Components, Mechanisms of Action, Success Under Greenhouse and Field Condition, Market Availability, Formulation and Inoculants Development on Biofertilizer

Daniel Yimer* and Tariku Abena

Department Ethiopian Institute of Agricultural Research (EIAR), National Agricultural Biotechnology Research Center (NABRC), Ethiopia

Received: December 28, 2018; Published: January 02, 2019

*Corresponding author: Daniel Yimer, Department Ethiopian Institute of Agricultural Research (EIAR), National Agricultural Biotechnology Research Center (NABRC), Ethiopia

Abstract

A bio-fertilizer is a modernized form of organic fertilizer into which beneficial microorganisms have been incorporated. This review mainly focuses on components, mechanisms, market availability on Biofertilizer. Nitrogen fixers, potassium solubilizers, phosphorus solubilizer and phosphorus mobilizers that are applied exclusively or in combination with fungi are the components of Biofertilizer. Various types of microbial cultures and inoculants are available on the market today and these have rapidly increased because of the advances in technology. There is a success to improve mineral uptake, release minerals from soil and organic matter, enhance plant hormone production, induce systemic resistance mechanisms, and induced root systems under greenhouse and field condition.

Abbreviations: EIAR: Institute of Agricultural Research; NABRC: National Agricultural Biotechnology Research Center; CMC: Cattle manure compost; ACC: aminocyclopropane-1-carboxylate; IAA: Indol acetic acid; PSB: phosphate-solubilizing bacteria; BNF: biological N₂ fixation; N: Nitrogen; VAM: Vesicular Arbuscular Mycorrhiza

Introduction

The utilization of synthetic fertilizers is a reason for air and ground water pollution as a result of eutrophication of water bodies [1]. As reported by [2], the practice of using chemical fertilizers and pesticides accelerates soil acidification, weakens the roots of plants as a result plants be susceptible to different diseases. The Negative effects posed to soil by the application of chemical fertilizers obligated human being to search for an alternative fertilizer the so-called biofertilizer to increase soil fertility and crop production in sustainable farming. These biofertilizers are essentially the microbial inoculants of living cells which aid in nutrient assimilation through the process of colonization, mobilization or solubilisation of nutrients. These biofertilizers that contain beneficial microorganisms accelerate and improve plant growth and protect plants from pests and diseases [3]. Biofertilizers would have the key role in productivity and sustainability of soil and also protect the environment as eco-friendly and cost-effective inputs for the farmers [4].

The commercial history of bio-fertilizer began with the launch of “Nitragin” by Nobbe and Hilther in 1895. This was followed by the discovery of Azotobacter and then Blue-green algae and a host of other microorganisms which are being used till date as bio-fertilizer [5]. Biofertilizers keep the soil environment rich in all kinds of macro and micro nutrients via nitrogen fixation, phosphate and potassium solubilisation or mineralization, release of plant growth regulating substances, production of antibiotics and biodegradation of organic matter in the soil [6].

Components of Biofertilizer

A bio-fertilizer is a modernized form of organic fertilizer into which beneficial microorganisms have been incorporated. In a broad sense, the term bio-fertilizer may referred as all organic resources that utilized for plant growth that are rendered in available form for plant absorption through microorganisms or plant associations or interactions [4]. The bio-fertilizers components include: nitrogen fixers, potassium solubilizers, phosphorus solubilizer...
and phosphorus mobilizers, that are applied exclusively or in combination with fungi. Most of the bacteria used in bio-fertilizers have close relationship with plant roots. Rhizobacterium has symbiotic interaction with legume roots, and Rhizobacteria inhabit root surfaces or rhizosphere soil [4]. The phosphor microorganisms mainly bacteria and fungi make insoluble phosphorus available to the plants.

Several soil bacteria and few species of fungi possess the ability to covert insoluble phosphate in soil into soluble forms by secreting organic acids. These acids lower the soil pH and bring about the dissolution of bound forms of phosphate. While Rhizobium, blue-green algae, and Azolla are crop specific, bioinoculants such as Azotobacter, Azospirillum, phosphorus solubilizing bacteria (PSB), and Vesicular Arbuscular Mycorrhiza (VAM) could be regarded as broad-spectrum bio-fertilizers. VAM are fungi that are found associated with majority of agricultural crops and enhanced accumulation of plant nutrients. Reports show that VAM stimulate plant by physiological effects or by minimizing the severity of diseases caused by soil pathogens. Examples of free-living nitrogen fixing bacteria are obligate anaerobes Clostridium pasteurinum obligate aerobes, facultative anaerobes, photosynthetic bacteria Rhodobacter; cyanobacteria (Azotobacter), and some Methanogens. The most commonly used potassium solubilizer is Bacillus mucilaginous, while phosphorus solubilizers are Bacillus megaterium, Bacillus circulans, Bacillus subtilis and Pseudomonas striata.

