



Biofertilizers as Eco-Friendly Alternatives in Fruit Cultivation for Sustainable Development- Review

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Abstract

Currently, sustainable agriculture uses environmentally safe practices such as biofertilization. How Do Biofertilizers Increase Crop Yield? Diverse forms of living beings could be applied as biofertilizers to improve soil productivity and its non-pollution through their biodegradability. These can be, for example, live microorganisms such as bacteria, microalgae and microfungi but also macroorganisms like macroalgae, macrofungi and advanced plants. The biofertilizing agents of living organisms along with their metabolites instead of applying chemical fertilizers will be more extensively developed, as the latter result in heavy metals becoming accumulated in soil. The goal of biofertilizer is to implement sustainable soil-conserving agriculture. This will be a release from, climate change and its consequences, as will also implement the proportion of numerous high pollution-based diseases including cancer, liver and kidney failures, and immune system dysfunction. Biofertilizers from various forms of life spanning the Monera and Plantae kingdoms (bacteria, algae, fungi, and higher plants), were considered in this study. The review aims at promoting the use of such organisms for commercial purposes which contribute significantly in increasing quality of soil nutrients in safe, inexpensive and environmental benign method. Beneficial Effects of Bio-fertilizer Overview. The investigation on biofertilizers indicates that due to eco-friendly nature, biofertilizers have several advantages particularly in soil health, crop yield and other ecological problems, a global meta-analysis carried out revealed which biofertilizers endowed in conjunction with characteristics like mobilizing phosphorus and fixing nitrogen significantly improve NUE coupled with crop yield, especially in dryland agriculture, this study underlines the importance of bio-fertilizers as a key input for an ecofriendly and sustainable agriculture to cope with climate change, which could usefully alleviate soil and water limitations (Schutz *et al.*, 2018).

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Introduction

The literature on biofertilizers as eco-friendly alternatives in fruit cultivation highlights their potential in addressing the global food challenge with advancement in agri-tech industry. The population is forecasted to surpass 10 billion in the next 30 years and by 2050 there will be an increase in food requirement by 60%. (According to Kinge *et al.*, (2022) ^[24] and Pambuka *et al.*, 2021, 2022) ^[32, 33].

The soil ecological system has been seriously damaged through insecticides herbicides and organic fertilizers, crop development in the future will be impacted by these soil treatments, Currently, adoption of natural plant biostimulants presents a progressive approach for solving the issue of agroecological farming and promoting better nutrient absorption by plants with increased crop yield and resistance against biotic stress has been shown to affect plants (Povero *et al.*, 2016) ^[34], expand the conversation by addressing the pressing challenges of pest and pathogen outbreaks, as well as abiotic stresses linked to climate change. Their work underscores the necessity of eco-friendly strategies, including the application of biofertilizers, to enhance plant health and productivity. The authors emphasize that biofertilizers can play a pivotal role in stress management, ultimately benefiting soil health and agricultural resilience. (Chaudhary *et al.*, 2022) ^[12]. On that basis, in (Wambacq *et al.*, 2022) ^[45] function of microbiobic organic fertilizers are studied. Their research shows as a deep microbial biomass could become self-sufficient nutrient recycling system in substituting chemical fertilizers. The results show that microbial fertilizer can lead to an improvement of plant product quality and resistance enhancement, which is beneficial for sustainable economic and environmental effects. Fertilizers are required to encourage the growth of high yielding crops. The nutrients are also very important from crop production point of view, as most crops in different soils need enormous amounts of them for their proper growth. These nutrients include nitrogen Essential plant nutrients including sulfur, phosphorus, nitrogen, calcium, iron, magnesium, potassium and zinc, are essential for plant growth and development (White and Brown, 2010) ^[47]. From a more professional perspective, we can study the ecological mechanism of biological organic fertilizer improving pear yield. Through their study, they add link between soil microbiome profiling and yield performance, identifying that distinct microbial communities induced by bio-organic fertilization are critical for enhancing fruit yield. This investigation contributes to the understanding of functional contents of the microbial cluster in the rhizosphere and might enhance the knowledge about how biofertilizers influence fruit trees. (Wang *et al.*, 2022) ^[46]. The most recent study (Osorio-Reyes *et al.*, 2023) ^[21] discusses a top-of-the-range sustainable and environmentally friendly microalgae based bio-fertilizers with potential applications on soil improvement and carbon credit as negative carbon emissions strategies. Their results indicate that chronic applications of biofertilizers would greatly decrease dependence on chemical fertilizers, many of which are harmful to the soil. Optimising nutrient balance and uses of microalgae, it is suggested that agricultural activities may change trends in growth while concurrently moderating soil degeneration and CO₂ release, in permaculture practices, plants are employed to enhance soil productivity, and the byproducts related to certain species (e.g., *Musa paradisiaca*, *Lathyrus oleraceus*, *Coffea arabica*) can serve as natural soil fertilizers (Singh *et al.*, 2013) ^[40].

