SUSTAINABLE ORGANIC FARMING USING BIOFERTILIZERS – OPTION FOR SYNTHETIC FERTILIZERS

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Abstract

In the last few decades, synthetic chemical fertilizers have played a major role in enhancing agricultural productivity in limited agricultural lands to feed the increasing world population. At the same time, the massive usage of chemical fertilizers in the agriculture sector causes harmful impacts on both environmental ecology and human health with great severity. Therefore, enhancing crop productivity and feeding the people without adversely affecting the environmental quality is challenging for the agricultural industry. To overcome these issues, biofertilizers and biopesticides were introduced during the green revolution as a sustainable solution to reduce the usage of synthetic chemicals. Biofertilizers enclose living microorganisms that colonize the rhizosphere or the interior of the plants to stimulate its growth. When these applied to soils, seeds, or plant surfaces, they enhance the source of primary nutrients to the target crops or its accessibility. The beneficial microorganisms used as biofertilizers can interact with the crop plants and enhance their immunity, growth, and development. So, biofertilizers can be introduced with traditional organic fertilizers to enhance soil fertility for healthy plant growth. Even though biofertilizers are used all around the world, they are not much popular in Sri Lanka. Currently Sri Lanka is planning to promote organic agriculture and must introduce biofertilizers to our agricultural lands to fill the gap of synthetic chemical fertilizers. However, biofertilizers should use with extreme care in control levels to avoid unnecessary impacts in the future. For those authorities should provide the correct guidance to the biofertilizer users, manufacturers, and importers to get the maximum benefit to the Sri Lankan agriculture sector. This will lead to the safe use and to obtain maximum benefit from biofertilizer in sustainable organic farming over synthetic fertilizers.

Keywords: Beneficial microorganisms, Biofertilizer, Standard and quality control, Sustainable Agriculture

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Introduction

The world population will be extended near to 10 billion by 2050 according to the prediction from the Food and Agriculture Organization of the United Nations (FAO, 2017). The total food demand will be increased from 35% to 56% along with this growing population (van Dijk et al., 2021). Global agricultural industries are trying to eradicate this global hunger by following several different strategies. Mainly utilization of synthetic chemical fertilizers as nutritional supplement to crops, application of biocides to manage diseases and pest in the field and operation of irrigation system to supply optimum environmental conditions. Climate change, ecosystem degradation, biodiversity loss, and soil erosion are some rivals these agricultural industries have to battle while they are trying to stabilize food security (Davis et al., 2016; Kumar et al., 2022).

Even though synthetic chemical fertilizers and biocides have played a major role in enhancing agricultural productivity in limited agricultural lands in the last few decades, enormous environmental damage has occurred. Now, this harmful impact challenges human health too. One best example is identifying the blooming number of Chronic Kidney Disease of unknown etiology (CKDu) patients from farmers' community in North central province in Sri Lanka (Jayalal et al., 2019; Jayasumana et al., 2013). Therefore, enhancing crop productivity and feeding the people without adversely affecting the environmental quality is a huge task for the agricultural industry. The development of sustainable, eco-friendly agriculture approaches are the ways to overcome this mission. Application of beneficial soil microorganisms, such as plant growth promoting rhizobacteria and mycorrhizal fungi, is an innovative, environmentally friendly biotechnique that could be used as an alternative to the chemical synthesis fertilizer (Ajmal et al., 2018).