Mechanisms of Plant Growth Promotion

According to [7], PGPR mediated plant growth promotion occurs by the alteration of the whole microbial community in rhizosphere niche through the production of various substances. Generally, PGPR promote plant growth directly by either facilitating resource acquisition (nitrogen, phosphorus and essential minerals) or modulating plant hormone levels, or indirectly by decreasing the inhibitory effects of various pathogens on plant growth and development in the forms of biocontrol agents [8].

Direct Mechanisms

Nitrogen Fixation: Nitrogen (N) is the most vital nutrient for plant growth and productivity. Since the plants have no ability to utilize the atmospheric \( N_2 \) it converted into plant-utilizable forms by biological N fixation (BNF) which changes nitrogen to ammonia by nitrogen fixing microorganisms using a complex enzyme system known as nitrogenase [9]. Biological nitrogen fixation occurs, generally at mild temperatures, by nitrogen fixing microorganisms, which are widely distributed in nature [10]. Furthermore, BNF represents an economically beneficial and environmentally sound alternative to chemical fertilizers [11]. Nitrogen fixing organisms are generally categorized as (a) symbiotic N\(_2\) fixing bacteria including members of the family rhizobiaceae which forms symbiosis with leguminous plants (e.g. rhizobia) [12,13] and non-leguminous trees (e.g. Frankia) and (b) non-symbiotic (free living, associative and endophytes) nitrogen fixing forms such as cyanobacteria (Anabaena, Nostoc), Azospirillum, Azotobacter; Gluconacetobacter diazotrophicus and Azocarbus etc [14]. However, non-symbiotic nitrogen fixing bacteria provide only a small amount of the fixed nitrogen that the bacterially-associated host plant requires [8]. Symbiotic nitrogen fixing rhizobia within the rhizobiaceae family (\( \alpha \)-proteobacteria) infect and establish symbiotic relationship with the roots of leguminous plants. The establishment of the symbiosis involves a complex interplay between host and symbiont [15] resulting in the formation of the nodules wherein the rhizobia colonize as intracellular symbionts. Plant growth-promoting rhizobacteria that fix \( N_2 \) in non-leguminous plants are also called as diazotrophs capable of forming a non-obligate interaction with the host plants [8]. The process of \( N_2 \) fixation is carried out by a complex enzyme, the nitrogenase complex [9]. Most biological nitrogen fixation is carried out by the activity of the molybdenum nitrogenase, which is found in all diazotrophs [16].

Phosphate Solubilization: Majority of Phosphorus (P) in the soil are insoluble forms and this causes shortage of the availability of P because plants absorb it only in two soluble forms, the monobasic \( \left( H_2PO_4^- \right) \) and the diabasic \( \left( HPO_4^{2-} \right) \) ions [14]. To overcome the P deficiency in soils, there are frequent applications of phosphatic fertilizers in agricultural fields. Plants absorb fewer amounts of applied phosphatic fertilizers and the rest is rapidly converted into insoluble complexes in the soil [17]. But regular application of phosphate fertilizers is not only costly but is also environmentally undesirable. This has led to search for rhizosphere, phosphate-solubilizing bacteria (PSB) that are considered as promising biofertilizers since they can supply plants with P from sources otherwise poorly available by various mechanisms [18]. bacterial genera like Azotobacter; Bacillus, Beijerinkiia, Burkholderia, Enterobacter, Erwinia, flavobacterium, Microbacterium, Pseudomonas, Rhizobium and Serratia are reported as the most significant phosphate solubilizing bacteria [14].

Typically, the solubilization of inorganic phosphorus occurs as a consequence of the action of low molecular weight organic acids which are synthesized by various soil bacteria [18]. Conversely, the mineralization of organic phosphorus occurs through the synthesis of a variety of different phosphates, catalyzing the hydrolysis of phosphoric esters [8]. Importantly, phosphate solubilization and mineralization can coexist in the same bacterial strain. Besides providing P to the plants, the phosphate solubilizing bacteria also augment the growth of plants by stimulating the efficiency of BNF, enhancing the availability of other trace elements by synthesizing important plant growth promoting substances [19,18].

