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Review Paper

Improving Crop Nutrition through Ecofriendly Biofertilizers: Concept, Types and Benefits in Agriculture

Bishal Mukherjee[1], Saumi Goswami[1*], Pragun Pal[1], Tanuj Kumar Mandal[1], Urjashi Bhattacharya[1], Manish Kumar Naskar[2] and Suman Dutta[3]

[1]School of Agriculture and Allied Science, The Neotia University, Sarisha, South 24 Parganas, West Bengal, India
[2]Department of Agricultural Meteorology and Physics, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India
[3]Department of Genetics and Plant Breeding, School of Agriculture and Rural Development, Ramkrishna Mission Vivekananda Educational and Research Institute, Belur Math, Howrah, West Bengal, India

*Corresponding author: saumi.goswami@tnu.in (**ORCID ID:** 0009-0004-7940-3554)

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ABSTRACT

Ensuring food for the continuously increasing global population is one of the most challenging aspects for scientists and researchers around the globe. To meet the growing demand for food, agricultural expansion is necessary. However, traditional agriculture is crucial to meet the nutritional requirements for humanity as well as to make countries self-sufficient in food production. Conventional farming techniques depend on the widespread use of synthetic fertilizers and pesticides for plant nutrition and disease pest management. The use of such chemical inputs in different crop fields is popular to farmers for plant growth, crop production, and quality, but also for farmers' income. However, these chemical inputs pose a considerable threat to the natural environment by contaminating water, air, and soil. Eco-friendly approaches, such as organic farming and bio-fertilizers, are gaining popularity as a more sustainable alternative to conventional agriculture. Organic farming helps in reducing dependence on artificial plant protection inputs in field crop production. Bio-fertilizers are a type of fertilizer that uses microorganisms that promote plant growth and are referred to as biofertilizers or microbial inoculants. Biofertilizers are getting priority in world agriculture due to simple production technology and low installation cost. The purpose of this review is to summarize the current knowledge on biofertilizers and their potential for sustainable agriculture.

HIGHLIGHTS

- Use of chemical fertilizers has caused havoc impacts on soil as well as on agroecosystem.
- Biofertilizers have enough potential to provide essential nutrients to crops.
- The quality of biofertilizers is to be maintained to harness proper benefits in an integrated nutrient management for crops.

Keywords: Biofertilizers, classification, importance, prospects, quality

Improvement in agriculture means improvement in feeding global population as well as fulfilling the economic demand for proper livelihood. Presently, ensuring food for the continuously increasing global population is one of the most challenging aspects to the scientists and researchers around the globe. Further, degradation and depletion of natural resources are also major concerns of the present-day agriculture (Sairam *et al*. 2023). Climate change, rising of sea level and frequent cyclones have been changing the crop production and cropping pattern

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in the tropical coastal region (Sagar *et al*. 2023). This rapid growth is indistinguishably associated with intensive urbanization, industrialization and agricultural production. To meet the growing demand for food, agricultural expansion is very much necessary. But now a days, traditional agriculture is crucial to meet the nutritional requirements for humanity as well as to make the countries self-sufficient in food production (Mahanty *et al.* 2016).

Soil is a dynamic living body and contains various numbers of diverse living organisms. These living organisms are very much sensitive towards soil physico-chemical property changes. However, the conventional farming techniques mainly depends on the widespread use of synthetic fertilizers and pesticides for ensuring plant nutrition and disease pest management (Vasile *et al.* 2015). The usage of such chemical inputs in different crop fields are so much popular to the farmers not only for the plant growth, crop production and quality, but also for the farmers' income. As artificial supplies in agricultural field become more prevalent, they may pose a considerable threat to the natural environment by contaminating water, air, and soil (Rahman and Zhang, 2018). The excess uses of chemical fertilizers in agriculture are costly also with adverse effects on physico-chemical properties of soils, eutrophication on water resources, greenhouse effect etc. (Goenadi *et al.* 2018). It is worth mentioning that long-term use of mineral fertilizers may cause soil nutrients to deplete and make crops susceptible to disease.