Together, these articles demonstrate the promising prospects of biofertilizers for sustainable fruit production. Their review underlines there is a continuing need for scientific advancements to maximize utilization and enhance the performance of biofertilizers so that they continue to function as viable substitutes for chemical fertilisers in pursuit of more sustainable agricultural practices.

Bacteria with Biofertilizing Potential

Bacterial inoculants given that biofertilizers are capable of increasing plant growth and productivity via diverse ways Such processes involve producing growth-promoting substances or plant hormones that are taken up by crops, along with the mobilization of soil nutrients in order to make them more available for plant uptake and/or protection of plants against stresses, the methods described here reduce the cost of tolerating or mitigating stress and increase resistance to plant pathogens, thus lowering disease incidence and plant death, a variety of Rhizobacteria with growth-enhancing for plants traits (PGPR) proved to be used around the world for several decades as bio-fertilizer (Kumar *et al.* 2022) ^[26]. They can increase crop yields and soil productivity, which are not only potential solutions for more sustainable farming and forestry, but also contribute to food security. Market demand for bacterial biofertilizers is increasing and technologies are improving for production of inoculant bacteria (Garcia Gonzalez and Sommerfeld 2016) ^[19]. Al-Zuhairi *et al.* (2021) studied the impact of treating 10 ml of *Citrus limon* L. seedlings with a suspension of *Bacillus subtilis* at 10 ml as well. A noticeable elevation in the levels of phosphorus, nitrogen and potassium was detected in the foliage and also of the above nutrients by treatments affecting their availability in soil. Nanofertilizer shows specific properties due to size effect and large area of surface., which expands the area available for uptake, enhancing photosynthetic efficiency and consequently promoting plant growth (Singh *et al.*, 2016). For instance, *Azotobacter* has been widely studied in the laboratory and the field, as well as being an established biofertilizer for more than hundred years. *Azotobacter* is an endophyte that stores nitrogen in the rhizosphere of the rice plant and roots and it helps in supporting the growth and development. Results show that *Azotobacter* not only nitrogen-fixes within the rhizosphere and functioning as an endophyte in rice, but also synthesizes phytohormones coupled with other growth promoting substances of plants, these bacteria not only influence nitrogen but also enhance phosphate solubilization lead to better crop growth According to Dar *et al.* (2021), Daniel *et al.* (2022), and Tualar (2013) ^[14, 13, 43]. The experiment included factors studies used pomegranate seedlings of the Halabja cultivar. The first element was the addition of *Bacillus subtilis* to the soil of the transplants. A remedy that lacked bacterial immunogen was also included as a control. Each seedling was handled with 10 ml of the bacterial solution once during the season. This procedure was completed in April according to a predetermined treatment plan (Ahmad *et al.*, 2024) ^[4] (Figure 01).