Siderophore Production

Iron is a vital nutrient for almost all forms of life. All microorganisms known hitherto, with the exception of certain lactobacilli, essentially require iron [20]. The existence iron in the form of Fe\(^{3+}\) at aerobic environment enables it to form insoluble hydroxides and oxyhydroxides, thus making it generally inaccessible to both plants and microorganisms [21]. Commonly, bacteria acquire iron by the secretion of low-molecular mass iron chelators referred to as siderophores which have high association constants for complexing iron. Most of the siderophores are water-soluble and can be divided into extracellular siderophores...
and intracellular siderophores. In both Gram-negative and Gram-positive rhizobacteria, iron (Fe$^{3+}$) in Fe$^{3+}$-siderophore complex on bacterial membrane is reduced to Fe$^{2+}$ which is further released into the cell from the siderophore via a gating mechanism linking the inner and outer membranes. During this reduction process, the siderophore may be destroyed/recycled [21].

Thus, siderophores act as solubilizing agents for iron from minerals or organic compounds under conditions of iron limitation [22]. Not only iron, siderophores also form stable complexes with other heavy metals that are of environmental concern, such as Al, Cd, Cu, Ga, In, Pb and Zn, as well as with radionuclides including U and Np [23]. Binding of the siderophore to a metal increases the soluble metal concentration [21]. Hence, bacterial siderophores help to alleviate the stresses imposed on plants by high soil levels of heavy metals. Plants assimilate iron from bacterial siderophores by means of different mechanisms, for instance, chelate and release of iron, the direct uptake of siderophore-Fe complexes, or by a ligand exchange reaction [24]. Numerous studies of the plant growth promotion vis-à-vis siderophore-mediated Fe-uptake as a result of siderophore producing rhizobacterial inoculations have been reported [21].

**Phyt hormon e Production**

Microbial synthesis of the phytohormone auxin (indole-3-acetic acid/IAA) has been known for a long time. Indol acetic acid (IAA) secreted by rhizobacteria interferes with the many plant developmental processes because the endogenous pool of plant IAA may be changed by acquiring IAA that has been secreted by soil bacteria [8,25]. Since, IAA acts as a reciprocal signaling molecule affecting gene expression in several microorganisms, it plays a very important role in rhizobacteria-plant interactions [25]. Moreover, down-regulation of IAA as signaling is associated with the plant defense mechanisms against a number of phytopathogenic bacteria as evidenced in enhanced susceptibility of plants to the bacterial pathogen by exogenous application of IAA or IAA produced by the pathogen [26]. IAA has been implicated in virtually every aspect of plant growth and development, as well as defense responses.

This diversity of function is reflected by the extraordinary complexity of IAA biosynthetic, transport and signaling pathways [27]. The bacterial IAA increases root surface area and length, and thereby provides the plant greater access to soil nutrients. Also, rhizobacterial IAA loosens plant cell walls and as a result facilitates an increasing amount of root exudation that provides additional nutrients to support the growth of rhizosphere bacteria [8]. Thus, rhizobacterial IAA is identified as an effector molecule in plant-microbe interactions, both in pathogenesis and phytostimulation [26]. An important molecule that alters the level of IAA synthesis is the amino acid tryptophan, identified as the main precursor for IAA and thus plays a role in modulating the level of IAA biosynthesis [18]. Strangely, tryptophan stimulates IAA production while, anthranilate, a precursor for tryptophan, reduces IAA synthesis. By this mechanism, IAA biosynthesis is fine-tuned because tryptophan inhibits anthranilate formation by a negative feedback regulation on the anthranilate synthase, resulting in an indirect induction of IAA production [25].

However, supplementation of culture media with tryptophan increases the IAA production by most of the rhizobacteria [26]. Biosynthesis of tryptophan starts from the metabolic node chorismate in a five-step reaction encoded by the triip genes. The branch point compound chorismate is synthesized starting from phosphoenolpyruvate and erythrose-4-phosphate in the shikimate pathway, a common pathway for the biosynthesis of aromatic amino acids and many secondary metabolites [26].