Currently, in this regard, eco-friendly approaches are gaining popularity with a view of bio-safety. A more sustainable agriculture *i.e.* ecologically sound, economically viable should aim to recycle minerals in the soil with no or few external inputs, maintain a high biodiversity in agro-ecosystem and have better exploitation of soil-plant microbe interactions for plant nutrition and protection. Organic farming is a perfect alternative to conventional agriculture and help in reducing the dependence on artificial plant protection inputs in field crop production. The area of organic agricultural land has recorded very impressive growth from 11 million hectares in 1999 to 57.8 million hectares in 2016 (Willer and Lernoud, 2018). One of the improved ways for sustainable farming to minimize environmental problems arising from the excessive mineral fertilization is application of biofertilizers containing strains of beneficial microorganisms (Mishra and Dash, 2014).

Bio-fertilizers are one of the greatest natural gifts as a replacement to chemical fertilizers. It is a type of fertilizer that uses microorganisms that promote plant growth and are referred to as biofertilizers or microbial inoculants (Maitra *et al*. 2021). These products are preparations containing live or latent cells of nitrogen fixing, phosphate solubilizing, or cellulytic microorganisms that fix nitrogen. Such biofertilizers are important components of integrated nutrient management in soil, while play a pivotal role in maintaining productivity and sustainability of soil. Biofertilizers are getting priority in world agriculture particularly due to simple production technology and low installation cost (Wahane *et al.* 2020). Historically, the bio-fertilizers were initially identified by a Dutch scientist in 1888 and the usage of bio-fertilizer initiated with the launch of Nitragin by Nobe and Hiltner with a laboratory culture of Rhizobia in 1895 (Ghosh, 2004). The Legume-*Rhizobium* symbiosis study was conducted by N.V. Joshi in 1920 with commercial production of biofertilizers in 1956 which seemed to be the first time biofertilizers production in India (Rana *et al.* 2013; Maitra *et al*. 2023). The purpose of this review on biofertilizers is to summarize the types of natural biofertilizers and beneficial impact on different agricultural crop production.

Importance of Biofertilizers: Need of the hour

In today's world, concern about environmental hazards and threats for achieving the goal for sustainable agriculture is growing day by day. Indiscriminate use of synthetic fertilizers has led to the pollution and contamination of the soil, has polluted water basins, destroyed micro-organisms and friendly insects, making the crop more vulnerable to pest and diseases and reduced soil fertility. Long term usage of different kind of biofertilizers can be eco-friendly, economical as well as efficient alternative of the synthetic chemical fertilizers which may be easily accessible to small and marginal farmers. The need for the use of biofertilizer thus arises primarily for some particular importance which are briefly pointed below:

- Promotion of plant growth without any side effects for environment and increasing harvest yields of different field crops is the major role of