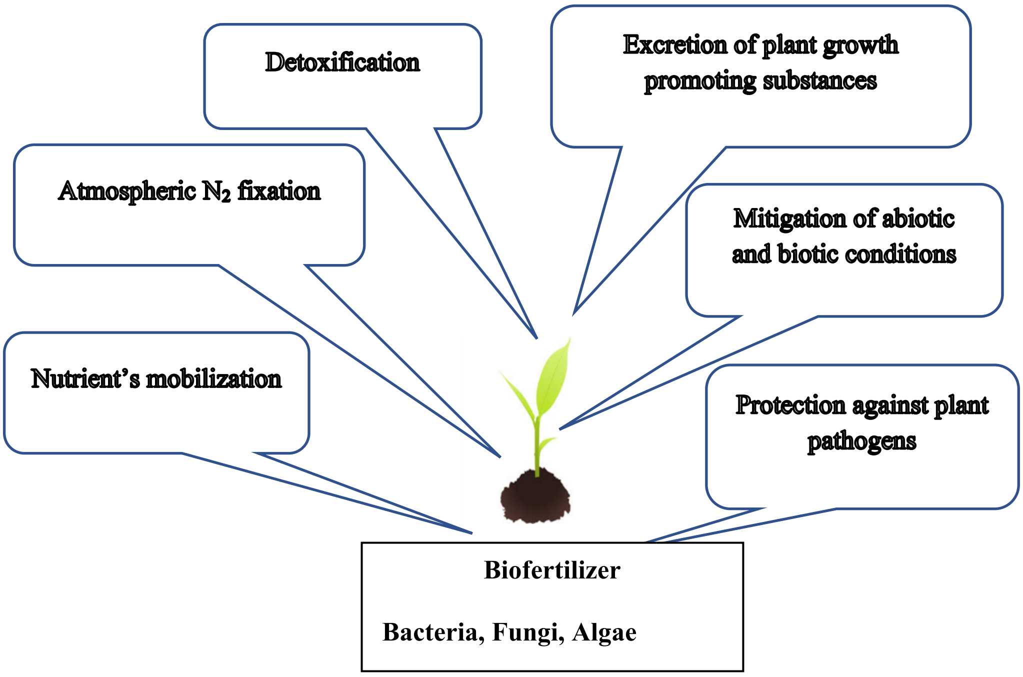
Even though these biofertilizers are used all around the world, they are not popular in Sri Lanka. Since the Sri Lankan government recently pressing society to switch over to organic farming, we should introduce biofertilizers to our agricultural sector. However, biofertilizers should be used in control levels to avoid unnecessary impacts in the future. In order to control the use of biofertilizers, policymakers should provide correct guidelines to biofertilizer importers, manufacturers, and users. This will lead to the safe use and to obtain maximum benefit from biofertilizer in sustainable organic farming over synthetic fertilizers.

What are biofertilizers?

Biofertilizers are living or biologically active products or microbial inoculants of bacteria, algae, and fungi. It can be introduced to seed, plant surfaces, or soil, and colonizes the rhizosphere or the interior of the plant to enhance the supply or accessibility of primary nutrients in numerous ways to the host plant (Figure 1) (Fasusi et al., 2021; Kawalekar, 2013; Kumar et al., 2022; Mącik et al., 2020a; Mahanty et al., 2017). The beneficial microorganisms are used as biofertilizers to establish symbiotic relationships with the plants and improve the soil nitrogen, phosphorous, organic matters, etc.

Figure 1.