**1-Aminocyclopropane-1-Carboxylate (ACC) Deaminase**

Plant growth promoting rhizobacteria which possess the enzyme, 1-aminocyclopropane-1-carboxylate (ACC) deaminase, facilitate plant growth and development by decreasing ethylene levels, inducing salt tolerance and reducing drought stress in plants. Currently, bacterial strains exhibiting ACC deaminase activity have been identified in a wide range of genera such as Acinetobacter, Achromobacter, Agrobacterium, Alcaligenes, Azospirillum, Bacillus, Burkholderia, Enterobacter, Pseudomonas, Ralstonia, Serratia and Rhizobium etc. Such rhizobacteria take up the ethylene precursor ACC and convert it into 2-oxybutanooate and NH3. Several forms of stress are relieved by ACC deaminase producers, such as effects of phytopathogenic microorganisms (viruses, bacteria, and fungi etc.), and resistance to stress from polyaromatic hydrocarbons, heavy metals, radiation, wounding, insect predation, high salt concentration, draft, extremes of temperature, high light intensity, and flooding [8]. As a result, the major noticeable effects of seed/root inoculation with ACC deaminase-producing rhizobacteria are the plant root elongation, promotion of shoot growth, and enhancement in rhizobial nodulation and N, P and K uptake as well as mycorrhizal colonization in various crops [8].

**Indirect Mechanisms**

The application of microorganisms to control diseases, which is a form of biological control, is an environment-friendly approach. The major indirect mechanism of plant growth promotion in rhizobacteria is through acting as biocontrol agents [8]. In general, competition for nutrients, niche exclusion, induced systemic resistance and antifungal metabolites production are the chief modes of biocontrol activity in PGPR. Many rhizobacteria have been reported to produce antifungal metabolites like, HCN, phenazines, pyrrolnitrin, 2,4-diacetylphloroglucinol, pyoluteorin, viscosinamide and tensin [14]. Interaction of some rhizobacteria with the plant roots can result in plant resistance against some pathogenic bacteria, fungi, and viruses. This phenomenon is called induced systemic resistance (ISR).

**Some Fungal Biofertilitizers Available On The Market**

The production of commercial mycorrhizal inoculum has evolved considerably in recent years [28]. There are various types of microbial cultures and inoculants available on the market today and these have rapidly increased because of the advances in technology [29]. There are various companies worldwide marketing mycorrhiza products [30]. There are also many Trichoderma products as fungal
biofertilizers available in the market that are commercialized by different companies worldwide. Some of them are Trichoderma Harzianum, Trichoderma hamatum by NovaScience Co. Ltd, [30]. And also, Penicillium bilaiae has been formulated as a commercial product named Jumpstart® and was released to the market as a [31].

Success under Greenhouse and Field Condition
Trichoderma species improve mineral uptake, release minerals from soil and organic matter, enhance plant hormone production, induce systemic resistance mechanisms, and induced root systems in hydroponics [32]. For these reasons Trichoderma species are known as plant growth promoting fungi [33] or are increasing plant growth (biofertilization) [34]. Trichoderma species have therefore, successfully been used as biofungicides and biofertilizers in greenhouse and field plant production [35]. According to [36] study result; Azospirillum sp. a very common PGPR, have showed the same features under greenhouse and field condition.

Formulation and Inoculants Development
In inoculant formulation and development that involves an effective bacterial strain can determine the success or failure of a biological agent [37]. A microorganism which is functioning optimally under laboratory conditions might not be able to produce equivalent results under field conditions after formulation production. Once an inoculants formulation which works in situ has been developed, it must be refined to allow for the sophistication of the end-user [38]. It is imperative that the formulation remain stable during production, distribution, storage, and transportation, irrespective of whether product is new or improved. The formulation produced should also be easy to handle and apply by the end users, it should be delivered to the target site in the most appropriate manner and form, it should be able to protect the agent from various harmful environmental factors and should be able to maintain or enhance activity of the organism in the field [39]. Another important consideration is the cost-effectiveness of the formulation it should not put much pressure on the end users financially [40].

Talc Formulation
Talc or magnesiam silicate \((\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_2)\), occurred in the form of inert and available as raw material from soapstone industries used as a carrier for formulation development. The potential of talc to be used as a carrier was demonstrated by [41]. Rhizobacteria could survive in talc for 2 months. The Fluorescent Pseudomonads after storage for two months in talc mixture with 20% xanthum gum at 4°C did not decline in no. also, there are different research reports that show the survival of bacterial strains in talc [42], [43] demonstrated that application of talc-based bioformulation of \(P.\) fluorescens Pf1 consistently reduced the blister blight disease and increased the yield on tea plants. Further, seed treatment, soil application and seedling dip of talc-based bioformulation of Pf1 effectively reduced the sheath rot disease on rice plants under glasshouse and field conditions [44].