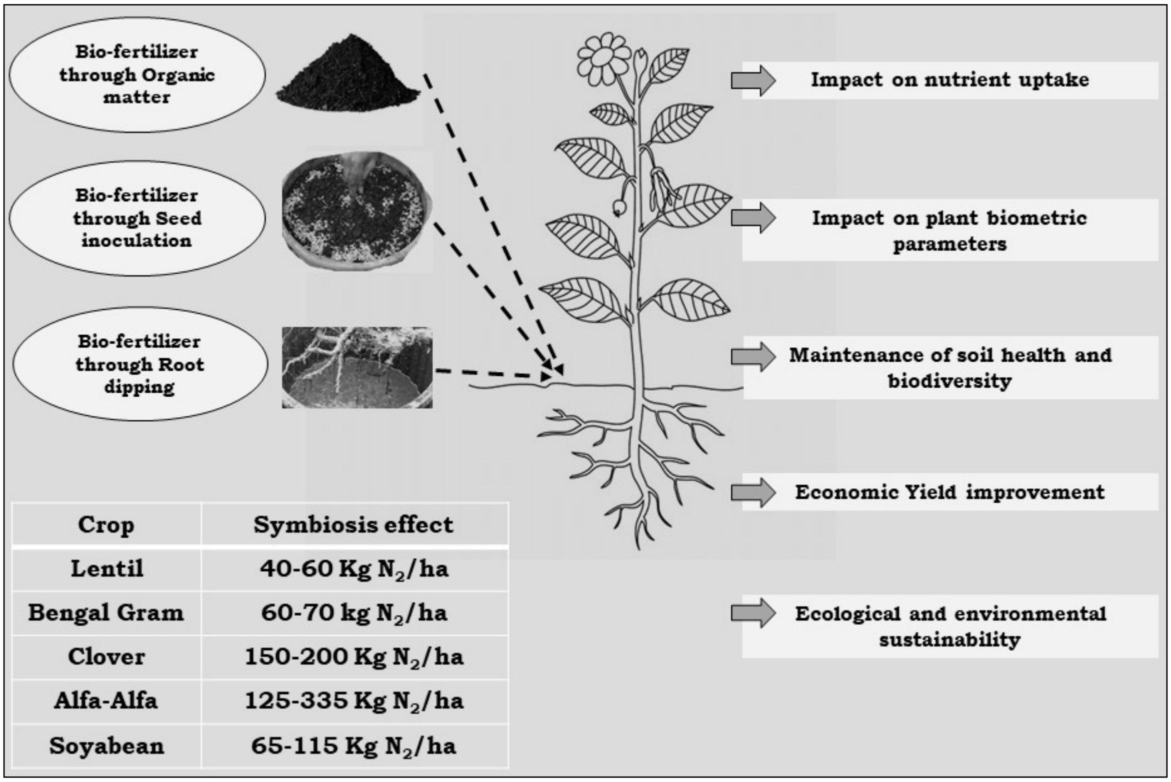

Fig. 1: Schematic Diagram on techniques of Biofertilizers application and its impact on plant development

biofertilizers (Mishra *et al.* 2013). As per report of Schutz *et al.* (2018), seed inoculation with biofertilizers increased crop yield averagely by 16.2% in comparison with non-inoculated controls.

- Microbial biofertilizers play a significant role in maintenance of soil fertility and improving soil structure by improving aggregation of soil particles (Rashid *et al.* 2015).
- *Arbuscular mycorrhizal* colonization induces drought tolerance in plants by improvement of leaf water and turgor potential as well as maintenance of stomatal functioning and transpiration.
- Biofertilizers also provide protection against drought, make plants less prone to some soil-borne diseases, including causing by fungi that additionally produce mycotoxins (Simarmata *et al.* 2016) and reduce the incidence of insect pests (Dey *et al.* 2014).
- These kind of organic fertilizers reduce the input expenses by replacing the cost of chemical fertilizers as they can be easily obtained from organic materials such as rice husk, neem fruit and seeds etc.
- Aquatic cyanobacteria which is also a kind of biofertilizers provide natural growth hormones, protein, vitamins and minerals to the soil.

Classification of Biofertilizers

Biofertilizers can be classified into different types based on their nature and functions which are mentioned below:

N Fixing Biofertilizers

1. *Rhizobium*: Rhizobium belongs to gram negative bacterial group and is symbiotic nitrogen fixer. They are one of the most efficient biofertilizers as per the quantity of nitrogen fixed concerned. It is found mostly in the root nodules where it establishes a symbiotic relationship with the roots of leguminous plants. It has been estimated that 40-250 kg N/ha/year is fixed by different legume crops by the microbial activities of *Rhizobium* (Kumar and Kumar, 2020). They are cheaper, pollution free, based on renewable energy sources and also improve soil fertility (Saeed *et al*. 2004).