Activity of Biofertilizers

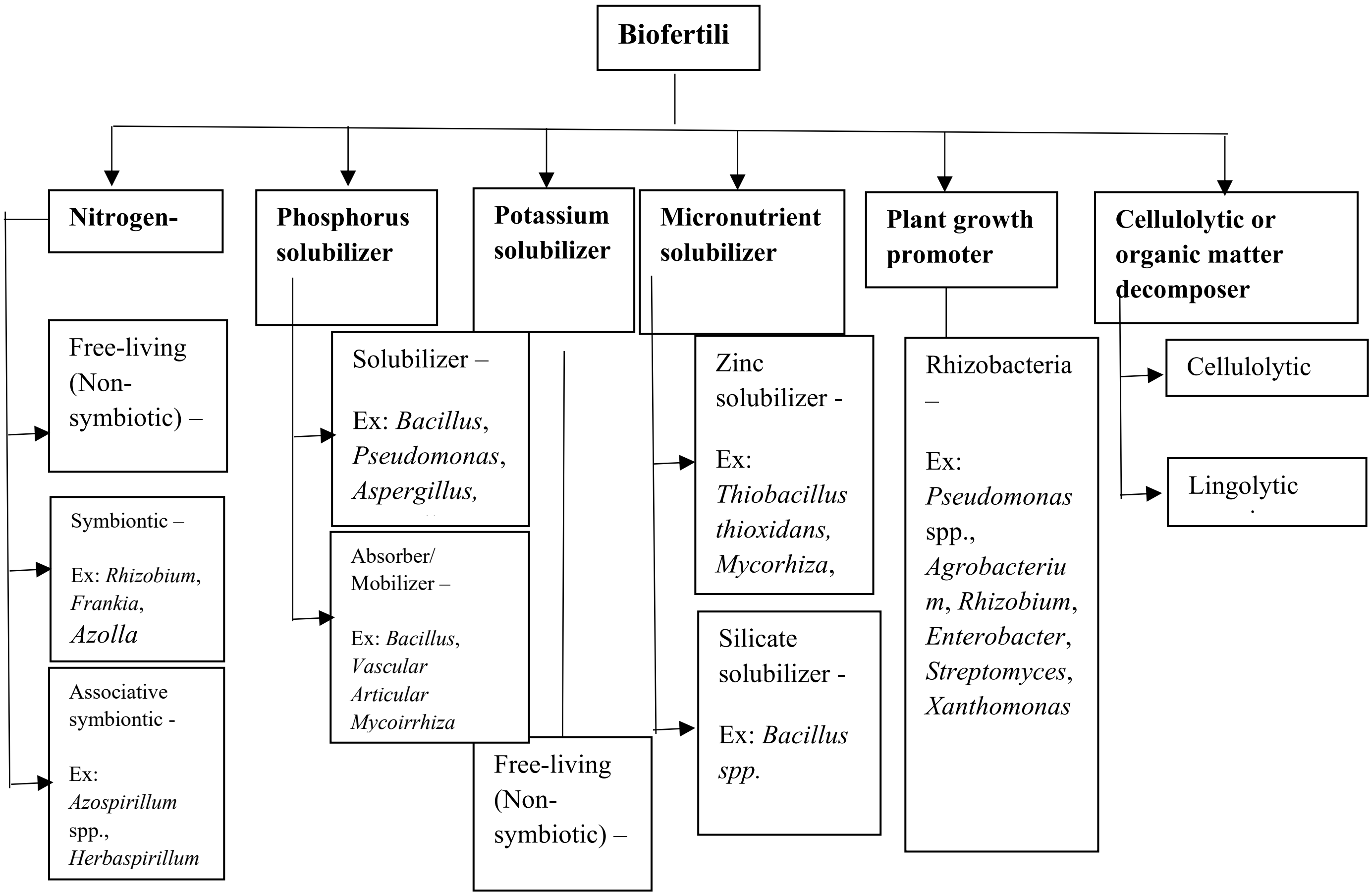


Types of biofertilizers

Microorganisms used as biofertilizers function as nourishments and convert the inaccessible forms of soil elements into accessible forms for plants. Based on the consist microorganisms, biofertilizers are categorized into different types (Figure 2) (Fasusi et al., 2021; Kumar et al., 2022; Mącik et al., 2020b; Mahanty et al., 2017; Mahdi et al., 2010).

Figure 2.

Different types of Biofertilizers



The diverse forms of biofertilizers are listed below:

1. ***Nitrogen-fixer***

Nitrogen is a crucial element for plants' amino acids, nucleic material, and chlorophyll production. Nearly 80% of the earth's atmosphere consists of nitrogen. However, plants cannot utilize it for its' needful from the air. The molecular nitrogen blends into plants in two ways through the process of lightning or the prokaryotes in the soil, such as bacteria, cyanobacteria, and fungi, converts atmospheric nitrogen into nitrates/ammonia, which is so called nitrogen-fixing. Some of these microorganisms have been used as biofertilizers, and they can be classified into three groups as free-living (*Azotobacter* and *Azospirillium*), symbionts (*Rhizobium*, *Frankia*, and *Azolla)*, and associative symbionts (*Azospirillum* spp., *Herbaspirillum* spp.) (Fasusi et al., 2021; Itelima et al., 2018; Mącik et al., 2020a). Different biofertilizers have an optimum consequence for different soil textures. Therefore, nitrogen biofertilizers are carefully selected based on the cultivated crop. A few examples are rhizobia are, used for legume crops, *Azotobacte*r or *Azospirillum* for non-legume crops, Acetobacter for sugarcane, and blue green algae and *Azolla* for lowland rice paddies (Mia & Shamsuddin, 2010).