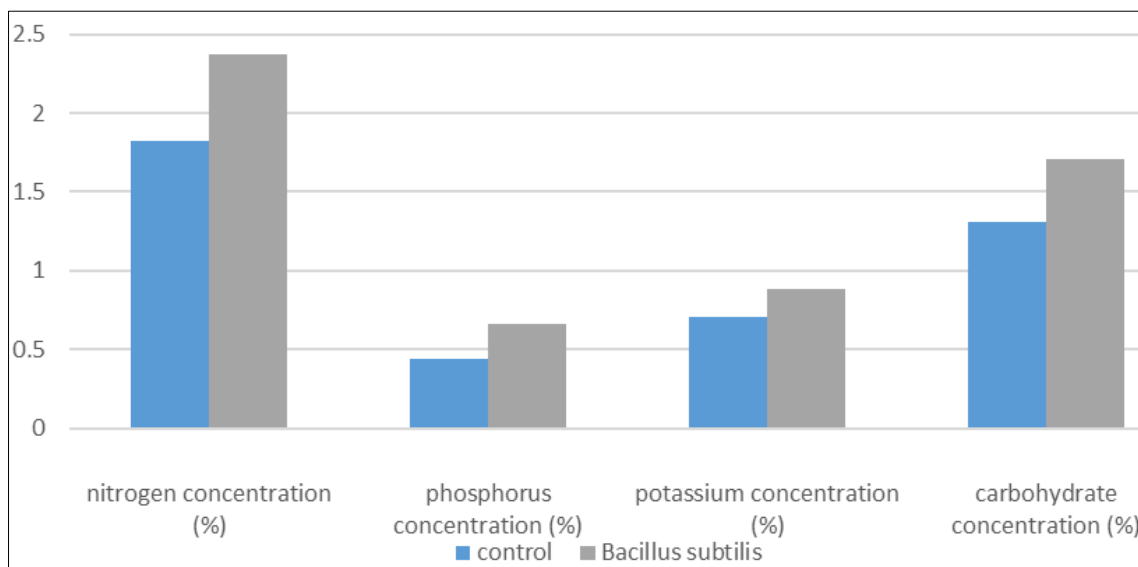


Fig 1: Effects of biofertilizer on nitrogen, phosphorus, potassium and carbohydrate, awareness (%) in leaves of pomegranate seedlings.

In contrast, *Cyanobacteria* are resilient and diverse group of prokaryote which has shown extreme age and efficiency on this planet. The biomass and extracts of *Cyanobacteria* remarkably enhance soil physical and chemical aspects. Moreover, *Cyanobacteria* constitute also Noted for the biosynthesis comprising bioactive (useful) compounds that may have future applications in controlling plant pathogens and in the remediation of industrial wastes, as highlighted by Bedair *et al.* (2022a, b) ^[10], they act as natural biofertilizers and contribute significantly to nutrient cycling, improving phosphorus availability, promoting N₂ fixation, and supporting environmental sustainability, in addition to disease control; with plant growth and yield being enhanced. *Cyanobacteria* likewise transfer radiant energy into chemical energy. Oxygen is created by these life forms through photosynthesis. These species are components of food, energy, secondary metabolites, cosmetics and drugs. CO₂ can be lowered with the environmentally friendly cultivation method of large yem, where also some high value products may be obtained by deepening low CO₂ so many Hurt. As such, in the long run, *Cyanobacterial* biofertilizers may also replace chemical fertilizers (Gören Sağlam2021; Mishraetal. 2021, Bhuyanetal. 2022) ^[20, 29, 11].

Negash and Wondimu (2022) ^[31] and Khosravi and Rahmani (2022) ^[23] demonstrated that *Rhizobium* being biofertilizer increases the agricultural productivity by making more available nitrogen fertilizers to crop. KSMOs like *Cyanobacteria*, Bacteria capable of nitrogen fixation along with microorganisms that solubilize phosphate have widely been used in different crops using biofertilizers. Survival of rhizobacteria in soil is influenced by multiple abiotic and biotic factors, to increase their survival rate bacteria are formulated using a carrier material that increases the viability as well as effectiveness of these organisms.