Population density of *Rhizobium* in soil mostly depends on the presence of pulse crops in the field (Sheraz *et al*. 2010). The Rhizobium bacteria

Table 1: Impact of different biofertilizers on crop growth and development

Type of product	Effect on crop growth	References
Integrated use of chemical fertilizers, FYM and *Azotobacter* biofertilizer	Uptake of N, P, K as well as growth parameters and grain yield of maize was improved significantly	Meena *et al.* 2013
Application of Vermicompost and vermiwash	Increase the yield of maize and all the other component of maize plants like cob weight, leaves production, plant height and weight	Roychowdhury *et al.* 2017
Azospirillium based biofertilizer	Significant yield improvement, agronomic efficiency of N fertilizer was also increased in rice	Banayo *et al.* 2012
Trichoderma enriched biofertilizers in combination with less inorganic fertilizers	Significant increase in N uptake and enhanced the yield of rice with better physiological attributes even with low inorganic fertilizer application.	Khan, 2018
Azospirillium based biofertilizer	Increased plant height, root length, root dry weight and panicle length due to *Azospirillum* inoculation through N fixation, growth promoting hormone secretion	Islam *et al.* 2012
Application of biofertilizers containing *Pseudomonas* sp. microbe	Growth parameters like plant height, dry matter accumulation as well as fresh weight of stem in green gram was increased compared to other pulses.	Ravikumar and Subramanian, 2018
Mesorhizobium strains	Different chickpea genotypes showed variable responses in terms of nitrogen fixing ability, nodulation potential (nodule number and nodule weight/plant) as well as plant growth	Swarnalakshmi *et al*. 2012
Piriformospora indica, a cultivable endophytic fungus	Colonizes plants' roots and helps in promoting plant growth and biomass production	Varma *et al.* 1999
Plant growth promoting rhizobacteria (PGPR) like *Pseudomonas* sp., *Bacillus* sp., *Flavobacterium* sp.	Production of plant hormones such as auxins, gibberellins and cytokinins as well as siderophores, control of soil pathogens by bio-control mechanisms through production of antibiotics, hydrogen cyanide (HCN), ammonia in pulse crops	Swarnalakshmi *et al*. 2016
Application of *Azotobacter* and PSB in combination with 75 and 50% NPK and FYM	Significant improvement in yield parameters viz. number of siliqua plant^{-1}, number of seed siliqua^{-1}, test weight (g) of seeds, seed yield and straw yield of Toria	Kalita *et al.* 2019
Seed inoculation with *Pseudomonas striata* or *Paecilomyces fussisporus*	Higher number and dry weight of nodules plant^{-1}, high protein content in kernels and improved haulm yield of groundnut	Asha *et al.* 1996

basically colonize plant cells within the root nodules and there, they convert atmospheric nitrogen into ammonia. The Rhizobium bacteria cannot fix atmospheric nitrogen on their own, they only develop the ability to fix nitrogen as a symbiont (Maitra *et al*. 2020; Mirriam *et al*. 2021; Palai *et al.* 2021). Here, bacteria are also benefited by the plants as they perform photosynthesis and prepare organic compounds that are provided to the bacteria as well. This way, a mutually beneficial relationship is established between the plants and the rhizobia. Each legume requires a particular species of *Rhizobium* to form effective nodules. Some examples are as follows:

1. *Rhizobium leguminosarum* in peas
2. *Rhizobium phaseoli* in beans
3. *Rhizobium japonicum* in soybeans
4. *Rhizobium lupini* in Lupins
5. *Rhizobium trifolii* in Berseem
6. *Rhizobium melilotii* in Medicago

2. *Azotobacter*: It is one of the most important and well established free living nitrogen fixing bacteria. *Azotobacter* spp. are heterotrophic and aerobic dominantly found in soils with property to fix nitrogen non-symbiotically (Doroshenko *et al*. 2007). These free-living, gram-negative, motile and mesophilic bacteria that are capable of fixing an average 20 kg N/ha/per year. It is used as a biofertilizer for all non-leguminous plants especially rice, cotton, vegetables etc. Among the several species of Azotobacter, A. chroococcum seems to be the dominant inhabitant in arable soils capable of fixing N_2 in culture media (Kumar and Kumar, 2020).