2. ***Phosphorus solubilizer***

Phosphorus is another key element for plant photosynthesis, signal transduction, biomolecule synthesis, and metabolic processes. Mostly phosphorus present in insoluble form in the soil. Therefore, it cannot reach the plant. Several soil bacteria and fungi have capability to transform insoluble forms to their soluble forms of phosphates, which can be absorbed by plants.
There are two types of phosphorus biofertilizers, including phosphorous solubilizing biofertilizers and phosphorus mobilizing biofertilizers (Fasusi et al., 2021; Kumar et al., 2022).

Phosphorous solubilizing biofertilizers consist of phosphate solubilizing bacteria (PSB) such as species of *Bacillus*, *Pseudomonas*, *Penicillium*, and *Aspergillus*, which could convert insoluble phosphorus into soluble inorganic phosphorus (Anand et al., 2016).

Plants rely on microorganisms to mobilize organically and inorganically bound phosphorus, which the plant can then readily utilize. Applying phosphorus mobilizing microorganisms to soils is a promising approach for improving phosphorus fertilization efficiency in agriculture. Mycorrhizal fungi are used as phosphorus mobilizing biofertilizers and create a link between the roots and the soil. It facilitates the absorption of nutrients, including phosphorus, from the soil and passes it to the roots.

3. ***Potassium solubilizing biofertilizers***

Potassium is a major player in determining the plant growth.

In the soil, about 98% of potassium is bound within a phyllosilicate structure and remains in solution or on exchange sites. Therefore, nearly 2% of soil potassium can be utilized by plants. Insoluble potassium present in phyllosilicates can be solubilized by some rhizobacteria. Some *Bacillus* spp. and *Aspergillus niger* are used as Potassium solubilizing biofertilizers (Fasusi et al., 2021; Kumar et al., 2022; Mishra & Dash, 2014).

4. ***Micronutrients solubilizing biofertilizers: Zinc solubilizers***

Zinc has low levels of mobility and solubility. Hence, it is commonly unavailable for plants to adsorb from the soil. Zinc solubilizing bacteria such as *Mycorhiza*, *Pseudomonas* spp., and *Bacillus* spp. can enhance the mobility of zinc present in the soil (Fasusi et al., 2021). So, biofertilizers with the efficient strain of zinc solubilizing bacteria advance soil nutrient content.

Silicate solubilizers

Even though silicon is the second most abundant element on the earth, it will not uptake by the plants due to the poor solubility. *Bacillus* spp., *Pseudomonas* spp., *Rhizobia, and Enterobacter* have ability to release silicon from silicates (Bist et al., 2020; Maleva et al., 2018). Then, it will aid in promoting plant growth.

5. *Plant growth promoting biofertilizers*

A wide variety of plant growth promoting rhizobacteria grow with the host plant and increase mobility, uptake, and enrichment of nutrients in the plant. These bacteria show diverse mechanisms of plant growth promotion but generally influence growth via nutrient uptake enhancement, plant growth hormone production, or production of a variety of antimicrobial compounds that act in different ways (Kumar et al., 2022; A. Yadav et al., 2017). Examples of plant growth promoting biofertilizers are *Pseudomonas* spp., *Agrobacterium*, *Rhizobium*, *Enterobacter*, *Streptomyces*, and *Xanthomonas*.

6. *Compost biofertilizers*

Biofertilizers in the compost enhance the bacterial processes to break down the compost waste. Cellulolytic fungal cultures and *Azotobacter* cultures are used in compost biofertilizers. Eco-friendly biocompost prepared from sugar industry waste material that is decomposed and supplemented with various plants and human-friendly bacteria and fungi. Biocompost consists of nitrogen, phosphate-solubilizing bacteria, and numerous beneficial fungi like the decomposing fungus *Trichoderma viridae*, which protects plants from various soil-borne diseases and helps to increase soil fertility (Yadav & Sarkar, 2019).