Micro Fungi as Biofertilizers

The literature related to the application of micro fungi as biofertilizers has developed significantly, showing its usage for possible agricultural fields along with soil health being taken into consideration. In (Schütz, 2017) ^[37], benefits of biofertilizers were reviewed in addition to the effects of a range of Microbial species, including arbuscular mycorrhizal

fungi (AMF) and other metabolites produced by specific fungal species including *Aspergillus niger* and *Trichoderma*. The article describes how they support plant growth by mechanisms, including nutrient cycling and opponent resistance such as in marginal lands of India. This preliminary study lays the foundation to further investigate and understand complex interactions among fungi. Host health of insects and plants is especially compromised in challenging environmental situations. Introduction In the last twenty years, worldwide application of chemical fertilizers to agriculture has increased tremendously and overuse of fertilizer is becoming a growing threat to soil as well as aquatic environments. In this scenario, mycorrhizal fungi biofertilizer seems interesting from economic viability, energy saving and eco friendly point of view According to Yadav & NathYadav (2020), Thakur., (2020) and Kour *et al.*, (2020) ^[30, 42, 25]. The mycorrhizosphere an enormous but relatively unprocessed resource of process controlling soil ecosystems. Electron Science for sample contamination by a variety of fungi, which are a type of haploid or diploid vegetative-growing organism associated with roots roots (Singhetal. 2019, NathYadavand Yadav2020,Kouretal. 2020; Thakur2020) ^[41, 30, 25, 42]. The biofertilizers are broadly categorized into Nitrogen fixing bacteria (including free living, symbiotic, associative symbiotic bacteria and fungi), solubilizing phosphate bacteria fungi and mobilizing phosphate microorganisms (including AMF, Ectomycorrhizae, Ericoid mycorrhizae and Orchid mycorrhizae) PGPR (Rastegariet *et al.* 2020 b) ^[35]. In order to solve the deficiency, different types of chemical fertilizers have been used, but they are not only harmful to nature. Therefore, fungi are one of the alternative methods because of their existence in nature and release available phosphorus in an environmentally safe manner (Arora, 2019, Deviatal., 2020, Ahmad *et al.*, 2022) ^[7, 15, 3]. Plants primarily assimilate phosphorus obtained from the soil as phosphate ions, this element shows a lower mobility in the plant compared to other macronutrients, RPOMs are the key organisms for plant P nutrition, because they increase its availability through mineralization and solubilization by releasing organic and inorganic pools of soil P (He *et al.*soluble AboNouh 2019, Aslametal. 2022) ^[1, 8]. In addition to the primary

macronutrient role of potassium required essential for plant growth and development, it further constitutes a vital part of the soil microflora (in particular in the rhizosphere) which need potassium for its functions dissolve K-containing mineral substances. Two medicinally important arbuscular mycorrhizal (AM) fungal groups, *G. intraradices* and *G. mosseae* have been successfully exploited as soil crop growth can be improved through the application of inoculants, as reported by Ahmad *et al.*, (2022), Devi *et al.*, (2020) and Arora (2019) [3, 15, 7]. (table 1).

Alternatively, read to investigate the effects of fertilization on fungal communities in the crop rhizosphere showed that applying organic fertilizers not only improves the development microbial biomass and fungal diversity but also inhibits phytopathogenic fungi, in contrast to that of mineral fertilizers, which favors pathogen growth. The current work emphasizes the importance of selecting appropriate fertilization methods to manipulate soil mycobiomes for beneficial fungi in order to promote plant health and resistance against diseases (V. Semenov *et al.*, 2022) [44]. elaborate mean values observed for microbial inoculants

application intended to converting bioorganic waste to bio-organic fertilizers, their bibliometric analysis shows an increasing research trend on sustainable technologies using microbial Inoculants for reducing dependence on synthetic fertilizers and environmental pollution, the authors propose the addition of this Microbial inoculants into composting and anaerobic digestion which increases biorefinery efficiency and improved soil health, introduce beneficial microorganism s (Michellin Kiruba N & Saeid, 2022) [28].

To explore the role of soil fungal communities (mycobiome) in enhancing sustainable agriculture Intensive methods of farming, though devised to maximize food production, they say, can come with harmful environmental effects like soil erosion. The authors emphasize the importance of reestablishing soil mycobiomes to improve soil quotidiany and plant condition. Their findings highlight the necessity to reinvent a paradigm to one of sustainable agriculture and that by focusing on understanding and manipulating soil microbial consortia, resilient crop stress tolerance can be improved (Fraq *et al.*, 2022) [18].