Stephens *et al.* (2000) reported that, some species of *Azotobacter* can establish symbiotic relationships with different parts of plants, and have the capability to develop specialized structures as the site of nitrogen fixation. Das (1991) studied the impact of *Azotobacter* on crop yield compared with chemical fertilizers where increase in yield over yields obtained with chemical fertilizers was 13, 16, 10, 5, 20, 40, 24, 27, 24 and 20% in potato, carrot, rice, maize, cauliflower, tomato, cotton, sugarcane and sorghum, respectively which definitely proves the positive impact of the particular bacterium in improvement of productivity of several crops.

3. *Azospirillium*: For the non-leguminous plants like cereals, millets, oilseeds, cotton etc. *Azospirillium* is a beneficial N_2 fixing microorganism. *Azospirillum* outstrips nitrogen enrichment through production of growth promoting substances. Apart from their nitrogen fixing ability of about 20-40 kg ha^{-1}, they also produce growth regulating substances (Wahane *et al.* 2020). It stimulates for the production of growth promoting substance (IAA), disease resistance and drought tolerance. It also showed profound influence in plants regarding improvement of shoot and root and increasing the rate of water and mineral uptake by plant roots (Gonzalez *et al.* 2005). As per report of Fulchieri and Frioni (1994), maize inoculated with *Azospirillum* had increased the dry weight of seed by 59% and yield was also improved in accordance with that. *Azospirillum lipoferum* and *A. brasilense* are the primary inhabitants of soil, the rhizosphere and intercellular spaces of root cortex of graminaceous plants (Kumar *et al.* 2017).

4. Cyanobacteria: Blue green algae or cyanobacteria are a group of microscopic, photosynthetic bacteria seen in a range of water bodies. Usually they are seen in a lower number and can turn ample in number in shallow, warm and undisturbed surfaces of water which receive abundant sunlight. Both free-living as well as symbiotic cyanobacteria (blue green algae) have been harnessed in rice cultivation in India. The benefits due to algalization is the ability to fix 20-30 kg N ha^{-1} under ideal conditions but the labour oriented methodology for the preparation of this biofertilizer is one of the major limitations (Kumar *et al.* 2017).

5. *Azolla*: *Azolla* is a floating aquatic pteridophyte (a fern) with symbiotically associated nitrogen fixing cyanobacteria (*Anabaenae azollae*). Azolla is a nature's gift for rice cultivation and has tremendous other agricultural uses. It is one of the most nutritive animal feed and also a source of green manure. Moreover, it is also an excellent biofertilizer too. Out of the 6 species, *Azolla pinnata* is very common and good yielder in tropical climates. *Azolla* is used as biofertilizer for wetland rice and it is known to contribute 40-60 kg N ha^{-1} for rice crop (Kumar *et al.* 2017). Biogas production capacity of Azolla is also exploited nowadays due to the fact that anaerobic digestion of Azolla with crop straws give good results of methane gas production.

Phosphate solubilizing microorganisms/ biofertilizers

Phosphate solubilizing microbes differ among themselves as per their habit and functions on the basis of phosphorus content present in the soil (Wahane *et al.* 2020). Thus, phosphorus management studies entirely depend on the response of those microorganisms. Phosphate solubilizing bacteria (PSB) solubilise phosphate by production of organic acids which can either dissolve the phosphorus by lowering the pH of the soil or they can chelate heavy metal ions such as calcium, aluminium, iron and release associated phosphorus with them (Moghimi *et al.* 1978). 20–25% phosphorus requirement of plants is fulfilled by PSB like *Pseudomonas putida* and *Bacillus megaterium* and phosphate solubilizing fungi (PSF) like *Aspergillus* and *Penicillium* (Kumar *et al.* 2018). Among the P-solubilizing microbial population in soil, bacteria constitute 1 to 50%, while fungi are only 0.1 to 0.5% in P solubilization potential (Chen *et al.* 2006).