Press Mud Formulation
Press mud is a by-product from sugar industries that is rich in micronutrients and can minimize the utilization of synthetic fertilizers. It supplies a right type of conditions to bacteria to undertake nitrogen fixation and phosphate solubilisation. The fertilizer produced should fulfill requirements like, being free from all pathogens, harmful bacteria, weeds, easy to handle, to pack and transport. As reported by [45] the biocompost contains 25-30% organic carbon, 1.2-2.0% nitrogen, 1.5-2.0% phosphorous and 2.5-3.0% potash. This carrier increases the survival of Azospirillum spp. by providing suitable conditions in comparison to lignite, [46].

Vermiculite Formulation
Vermiculite is a naturally occurring layer silicate mineral \([(\text{Si}_3\text{Al})\text{Mg}_{(\text{OH})_2}]\text{Mg}_0.5\text{n H}_2\text{O})\) [47] and could also be considered as possible carriers, especially when the process of their production involves the use of specific selected strains. For example, increased amount of N and P availability in the final product can be achieved by adding N-fixing and P-solubilizing bacteria to a vermicompost [48]. Characteristics like enough space for microbial proliferation, superior aeration due to its multilamellate structure, widely availability and less cost [49], make vermiculite attractive material for the inoculant production [50].

Peat Formulations
Peat formulations have been the carriers of choice and are the most commonly used in the rhizobia inoculation industry [51]. Peat is widely available and has a long history of field trials, therefore commonly used as a carrier for PGPR, particularly for rhizobia inoculants. Peat inoculants applied to the seed as slurry is the most commonly -used method to inoculate grain legumes with rhizobia (e.g. Bradyrhizobium spp., Mesorhizobium spp., Rhizobium spp. etc.). Peat slurry inoculants are made using finely-milled peat that have been sterilised by gamma irradiation and these sterilised inoculants can support high concentrations of rhizobia, generally 109 –1010 cells/g-1 peat at manufacture [52].

Organic Residues
since using peat as a substrate is challenged with the increase in demand and rise in cost guided to the search of an alternative substrate which possess high quality and low cost [53]. Various studies have shown that organic residues such as urban solid wastes, sewage sludge, animal manure and dung, paper waste, pruning waste, spent mushroom and even green wastes, after proper composting, can be used with very good results as container growth substrates instead of peat [53,54]. Cattle manure compost (CMC) [55], freeze-dried cells [56] and lyophilized rhizobial cells [57] can also be used as an alternatives to peat.

Lignite Formulations
Alginate is the most commonly used substance for microbial cell encapsulation. It is a natural polymeric compound made up of D-mannuronic acid and L-glucuronic acid and is available from several bacteria (Pseudomonas and Azotobacter) [58]. Alginate
beads generally have a diameter of 2-3 mm, but microbeads with a size of 50 to 200 μm that can entrap up to 108 to 109 CFUg-1 have also been proposed [59]. The gel-like matrix with its catalytic ability allows the cells to remain viable for longer duration. Moreover, alginate beads entrap sufficient number of bacteria [60] which shows several advantages over free cell formulations like, it protects the bacteria from biotic stresses [61] and abiotic stresses such as the inhibitory effect of toxic compounds [62], enhanced survival and improved physiological activity. This technology was primarily used to encapsulate the plant-beneficial bacteria such as A. brasilense and P. fluorescens that were used to inoculate wheat plants under field conditions [63].

**Particles from Gas Saturated Solutions (PGSS)**

Is used based on the application of supercritical fluid properties. It is carried out at low temperatures and uses carbon dioxide as a supercritical fluid. The final product of the process is almost spherical particles that form a free-flowing powder which can be suspended in water. The possibilities of the PGSS process have already successfully been demonstrated for several solids and liquids [64].

**Bacterial Biofilms As A Possible Carrier**

Two types of biofilms are employed in that case: biofilms growing onto inert supports (charcoal, resin, concrete, clay brick, sand particles) in which biofilms grow all around the particles, and the size of the biofilm particles grows with time usually to several mm in diameter and biofilms that are formed as a result of aggregate formation also called granular biofilm which may take from several weeks to several months [65]. Wheat seedlings inoculated with biofilm-producing bacteria exhibited an increased yield in moderate saline soils [66].

**Bionanotechnology**

Applications which employ nanoparticles made of inorganic or organic materials could also provide new avenues for the development of carrier-based microbial inocula [67]. The use of nanoformulations may enhance the stability of biofertilizers and biostimulants with respect to desiccation, heat and UV inactivation.

