with the United States alone spending about 1 billion USD yearly for this purpose.

Microorganisms play important roles in effective and sustainable waste management through bio-conversion of organic wastes to economically useful products such as manures, biofertilizers, bioethanol, biodiesel, biogas etc. (wastes to wealth). Microorganisms belonging to the genus *Pseudomonas*, *Bacillus*, *Actinobifida*, *Thermoactinomycetes*, *Microbispora*, *Candida*, *Cryptococcus* etc. are being used for composting solid wastes, an economically viable process that converts its organic constituents into manure that is used to improving the productivity of crops. (Finstein and Morris, 1975; Akinsemolu, 2018; Aguilar-Paredes *et al.*, 2023). *Saccharomyces cerevisiae and Mucor indicus* convert the organic portion of municipal solid wastes to ethanol while *Clostridium acetobutylicum* produces butanol from organic portion of municipal solid wastes sampled from composting (Aguilar-Paredes *et al.*, 2023). Oleaginous microorganisms such as *Mucor circinelloides* and heterotrophic microalgae are capable of using various organic portion of municipal solid wastes as carbon source and converting them into microbial oil, which is further utilized for the production of biodiesel through transesterification (Chintagunta *et al.*, 2021).

Also, during the collection and treatment of sewage, methanogenic microbes convert acetate, hydrogen, or formate to methane, following anaerobic fermentation and acetogenesis. Methane gas can be economically useful if properly captured from the process since it is a potential greenhouse gas while the carbon dioxide produced as part of the process of the microbes is effectively transferred to the atmosphere completing a cycle of carbon flow (Cuihong *et al.*, 2023). These are effective processes in tackling wastes because in as much as they ensure management of the persistent problem of accumulating municipal solid and liquid wastes in the environment, economically valuable products are simultaneously generated thereby creating wealth.

Bioremediation

The environment is deliberately or accidentally subjected to various forms of pollutants as a result of the anthropogenic activities of man which has led to its degradation. According to the Polluter Pay Principle (PPP) which is one of the principles in environmental management, a polluter is not only liable to compensate the victims of the harms caused by the pollution but also the cost of restoring the environmental degradation. One of the most effective ways of reversing ecological damages is by bioremediation. Bioremediation involves using biological agents such as plants and microbes to eliminate or lessen the effects of environmental pollutants. As a result of their rapid growth and ability to be easily manipulated, microbes are more used for bioremediation purposes (Ayilara and Babalola, 2023). Microbes from a variety of environments have been used to carry out bioremediation. *Chromobacterium*, *Micrococcus*, *Candida*, *Pseudomonas*, *Arthrobacter Bacillus* and *Burkholderia* can degrade crude oil and hydrocarbons contaminated sites, by the process known as intrinsic remediation which is a type of remediation without any artificial enhancement, (Kumar and Gopal, 2015), *Aspergillus sp.*, *Mucor sp.*, *Penicillium sp.*, *Cladosporium sp.* and *Rhizopus sp.* are useful in the remediation of iron or sulfur contaminated sites by creating an acid environment which solubilize heavy metals in an immobilized state, into an aqueous form, a process called bioleaching (Medfu Tarekegn *et al.*, 2020; Bhandari *et al.*, 2023). *Rhizopus arrhizus* and *Pseudomonas putida* have been used to remediates mercury and cadmium polluted sites respectively by absorbing the pollutants into their cell by a process known as bioaccumulation (Sharma *et al.*, 2022a), *Brevundimonas diminuta* and *Pseudomonas sp*. have been reported to be effective in the remediation of pesticides using the Phosphotriesterase and Oxygenase enzymes respectively (Thakur *et al*., 2019; Malakar *et al.*, 2020).

Although the effectiveness of bioremediation is determined by several factors such as the contaminants, types of microbes and environmental circumstances, advanced technologies such as bioinformatics, proteomics and metabolomics, genomics, transcriptomics and metatranscriptomics, genetic and metabolic engineering and nanotechnology have provided deep understanding on the processes and interactions of microbial communities in bioremediation, thereby enabling and improving the effectiveness of the process for managing and mitigating pollution (Zhang *et al*., 2020; Bala *et al.*, 2022).