The PSBs which are also called as 'Phosphobacterium' not only helps to enhance the P solubilization but also being reported to solubilize the Zn, K, Fe, Mn etc. in the soil (Amalraj *et al.* 2012). Root proliferation enhancement also happens due to release of growth-promoting hormones by these bacterias.

In the other hand, PSFs like *Aspergillus* and *Pencillium* are potent P- solubilizing fungi (Vassilev *et al*. 2007). PSF gave significantly superior (by 12.6%) grain yield than the control alone by increasing solubility of the unavailable P forms in soil (Kapri and Tewari, 2010).

Phosphate absorbers/ Vesicular Arbuscular Mycorrhiza (VAM)

VAM fungi are mycorrhizal species of fungus that live in the roots of different higher-order plants. They develop a symbiotic relationship with the plants in the roots of these plants. This type of fungus can penetrate and enter the cortical cells of vascular tissues of plants and form an arbuscule. The prime features that help to determine this fungus are its vesicular or arbuscule formation. VAM fungi infect and spread inside the root. They possess specialised structures known as vesicles and arbuscules (Wahane *et al.* 2020). The prime function of this fungus is to capture important nutrients from the soil such as sulphur, nitrogen, phosphorus, and other micronutrients for the host plants. The host plants, on the other hand, provide nutrition by performing photosynthesis. The fungal hyphae may extend the root lengths 100-fold.

Plant growth promoting rhizobacteria (PGPR)

These organisms represent a wide range of soil bacteria which stimulates the growth of their host plants when grown in association with them (Wahane *et al.* 2020). PGPR inoculants stimulate growth by suppressing plant diseases, improving nutrient acquisition, and producing phytohormones. The major phytohormones that PGPR produces includes indole acetic acid, cytokinin, gibberellins etc. and they also produce ethylene production inhibitors. PGPR are also divided into iPGPR and ePGPR.

Zinc solubilizers

The N fixing microorganisms as well as P solubilizers only supply major nutrients for the plants but a host of microorganism that can transform micronutrients are there in soil which can be used as bio-fertilizers to supply micronutrients like zinc, iron, copper etc. Zinc applied to submerged soil conditions has a poor fate; only 1-4% of the total zinc available is utilized by the crop, and 75% of it is converted into different mineral fractions (Zn-fixation), which are not available to the plant. The zinc in the soil can be solubilized by microorganisms *viz*., *B. subtilis, T. thioxidans* and *Saccharomyces sp.* (Raj, 2007). Thus, the biofertilizers prepared from these microorganisms are termed as Zn solubilizers.

Liquid biofertilizers

These are the particular category of biofertilizers which contains living or dormant microbes (bacteria, fungi, algae, actinomycetes etc.) alone or in combination which help in fixing atmospheric nitrogen or solubilizers of different soil nutrients for ensuring crop growth and productivity. Longer shelf life (18–24 months), no contamination, easy handling and application of ingredients which improve growth and survival of the microbial strains are the major characteristics which makes liquid bio formulations more attractive in nature (Surendra Gopal and Baby, 2016). Generally, liquid biofertilizers contain 10–40% microbial organisms, 1–3% suspender ingredient, 1–5% dispersant, 3–8% surfactant and 35–65% carrier liquid (Yadav and Chandra, 2014).

Liquid bio formulations can be classified as the following types: suspension concentrates, oil-miscible flowable concentrate, ultralow volume suspension and oil dispersion (Mishra and Arora, 2016). Sucrose, glycerol, gum arabic, polyvinylpyrrolidone (PVP) addition may contribute to the improvement of survivability of microorganisms in liquid formulations (Kaur *et al*., 2018).