**References**

1. Youssef MM A, Eissa MFM (2014) Biofertilizers and their role in management of plant parasitic nematodes: A review. Biotechnology Pharmaceutical Resource 5: 1-6.
2. Chun Li W, Shiuan Yuh C, Chiu Chung Y (2014) Present situation and future perspective of bio-fertilizer for environmentally friendly agriculture. Annual Reports p. 1-5.
3. El Yazeid AA, Abou Aly HA, Mady MA, Moussa SAM (2007) Enhancing growth, productivity and quality of squash plants using phosphate dissolving microorganisms (bio phosphor) combined with boron foliar spray. Res. J Agric Biol Sci 3: 274-286.
4. Khoros M, Yousef S (2012) Bacterial bio-fertilizers for sustainable crop production: Journal of Agricultural and Biological Science 7: 237-308.
5. Kribacho (2010) Fertilizer ratios, River blindness and abiotic stresses which shows several advantages over free bacteria [60].
6. Sinha RK, Valani D, Chauhan K (2014) Embarking on a second green revolution for sustainable agriculture by vermicomposting technology using earthworms. International Journal of Agricultural Health Safety 4: 50-64.
7. Klepper JW, Schrot MN (1981) Development of powder formulation of rhizobacteria for inoculation of potato seed pieces. Phytopathology 71: 590-592.
8. Glick BR (2012) Plant Growth-Promoting Bacteria: Mechanisms and Applications Hindawi Publishing Corporation, Scientificap. 15.
9. Kim J, Rees DC (1994) Nitrogenase and biological nitrogen fixation. Biochemistry 33: 389-397.
10. Raymond, J; Siebert JL, Staples Blankenship CR (2004) The natural history of nitrogen fixation. Mol. Biol Evol 21(3): 541-554.
11. Ladha JK, de Brujin, PJ, Malik KA (1997) Introduction: assessing opportunities for nitrogen fixation in rice-a frontier project. Plant and Soil 194(1-2): 1-10.
12. Ahemad M, Khan MS (2012) Effects of pesticides on plant growth promoting traits of *Mesorhizobium* strain MRC4 J Saudi Soc Agric Sci 11: 63-71.
13. Zahran HH (2001) Rhizobia from wild legumes: diversity, taxonomy, ecology, nitrogen fixation and biotechnology. J Biotechno 91(2-3): 143-153.
14. Bhattacharyya PN, Jha DK (2012) Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbiol Biotechnol 28(4): 1327-1350.
15. Giordano W, Hirsch AM (2004) The expression of *Maexpi*, a *Melilotus* albo expansin gene, is upregulated during the sweet clover- *Sinosorhizobium meliloti* interaction. Mol Plant Microbe Interact 17(6): 613-622.
16. Bishop PE, Jorringer RD (1990) Genetics and molecular biology of an alternative nitrogen fixation system. Plant Mol Biol 41: 109-125.
17. McKenzie RH, Roberts TL (1990) Soil and fertilizers phosphorus update. In: Proceedings of Alberta Soil Science Workshop Proceedings, Edmonton, Alberta pp. 84-104.
18. Zaaidi A, Khan MS, Ahemad M, Oves M (2009) Plant growth promotion by phosphate solubilizing bacteria Acta Microbiol Immunol Hung 56(3): 263-284.
19. Ahmad F, Ahmad I, Khan MS (2008) Screening of free-living rhizospheric bacteria for their multiple plant growth promoting activities. Microbiol Res 163(2): 173-181.
20. Neillands JB (1995) Siderophores: structure and function of microbial iron transport compounds. J Biol Chem 270: 26723-26726.
21. Rajkumar M, Ne A, Prasad MNV, Freitas H (2010) Potential of siderophore-producing bacteria for improving heavy metal phytotoxication. Trends Biotechnol 28: 142-149.
22. Indragandhi P, Anandham RM, Adhaiyan M, SaTM (2008) Characterization of plant growth-promoting traits of bacteria isolated from larval guts of diamondback moth Plutella xylostella (*Lepidoptera*: Plutellidae). Curr Microbiol 56(4): 327-33.
23. Neubauer U, Furrer G, Kayser A, Schulin R (2000) Siderophores, NTA, and citrate: potential soil amendments to enhance heavy metal mobility in phytoremediation. Int J Phytoremediation 2(4): 353-368.
24. Schmidt W (1999) Mechanisms and regulation of reduction-based iron uptake in plant. New Phytol 141: 1-2.
25. Spaepen, S, Vanderleyden J, Remans R (2007) Indole-3-acetic acid in microbial and microorganism-plant signaling. FEMS Microbiol Rev 31: 425-448.
26. Spaepen S, Vanderleyden J (2011) Axin and plant-microbe interactions Cold Spring Harb. Perspect. Biol 3(4): a001438.
27. Santner A, Calderon Villalobos LIA, Estelle M (2009) Plant hormones are versatile chemical regulators of plant growth. Nature Chem Biol 5(5): 301-307.
28. Douds DD, Gadkar JV, Adholeyan A (2000) Mass production of VAM fungus biofertilizer. In: Mycorrhizal Biology pp. 197-214.
29. Raja P (2006) Status of endomycorrhizal (AMF) biofertilizer in the global market. In: Handbook of Microbial Biofertilizers (Rai MK edn.), pp. 395-416.