Production and bioformulation of biofertilizers

Microorganisms to be inoculated as biofertilizers need to be isolated and identified from soil or plant roots. Then, the relevant microorganism is multiplied on artificial media to harvest on a large scale in a bioreactor. Commonly, biofertilizers are prepared as carrier-based inoculants of effective microorganisms. The carrier is a medium to transfer adequate quantities of live microorganisms under specified conditions and conveniently supply to the farmers. Clay, compost, coconut shell powder, peat, talc, perlite, zeolite, vermiculite, perlite, rice bran, wheat bran, polyacrylamide, charcoal, sawdust, and organic manure are used as carrier materials for the production of biofertilizers (Vassilev et al., 2020). Eco-friendly novel carriers develop like encapsulated bio formulations that use natural polymer-based carriers (cellulose, chitosan, sodium alginate, starch, lignin, agarose) or synthetic polymer-based carriers (polystyrene, polyacrylamides, and polyurethane, polyvinyl acetate, polyvinylpyrrolidone, polyethylene glycol and polyethersulfone) for encapsulation of bacteria into a biodegradable matrix.

Liquid biofertilizers are broth cultures containing dormant forms of desired microorganisms along with required nutrients, minerals, and organic oils. Liquid form is easy to produce and can be applied directly on seeds, increasing the adherence of bacteria to plant roots. However, the survival of microorganisms in liquid biofertilizers decreases with time because it does not provide protection to microorganisms against environmental conditions and prone to contamination during transportation or storage (Kumar et al., 2022).

How to apply biofertilizers?

Seed treatment, root dipping, and soil application are the main methods used to introduce biofertilizers to plants. Effective and economic seed treatment is the most common method adopted for all types of inoculants. In this method, seeds are uniformly wetted with liquid biofertilizers or mixed with carrier-based biofertilizers, followed by shade drying for 20-30 minutes. The seed treatment can be done with any of two or more bacteria. Then, the biofertilizer treated seeds will be introduced to the fields (Mącik et al., 2020a).

Biofertilizer application on paddy transplanting and vegetable crops use the root dipping method. The required quantity of biofertilizer was mixed with 5–10 liters of water and dipped in the roots of seedlings for a minimum of 30 minutes before transplantation.

The traditional main field application method is also used with some biofertilizers during the leveling of soil or to the plant growing fields.

Global market for biofertilizers

More than 100 years ago, biofertilizers were introduced into the agricultural market on a commercial scale after recognizing *Rhizobium* sp. as a nitrogen fixing bioinoculant (O'Callaghan, 2016). Biofertilizers comprise approximately 5% of the total fertilizer market, and more than 150 products were registered in the global market based on their microbial strains (Mącik et al., 2020a).

Nearly 80% of the global biofertilizer market is occupied with nitrogen fixing biofertilizers and roughly 15% with phosphate solubilizing biofertilizers. The global biofertilizer market is geographically divided into several regions, such as North America, Europe, Asia-Pacific, Latin America, Middle East, and Africa. North America, Europe, and Asia-Pacific regions show high demand for biofertilizers, and Asia-Pacific is the fastest growing market. The growth rate of biofertilizers is shown in the Latin America sector and the low rate in the Middle East and Africa. However, the global biofertilizer market is gradually increasing. According to the available information, the global biofertilizer market reached USD 1.26 and 2.6 billion in 2017 and 2021, respectively (Mącik et al., 2020a). As well as it is predicted to reach USD 4.5 billion by 2026.

The global biofertilizer market was relatively stable during the global COVID-19 pandemic. This may be due to the biofertilizers can be easily developed by the domestic manufacturers and each country start to set up domestic food production during this crisis. Therefore, the global biofertilizer market is projected to grow drastically in the future.