Quality of biofertilizers

In addition to influencing the acceptance and progress of a whole biofertilizer industry, the quality of the biofertilizers is a parameter influencing not only the response of farmers, but also their perceptions (Sethi and Adhikary, 2012). The quality and standard of biofertilizers can be better regulated in popularized countries. Standard quality parameters regarding bio formulations are established in India for seven parameters: the physical form, the minimum count of viable cells, the contamination level, the particle size of carrier materials, the water content, pH, and the efficiency (Macik *et al*., 2020). The Indian government sets standards for four types of microorganisms: *Rhizobium* sp., *Azotobacter* sp., *Azospirillum* sp., phosphate solubilizing bacteria and mycorrhizal plants.

Methods of biofertilizers application

Biofertilizers can be easily applied on seedlings, seed as well as directly into the soil for improving soil productivity and crop growth. Based on inoculant characteristics, crop type, environmental conditions, and farmer's background, each application technique has certain advantages and disadvantages (Mahmood *et al.* 2016). However, some precautions before application of biofertilizers in the field are necessary for improving their efficacy and rate of nutrient supply to the targeted place like direct exposure to sunlight and keeping used solution overnight is not good before application. Some improved methods of bio formulations application are as follows:

Seed treatment: Because of its simplicity and small amount of product required for inoculation, seed treatment remains the most popular method of applying biofertilizers (Asif *et al.* 2018). A variety of adhesives are used in order to coat each seed with an appropriate amount of microorganisms, including gum arabic, carboxymethyl cellulose, sucrose solutions, vegetable oils and other non-toxic products (Bashan *et al.* 2014). 25% solution of molasses or 1% milk powder to the suspension needs to be added if adhesives are not present with biofertilizers while application (Macik *et al.* 2020). A variety of bacteria can be used for seed treatment, including *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphorus solubilizing microorganisms (PSM) etc. For seed treatment, the seeds are uniformly mixed in the slurry of inoculant and then shade dried for 30 minutes. The shade dried seed are to be sown within 24 hours. One packet of the inoculant (200 g) is sufficient to treat 10 kg of seeds.

Soil inoculation: When a huge population of microbial strain is introduced in soil, the major recommendation is based on soil inoculation of biofertilizers. The carrier material in this technique is typically granules (0.5–1.5mm) of peat, perlite, talcum powder or soil aggregates (Macik *et al.* 2020). The soil inoculation enhances chance of seed contact with the higher concentration of biofertilizers in comparison with seed treatment. Using soil treatment techniques allow inoculants to be applied at the right place and at the right rate, while protecting them from the harmful effects of pesticides and fungicides (Macik *et al.* 2020).

Seedling root dipping: This method is useful for transplanted crops. Two packets of the inoculant