30. Kaewchaisri S, Soytong K, Hyde KD (2009) Mycofungicides and fungal biofertilizers. Fungal Diversity 38: 25-50.

31. Burton EM, Knight SD (2005) Survival of Penicillium biliae inoculated on canola seed treated with Vitavax RS and Extender. Biology and Fertility of Soils 42: 54-59.

32. Yedidia I, Benhamou N, Chet I (1999) Induction of defense responses in cucumber plants (Cucumis sativus L.) by the biocontrol agent Trichoderma harzianum. Applied and Environmental Microbiology 65(3): 1061-1070.

33. Hyakumachi M, Kubota M (2004) Fungi as plant growth promoter and disease suppressor. In: Fungal Biotechnology in Agricultural, Food, and Environmental Applications (KA Dilip edn.), Basel, New York, USA, pp. 101-110.

34. Benitez T, Rincon MA, Limon MC, Codon CA (2004) Biocontrol mechanisms of Trichoderma. Int Microbiol 7(4): 249-260.

35. Vinale F, Svasithamparam K, Ghisalberti EL, Marra R, Woo SL, et al. (2008) Trichoderma plant pathogen interactions. Soil Biology & Biochemistry 40: 1-10.

36. Macario Bacilio, Manuel Moreno Legorreta, D Raúl Lopez Aguilar, Yoav Bashan (2017) Scaling from the growth chamber to the greenhouse to the field: Demonstration of diminishing effects of mitigation of salinity in peppers inoculated with plant growth-promoting bacteria and humic acids. Applied Soil Ecology 119: 327-338.

37. Bashan Y (1998) Inoculants of plant growth-promoting bacteria for use in agriculture Biotech Adv 16(4): 729-770.

38. Stephens JHG, Rask HM (2000) Inoculation production and formulation. Field Crops Res 65: 249-258.

39. Jones KA, Burges HD (1998) Technology of formulation and application. In: Formulation of microbial pesticides: beneficial microorganisms, nematodes and seed treatments. P 7-29.

40. Xavier IJ, Holloway G, Leggett M (2004) Development of rhizobacterial inoculants formulations. Online. Crop Manage 3(1).

41. Kloepper JW, Schroth MN (1981) Relationship of in vitro antibiosis of plant growth promoting rhizobacteria to plant growth and the displacement of root microflora. Phytopathology 71: 1020-1024.

42. Amer GA, Uthbede RS (2000) Development of formulations of biological agents for management of root rot of lettuce and cucumber. Can J Microbiol 46: 809-816.

43. Saravanakumar D, Harish S, Loganathan M, Vivekananthan R, Rajendran L, et al. (2007) Rhizobacterial bioformulation for the effective management of Macrophomina root rot in mungbean. Arch Phytopathol Plant Protect 40: 323-337.

44. Manikandan R, Saravanakumar D, Rajendran L, Raguchander T, Samiyappan R, et al. (2010) Standardization of liquid formulation of Pseudomonas fluorescens P11 for its efficacy against Fusarium wilt of tomato. Biol Control 54: 83-89.

45. Partha N, Sivabrahmam S V (2006) Recovery of chemicals from pressmud a sugar industry waste. Indian Chemical Engr 48: 161-163.

46. Muthukumarasamy R, Revathi G, Lakshminarasimhan C (1999) Diazotrophic associations in sugarcane cultivation in South India. Trop Agric 76: 171-178.

47. Bozolo A, Evans MR (2013) Efficacy of corn granulates as a top coat substrate component for seed germination as compared to vermiculite. Horttechnol 23: 114-118.

48. Vassileva M, Serrano M, Bravo V, Jurado E, Nikolaeva I et al. (2010) Multifunctional properties of phosphate-solubilizing microorganisms grown on agro-industrial wastes in fermentation and soil conditions. Appl Microbiol Biotechnol 85(5):1287-1299.