Table 1: Utilization of microfungi as Biofertilizers.

Micro-fungi	Class	Function	References
<i>Acaulospora Sp.</i>	Arbuscular Mycorrhizal - Fungi	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Sclerocystis Sp.</i>	Arbuscular Mycorrhizal - Fungi	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Giaspora Sp.</i>	Arbuscular Mycorrhizal - Fungi	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Glomus Sp.</i>	Arbuscular Mycorrhizal - Fungi	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Boletus Sp.</i>	Ectomycorrhiza	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Scutellospora Sp.</i>	Arbuscular Mycorrhizal - Fungi	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020a) [35]
<i>Laccaria Sp.</i>	Ectomycorrhiza	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Pisolithus Sp.</i>	Ectomycorrhiza	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> ,(2020 a) [35]
<i>Rhizoctonia solani</i>	Orchid Mycorrhiza	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Pezizella Erica</i>	Ericaceous mycorrhiza	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Amanita Sp.</i>	Ectomycorrhiza	Phosphate-releasing biofertilizer	Rastegari <i>et al.</i> , (2020 a) [35]
<i>Glomus Mosseae</i>	Arbuscular Mycorrhizal- Fungi	Potassium-releasing biofertilizer	Arora (2019), Devi <i>et al.</i> , (2020), Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Glomus Intraradices</i>	Arbuscular Mycorrhizal- Fungi	Potassium-releasing biofertilizer	Arora (2019), Devi <i>et al.</i> (2020), Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Oidiodendron Maius</i>	Ericaceous mycorrhiza	Zinc-mobilization	Arora (2019), Devi <i>et al.</i> , (2020); Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Suillus Luteus</i>	Ericaceous mycorrhiza	Zinc-mobilization	Arora (2019), Devi <i>et al.</i> , (2020); Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Suillus Bovines</i>	Ericaceous mycorrhiza	Zinc-mobilization	Arora (2019), Devi <i>et al.</i> , (2020); Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Paxillus Involutus</i>	Ericaceous mycorrhiza	Zinc-mobilization	Arora (2019), Devi <i>et al.</i> , (2020); Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Beauveria Caledonica</i>	Ericaceous mycorrhiza	Zinc-mobilization	Arora (2019), Devi <i>et al.</i> , (2020), Ahmad <i>et al.</i> , (2022) [7, 15, 3]
<i>Hymenoscyphus Erica</i>	Ericaceous mycorrhiza	Zinc-mobilization	Arora (2019), Devi <i>et al.</i> , (2020); Ahmad <i>et al.</i> , (2022) [7, 15, 3]

Zinc (Zn), the 23rd most occurring element in the Earths' crust, has five stable isotopes, it is essential for numerous

contributes to metabolic activities and functions as a cofactor in proteins and over 120 enzymes, zinc finger has been

described for its versatile role in transcriptional regulation fungi, being organic acid producers, promote solubilization of zinc facilitating its absorption by plants in chelated form, as reported by Ahmad *et al.*, (2022), Devi *et al.*, (2020), and Arora (2019) [3, 15, 7].

Macrofungi as, bio- Agrochemicals.

A repertoire of plant root-associated microbiomes that shape the plant growth along with defense mechanisms. Microbiomes support the cultivation of bacteria,

actinomycetes, fungi, and eukaryotic microbes. Rhizosphere Rhizobacteria refer to known to contribute in improving plant growth and the potential of harvest output. The highest important micro-organism Fungi such as *Penicillium*, *Fusarium*, *Trichoderma* and *Phoma* act as plant growth promoters. In cucumbers, the presence of these growth-promoting fungi has been associated with enhanced systemic resistance against various diseases. Romera *et al.*, (2019) [36]. (Table 2).

Table 2: Bioactive Fungal Species and Their Mechanisms of Action.