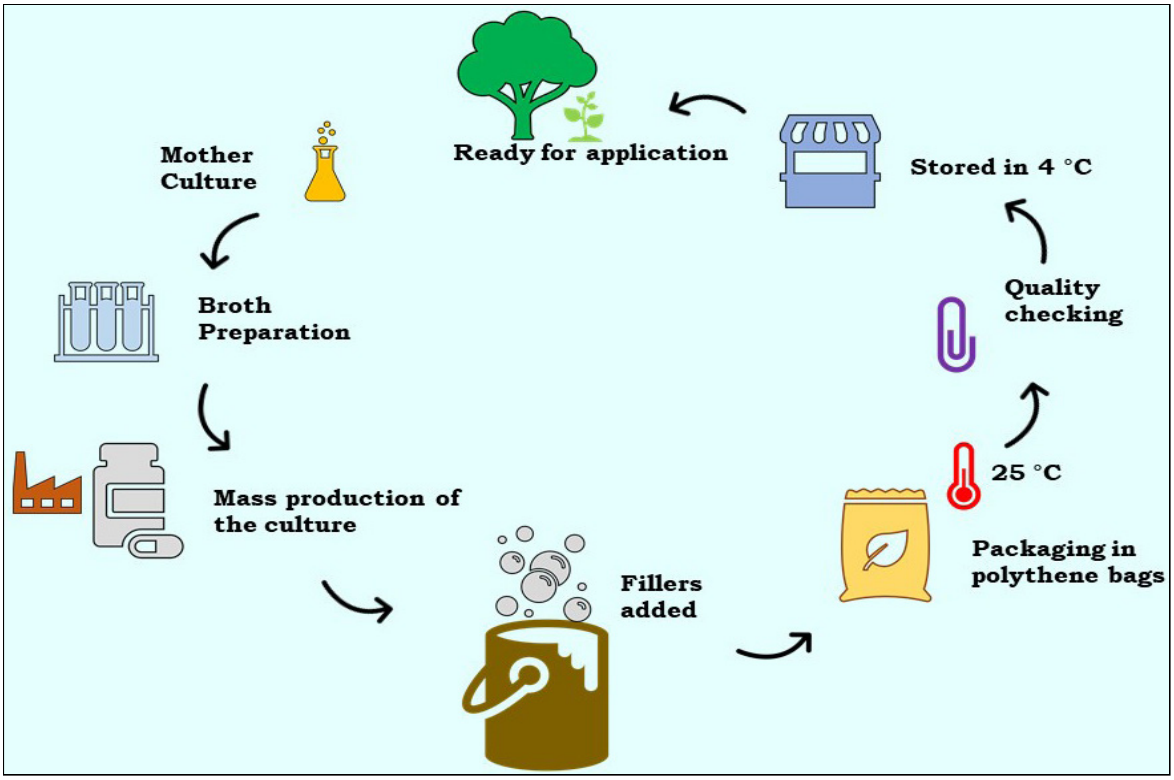

Fig. 2: Schematic Diagram on Production technology of Biofertilizers

are mixed in 40 litres of water. The root portion of the seedling is dipped into the mixture for 5 to 10 minutes and then transplanted.

Foliar application: It is possible to apply liquid biofertilizers through fertigation or foliar application to suitable crops.

Main field application: Four packets of the bio inoculant are thoroughly mixed with 20 kg of dried and powdered farm yard manure and then broadcasted in the main field just before transplanting (Wahane *et al.* 2020).

Future prospect of biofertilizers

The use of biofertilizers is an eco-friendly, biological approach towards sustainable agriculture. Agricultural crops are grown under diversified environmental conditions including wide ranges of temperature, rainfall, soil type and crop variety. So, it is a huge task to provide sufficient growth and development of the crops ensuring profitable return in a sustainable way. Actually, excessive amount of chemical fertilizers application by the farmers during intensive cultivation leads to environmental degredation and health hazards also. Thus, major focus should be on reducing inorganic fertilizer applications significantly to avoid further pollution problems through the development of bio-fertilizers. Selection of multifunctional and effective biofertilizers, agronomic as well as economic evaluation of biofertilizers, proper implementation of quality control mechanism and Bio Fertilizer Act are the major research areas which needs to be focused immediately. A conjugation of gold, aluminium, and silver nanoparticles will contribute to extending the release of PGPR to target cells by encapsulating nano biofertilizers (Gupta *et al.* 2021).

CONCLUSION

Supply of essential plant nutrients in soil is very much necessary for ensuring proper growth and development of different crops. Biofertilizers can boost the agricultural economy in a natural and eco-friendly manner which will ultimately help in maintaining environmental sustainability. Bio-fertilizers would be the viable option for farmers to increase productivity per unit area in organic farming for an era of prosperity and clean environment. These formulations hold a promising place under 'Integrated Plant Nutrient System' (IPNS) as they have the ability to transform nutritionally important elements from non-usable to plant assimilable forms without any detrimental effects. With today's changing agricultural practices, biofertilizers are gaining huge importance at national level. With respect to cost and environmental hazards, much dependence on chemical fertilizers is not practicable for longer period of time. In this context, biofertilizers can be a viable and productive option. Proper dissemination of technologies related to application of different kind of biofertilizers has significant importance for boosting the future economy.

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