Quality control of biofertilizers

Currently, there is a blooming demand for the biofertilizers because they are playing a key role in the chemical free, ecofriendly sustainable agriculture. Therefore, quality control of the biofertilizers associated with the various stages, such as production, transportation, application etc., has become an essential task. These biological products related processes include the operations performed in the laboratory and field. Most countries develop their own standard frame for their biofertilizer by considering several factors. Sri Lanka Standards Institution (SLSI) prepared the Sri Lankan standards for biofertilizers, and they are referring to Sri Lanka standard 1704:2021 for solid organic fertilizers and 1702:2021 for liquid organic fertilizers under UDC 628. The summary of those specifications is shown in Table 1(Sri Lanka standard specification for liquid organic fertilizers, 2021; Sri Lanka standard specification for sterilized solid organic fertilizer, 2021). There is a high potential for the presence of heavy metals in the biofertilizers. Therefore, introducing minimum toxic levels for the heavy metals present in biofertilizers is crucial when preparing the standards for them. Table 2 shows the permitting toxic levels could be present in the biofertilizer in the Sri Lankan content (Sri Lanka standard specification for liquid organic fertilizers, 2021; Sri Lanka Standard specification for sterilized solid organic fertilizer, 2021). Living organisms, antibiotic residues, organic pollutants, microplastic, pesticide residues, and nitrogenous residues are other factors considered in organic solid fertilizers. Compared to the solid biofertilizers, Faecal *coliform* and *Salmonella* are specially checked in the liquid form, and both these microorganisms need to be absent in the biofertilizers.

Table 1.

Sri Lanka standard specifications for the biofertilizers

Requirement	Characteristics	Requirement	
		Solid organic fertilizers	Liquid organic fertilizers
Physical	pH	6.5-8.5	6.0-8.5
	Electrical conductivity, dS/m, max.	4.0	20.0
	Foreign Matter/ visible contaminants	Free from visible non-biodegradable materials	
	Sand content, percent by mass, on dry basis, max	5	
	Particle size, residue particles when passing through 4 mm sieve, percent by mass, max. (not applicable for pelleted forms)	2	
Chemical	Total Nitrogen content as N, percent by mass, min.	5.0	1.0
	Total Phosphate content as P_2O_5, percent by dry basis, min.	1.0	0.5
	Total Potassium content as K_2O, percent by mass, min	2.0	0.3
	Total Magnesium content, as MgO percent by dry basis, min.	0.5	
	Total Calcium content, as CaO percent by dry basis, min.	0.5	
	Organic Carbon as C, percent, by dry basis, min.	15	5.0

Table 2.

Sri Lanka standard specifications for the biofertilizers

Element	**Limit (mg/ kg basis, max.)**	
	Solid organic fertilizers	Liquid organic fertilizers
Cd	1.5	0.5
Cr	50.0	0.5
Pb	30.0	1.0
Hg	0.5	0.5
As	3.0	0.5
Ni	40.0	

The quality of the packaging of biofertilizers is the other factor that needs to be controlled. Solid biofertilizers required strong, moisture proof packages such as polypropylene bags with an inner lining of a minimum thickness of 50 µm, and liquid could be packed in strong plastic or glass containers. The label which shows all the necessary information is must on the biofertilizer package or bottle.

Currently Biofertilizers use in Sri Lanka could test following those quality parameters established by SLSI like most of the countries formed their own standard to maintain the quality of biofertilizers used in their own country. One such example is the minimum requirement for total N, P, K of organic fertilizer in Philippine is 5-7% (Philippine national standard, 2013). However, according to the Sri Lankan standard, this parameter has to be 8% for solid and 2% for liquid biofertilizers. Allowable limits for the toxic elements show wide diversity based on their local content. Compared to the Sri Lankan permit levels in Table 2, Philippine set up their permit levels for Cd, Cr, Pb, Hg, As, and Ni are 5, 150, 250, 2, 5, and 50 mg/ kg dry weight, respectively. This clearly indicates that the regulation of the quality of biofertilizers is completely dependent on the individual country policies regardless of the international concern. However, in any event it will be impractical to set up the international regulations to maintain the biofertilizers.