Species Of Fungi	Mode of action	Impact on plants	References
<i>Aspergillus flavus</i> <i>Aspergillus sydawi</i> <i>Aspergillus candidus</i> <i>Aspergillus parasiticus</i> , <i>Aspergillus fumigatus</i> <i>Aspergillus tubingensis</i> <i>Trichoderma viride</i> <i>Aspergillus flavus</i>	Production of including citric, organic acids, gluconic, oxalic, succinic, malic and glycolic acids	Soilacidification	Kalayu., (2019) [22]
<i>Aspergillus niger</i> <i>Penicillium digitatum</i> <i>Aspergillus awamori</i>	Phosphate-releasing biofertilizer	cellular processes like photosynthesis, respiration, energy accumulation and signal transduction, transfer, macromolecular biosynthesis, as well as cell enlargement and division contribute significantly to plant growth and development	Babalola <i>et al.</i> , (2021) [9]
<i>Penicillium bilaii</i> <i>Penicillium citrinum</i> <i>Penicillium lilacinium</i>	Synthesis of organic acids like succinic acid, oxalic acid, gluconic acid, malic acid and citric acid	Decreasing the pH of soil	Kalayu., (2019) [22]
<i>Aspergillus nomius</i> <i>Aspergillus oryzae</i> <i>Aspergillus niger</i> <i>Penicillium luteum</i> <i>Beauveria caledonica</i> <i>Trichoderma harzianum</i>	zinc-mobilization	Enhance soil nutrient status and crop growth productivity	Dubey <i>et al.</i> , (2019) [16]
<i>Glomus mosseae</i> <i>Glomus intraradices</i>	Potassium-releasing biofertilizer	promotes the growth of various crops, including cotton, rapeseed, khella, sorghum, wheat, chili, tomato, Sudan grass, and tobacco	Maçik <i>et al.</i> (2020) [27]
<i>Cylindrocladium spp.</i> <i>Aphanomyces spp.</i> <i>Thielaviopsis spp.</i> <i>Fusarium spp.</i> <i>Macrophomina spp.</i> <i>Rhizoctonia spp.</i> <i>Phytophthora spp.</i> <i>Sclerotinium spp.</i> <i>Pythium spp.</i> <i>Verticillium spp.</i>	Promoting the establishment constituting the framework of macroaggregates in soil	Promote the acquisition of essential micronutrients, including Zn, Cu, Fe, and Mn	Dubey <i>et al.</i> (2019) [16]

A. niger, *Aspergillus awamori* and *Penicillium digitatum* these are other organisms applied as biofertilizers as a result of their capability to solubilize phosphates and their participation in several biological mechanisms including respiration, energy transfer, photosynthesis, and storage compound signal transduction accumulation energy which occur inside during cell elongation process, cell division; macromolecular synthesis. Soil pH decreasing caused by microbial production of organic acids or proton release has been regarded as an important mechanism for soil phosphorus solubilization (Babalola *et al.*, Venegas Gutiérrez *et al.*, 2021) [9]. Phosphorus tends to be fixed in the soil under alkaline conditions as calcium phosphates, for example rock phosphate (fluorapatite and francolite) being less soluble in soils, they are being released more readily with the decrease in soil pH. Phosphorus solubilizing micro organisms generate Organic acids reduce soil pH, thereby increasing the bioavailability of phosphorus, OMA and solubility index are highly positively correlated. Phosphorus solubilizing micro organisms produce acidity by CO₂ release by which they can affect calcium phosphate solubility. Dissolution of P is caused by organic acid formation and a decrease in the pH due to microbial activity. Several fungi as *P. bilaii*, *P. citrinum*, *Trichoderma viride*, *Aspergillus sydowi* and *A. tubingensis* utilize this strategy (Kalayu, 2019) [22].

Conclusion

Ecology friendly technologies will from now on be a biofertilizers with purpose of sustainable agriculture. Bio drugs - Since biofertilizers have way more nutrients, it improves the soil fertility and increases the productivity of plant. Biofertilizers can be obtained from diverse organisms. These microorganisms are bacteria (*Nitrobacte*, *Azotobacter* and *Cyanobacter*), microalgae (*Haematococcus pluvialis*, *Spirulina platensis*, *Chlorella vulgaris*, *Acutodesmus dimorphus*) and micro-fungi (*Glomus spp.*). Macroscopic organisms, including algae and fungi that help in maintaining the cleanliness and Natural environment (including an ecosystem) also supporting the concept of sustainable development.

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