49. Meisinger AC (1984) Vermicult. In Bureau of Mines minerals yearbook, vol. 1. Superintendent of Documents, Government Printing Office, Washington, USA, p. 1-4.

50. Hemphill DD (1982) Anticrustant effects on soil mechanical resistance and seedling emergence. HortSci 17: 391-393.

51. Kaletje S, Keyevo F, Amir HG (2011) Influence of carrier materials and storage temperature on survivability of rhizobial inoculant. Asian J Plant Sci 10: 331-337.

52. Hartley EJ, Gemmell LG, Slatterly JF, Howesin GJ, Herridge DF, et al. (2005) Age of peat-based lupin and chickpea inoculants in relating to quality and efficacy. Austral J Exp Agr 45(3): 183-188.

53. Moral R, Paredes C, Bustamante MA, Egea FM, Bernal M, et al. (2009) Utilization of manure composts by high value crops: Safety and environmental challenges. Bioresour Technol 100(22): 545-5460.

54. Bustamante MA, Paredes C, Moral R, Aguilo E, Perez Murcia, et al. (2008) Composts from distillery wastes as peat substitutes for transplant production. Resour Conserv Recycl 52: 792-830.

55. Ho KJ, Kim KY, Kim HT, Kim CN, Umeda M, et al. (2008) Evaluation of maturuty parameters and heavy metal contents in composts made from animal manure. Waste Manage 28(5): 813-820.

56. McLlmes A, Date RA (1999) Improving survival of rhizobia on Stylesanthes and Desmanthus seed at high temperature. Australian Journal of Experimental Agriculture p. 3-4.

57. Caesar AJ, Burr TJ (1991) Effect of conditioning, betaine, and sucrose on survival of rhizobia in powder formulations. Appl Environ Microbiol 57: 169-172.

58. Hay ID, Rehman ZU, Ghafoor A, Rehm BHA (2010) Bacterial biosynthesis of alginites. J Chem Technol Biotechnol 85: 752-759.

59. Bashan Y, Luis AIPH, Bacilio LM (2002) Alginate microbeads as inoculant carriers for plant growth-promoting bacteria. Biol Fertil Soils 35(5): 359-368.

60. Zohar PC, Ritte E, Chernin L, Chet I, Nussinovitch A, et al. (2002) Preservation of chitinolytic Pantoea agglomerans in a viable form by cellular dried alginate-based carriers. Biotechnol Prog 18(6): 1133-1140.

61. Smit E, Wolters AC, Lee H, Trewors JT, Van Elsas JD, et al. (1996) Interaction between a genetically marked Pseudomonas fluorescens strain and bacteriophage øR2f in soil: Effects of nutrients, alginate encapsulation, and the wheat rhizosphere. Microb Ecol 31(2): 125-140.

62. Cassidy MB, Lee H, Trewors JT (1997) Survival and activity of lac-lux marked Pseudomonas aeruginosa U62Lr cells in encapsulated kcaragennan over 4 years at 48 ºC. J Microbiol Meth 30: 167-170.

63. Bashan Y (1986) Alginate beads as synthetic inoculants carriers for the slow release of bacteria that affect plant growth. Appl Microbiol 51(5): 1089-1098.

64. Cocero MJ, Martin A, Mattea F, Varona S (2009) Encapsulation and co-precipitation processes with supercritical fluids: fundamentals and applications. J Supercrit Fluid 47: 546-555.

65. Qureshi N, Ammos MA, Ezeji TC, Karcher, P, Maddo IS, et al. (2005) Biofilm reactors for industrial bioconversion process: employing potential of enhanced reaction rates. Microfb Cell Factories 4: 24.

66. Ashraf M, Hasnain S, Berge O, Mahmood T (2004) Inoculating wheat seedlings with exopolysaccharide-producing bacteria restricts sodium uptake and stimulates plant growth under salt stress. J Food Sci 40(3): 157-162.

67. Malusa E, Szapazt L, Cieslinska J (2012) Technologies for beneficial microorganisms inocula used as biofertilizers. T Sentific World J p. 12.
Cite this article: Daniel Y, Tariku A. Components, Mechanisms of Action, Success Under Greenhouse and Field Condition, Market Availability, Formulation and Inoculants Development on Biofertilizer. Biomed J Sci & Tech Res 12(4)-2019. BJSTR. MS.ID.002279. DOI: 10.26717/BJSTR.2019.12.002279.