Limitations of biofertilizers

Low cost, eco-friendly biofertilizer technology constraints some limitation in the application or implementation of the technology. Biofertilizers contain live microorganisms that could die with temperature fluctuation. The shelf-life of biofertilizers in powder form is limited to 6–12 months. Some biofertilizers are specific for crop and/or location. Therefore, their efficacy does not remain the same at different locations due to natural differences in agro-climatic conditions. Soil characteristics like high nitrate, low organic matter, less available phosphate, high soil acidity or alkalinity, high temperature, as well as the presence of high levels of agrochemicals or low levels of micro-nutrients contribute to failure of inoculants or adversely affect their efficacy.

Lack of qualified technical personnel in production units and production of poor-quality inoculants without understanding the basic microbiological techniques are other major issues associated in biofertilizer manufacturing process. Finally, the lack of awareness among farmers regarding the benefits of biofertilizers is a major concern in promoting eco-friendly biofertilizers over synthetic fertilizers.

Conclusion

As the population is increasing, fertilizers play a major role to meet the population food demand. Chemical fertilizers have been used to increase crop production and yield, resulting in tremendously increases in its usage demand. However, chemical fertilizers have many disadvantages, including the pollution of air, water, soil, plant disease infestations, and emergence of new pests etc. Therefore, chemical fertilizers become a challenge for the sustainability of agriculture for the future. That increased the necessity of developing biofertilizers as a possible alternative to chemical fertilizers. The beneficial microorganisms that are used as biofertilizers promote crop productivity to a large extent. These biofertilizers would play a key role in crop productivity as well as the sustainability of soil and environment friendly and cost-effective inputs for the farmers. Maintaining the quality of biofertilizers with the established standards is essential in the growing biofertilizer market. The future direction of biofertilizers is the development of genetically modified microbes with higher efficiency and improved properties such as better handling system and enhanced storage shelf-life. Hence, biofertilizers have enormous future prospects in sustainable agriculture.

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Conflicts of interest

The authors declare that there is no conflict of interest.

References

Ajmal, M., Ali, H. I., Saeed, R., Akhtar, A., Tahir, M., Mehboob, M. Z., & Ayub, A. (2018). Biofertilizer as an Alternative for Chemical Fertilizers. *Research & Reviews: Journal of Agriculture and Allied Sciences*, *7*(1), 1–7.

Anand, K., Kumari, B., & Mallick, M. (2016). Phosphate solubilizing microbes: An effective and alternative approach as biofertilizers. *J. Pharm. Pharm. Sci.*, *8*, 37–40.

Bist, V., Niranjan, A., Ranjan, M., Lehri, A., Seem, K., & Srivastava, S. (2020). Silicon-Solubilizing Media and Its Implication for Characterization of Bacteria to Mitigate Biotic Stress. *Frontiers in Plant Science*, *11*(February), 1–19. https://doi.org/10.3389/fpls.2020.00028

Davis, K. F., Gephart, J. A., Emery, K. A., Leach, A. M., Galloway, J. N., & D'Odorico, P. (2016). Meeting future food demand with current agricultural resources. *Global Environmental Change*, *39*, 125–132.

FAO, F. and A. O. of the U. N. (2017). The future of food and agriculture: trends and challenges. In *The future of food and agriculture: trends and challenges, 4*(4).

Fasusi, O. A., Cruz, C., & Babalola, O. O. (2021). Agricultural sustainability: Microbial biofertilizers in rhizosphere management. *Agriculture (Switzerland)*, *11*(2), 1–19. https://doi.org/10.3390/agriculture11020160Itelima, J., Bang, W., Onyimba, I., & Oj, E. (2018). A review: Biofertilizer; a key player in enhancing soil fertility and crop productivity. *J. Microbiol. Biotechnol. Rep.*, *2*, 22–28.