Renewable Energy Production

The early stage of industrial revolution which saw us outperforming the capabilities of animals and human powers, paved way for the utilization of fossil fuel as energy source. However, this has led to negative environmental changes due to the emission of carbon dioxide and other pollutants associated with its use. With the world's population that is expected to meet the 9 billion mark by 2050, the demand for energy to power the processes of productions to match this growing population would also increase. This would lead to more environmental challenges, thereby necessitating the need for the production and utilization of sustainable, affordable and green sources of energy (Lee, 2011).

Bioenergy, a renewable, clean and affordable energy source produced from biological raw materials, when rightly done, has the potentials of mitigating world's energy problems. Microbes play critical roles in the production of biofuel such as biogas, biodiesel and bioethanol by utilizing the organic components of municipal solid and liquid wastes as described earlier. They are also capable of fermenting various plants products to biofuel.

The advantages of using microbes for the production of bioenergy is in their ability to utilize organic wastes to produce biofuels which when properly refined, emit lesser carbon dioxide than their fossil counterparts. Hence the need for the establishment of more biorefineries. Also, in the event of a spill, bioethanol and biodiesel are easily degradable without causing harm to the environment.

Climate Change Mitigation

The unprecedented rate of increase in the earth's average global surface temperature in the last 150 years has made climate change to be considered the "biggest health threat against humanity" by the World Health Organization. (IPCC, 2021; WHO, 2023). While microbes play a major role in the natural production of key greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and Nitrous oxide (N_2O) responsible for climate change, the activities of humans are the major drivers as they result in microbes having more access to carbon and nitrogen that they convert into these three products (Tiedje, 2022). According to Saunois *et al.,* 2020, more than 50% of methane emission comes from human activities. An example is the raising of livestock, where the microbiomes of the rumen convert plant sugars into energy for the animal, with methane being produced as a byproduct, that is released to the atmosphere through belching. The excessive use of nitrogenous fertilizers also increases the rate at which denitrifying microbes release of Nitrous oxide (N_2O), which is not only a potential greenhouse gas but also a major agent of ozone layer depletion in the stratosphere (Sha *et al.,* 2021).

Fortunately, microbes also play important roles in climate change mitigation as they are capable of consuming these greenhouse gases when conditions favour the use of these gases for their growth. For example, cyanobacteria and algae use carbon dioxide (CO_2) during photosynthesis to produce glucose, methanotrophs utilize methane by oxidizing it, while denitrifying microbes use the nitrous oxide for growth by reducing it.

On the other hand, microbes have been reported to protect plants against abiotic stresses caused by climate change, such as drought, flooding, low or high temperature, etc. through the production of biostimulants (Athanasia *et al.,* 2020). For example, the growth potato was reported to be normal in spite of heat stress condition when it was inoculated with 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase producing bacterium *Paraburkholderia phytofirmans* PsJN (Bensalim *et al.,* 1998; Sangiorgio, 2020).

Hence, the study of the conditions that determine the production or consumption of these gases by microbes as well as the mechanisms of their interaction with plants to protect them against abiotic stresses caused by climate change has the potential of enhancing the mitigation of climate change.

Conclusion

The enormous roles played by microbes in agriculture, waste management, bioremediation, renewable energy product and climate change mitigation, make then an indispensable tool towards the achieving environmental and economic sustainability. Their ability to grow faster, easily being manipulated as well as their ubiquitous diverse nature is an asset that cannot be overlooked. Identifying, creating awareness and utilizing their potentials are vital for development of effective strategies to creating a more sustainable world. In addition to these, more researches need to be done to have a better understanding on how microbes interact with the environment. Also, beneficial microbial processes should be built on industrial scale in order to fully achieve the benefits of microbial roles towards the actualization of effective environmental management and sustainable economic development.

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