Jayalal, T. B. A., Jayaruwan Bandara, T. W. M. A., Mahawithanage, S. T. C., Wansapala, M. A. J., & Galappaththi, S. P. L. (2019). A quantitative analysis of chronic exposure of selected heavy metals in a model diet in a CKD hotspot in Sri Lanka. *BMC Nephrology*, *20*(1). https://doi.org/10.1186/s12882-019-1371-5

Jayasumana, M. A. C. S., Paranagama, P. A., Amarasinghe, M. D., Wijewardane, K. M. R. C., Dahanayake, K. S., Fonseka, S. I., Rajakaruna, K. D. L. M. P., Mahamithawa, A. M. P., Samarasinghe, U. D., & Senanayake, V. K. (2013). Possible link of Chronic arsenic toxicity with Chronic Kidney Disease of unknown etiology in Sri Lanka. *Journal of Natural Sciences Research*, *3*(1), 64–73.

Kawalekar, J. S. (2013). Role of biofertilizers and biopesticides for sustainable agriculture. *J. Bio. Innov.*, *2*, 73–78.

Kumar, S., Diksha, Sindhu, S. S., & Kumar, R. (2022). Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences*, *3*, 100094. https://doi.org/10.1016/j.crmicr.2021.100094

Mącik, M., Gryta, A., & Frąc, M. (2020a). Biofertilizers in agriculture: An overview on concepts, strategies and effects on soil microorganisms. *Advances in Agronomy*, 1–57.

Mącik, M., Gryta, A., & Frąc, M. (2020b). Biofertilizers in agriculture: An overview on concepts, strategies and effects on soil microorganisms. *Advances in Agronomy*, *162*, 31–87. https://doi.org/10.1016/bs.agron.2020.02.001

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., & Tribedi, P. (2017). Biofertilizers: a potential approach for sustainable agriculture development. *Environmental Science and Pollution Research*, *24*(4), 3315–3335. https://doi.org/10.1007/s11356-016-8104-0

Mahdi, S. S., Hassan, G., Samoon, S., Rather, H., Dar, S. A., & Zehra, B. (2010). Bio-fertilizers in organic agriculture. *J. Phytol.*, *2*, 42–54.

Maleva, M., Borisova, G., Koshcheeva, O., & Sinenko, O. (2018). Biofertilizer Based on Silicate Solubilizing Bacteria Improves Photosynthetic Function of Brassica Juncea. *Agrofor*, *2*(3), 13–19. https://doi.org/10.7251/agreng1703013m

Mia, M. B., & Shamsuddin, Z. (2010). Rhizobium as a crop enhancer and biofertilizer for increased cereal production. *Afr. J. Biotechnol.*, *9*, 6001–6009.

Mishra, P., & Dash, D. (2014). Rejuvenation of biofertilizer for sustainable agriculture and economic development. *Consilience*, 41–61.

O'Callaghan, M. (2016). Microbial inoculation of seed for improved crop performance: : issues and opportunities. *Appl. Microbiol. Biotechnol.*, *100*, 5729–5746. https://doi.org/https://doi.org/10. 1007/s00253-016-7590-9

Philippine national standard, (2013).

Sri Lanka standard specification for liquid organic fertilizers, (2021).Sri Lanka standard specification for sterilized solid organic fertilizer, (2021).

Van Dijk, M., Morley, T., Rau, M. L., & Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food*, *2*(7), 494–501. https://doi.org/10.1038/s43016-021-00322-9

Vassilev, N., Vassileva, M., Martos, V., Garcia Del Moral, L. F., Kowalska, J., Tylkowski, B., & Malusá, E. (2020). Formulation of Microbial Inoculants by Encapsulation in Natural Polysaccharides: Focus on Beneficial Properties of Carrier Additives and Derivatives. *Front Plant Sci.*, *11*, 270. https://doi.org/10.3389/fpls.2020.00270

Yadav, A., Verma, P., Singh, B., & Chauahan, V. (2017). Plant growth promoting bacteria: Biodiversity and multifunctional attributes for sustainable agriculture. *Adv. Biotechnol. Microbiol.*, *5*, 1–16.

Yadav, K. K., & Sarkar, S. (2019). Biofertilizers, impact on soil fertility and crop productivity under sustainable agriculture. *Environ. Ecol*, *37*, 89–93.