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Plant Growth Promoting- Rhizobacteria (PGPR): Their Potential as Biofertilizer and Biopesticide Agents: A Review

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Authors' contributions

This work was carried out in collaboration between b oth authors. Aurthors Purnima and PS did the Preparation of manuscript. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Currently, world is dealing with the curse of pollution in agricultural fields due to rampant use of chemical fertilizers and pesticides. These agrochemicals cause great harm to human health when consumed in food (e.g. cancer and thyroid) and also to environment (reduce fertility of soil etc) when released out there. Hence, there is an intense demand of such biological agents (e.g. microorganisms) which could partially or fully replace these agrochemicals. Plant growth promoting rhizobacteria could come to the rescue and would help to escalate growth and productivity of plants in an environment friendly way.

Plant growth promoting rhizobacteria occurs in/around plant roots; enhance its growth and development, directly or indirectly by depleting or secreting several regulative chemical compounds. The direct method by which plant growth promoting rhizobacteria escalates plant growth is, by making easy availability of phosphorus, nitrogen and other essential minerals as well as by

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controlling quantity of plant hormones whereas indirect methods include, reducing impeding effects of pathogenic microbes (e.g. by siderophore production) which adversely affect development and growth of plants. There are several studies which registers that plant growth promoting rhizobacteria escalates health and yield of several plant species, both in normal and adverse situations. Therefore, plant growth promoting rhizobacteria could possibly lower the reliability of world on harmful agricultural chemicals which disturbs ecosystem. They can be used as a potent biofertilizers and biopesticides whose market demand is also hiking globally, currently as reported here.

Keywords: PGPR; biofertilizers; biopesticides.

1. INTRODUCTION

1.1 PGPR: An efficient Soil Restoring Agents

Soil restoration is an important phenomenon needed to replenish the eroded and degraded soil, as soil erosion reduces crop yield. It has been determined, out of the world's 5.2 billion hectare of dry land agriculture; 3.6 hectare is affected by the problem of soil erosion and degradation. Several biotic and abiotic factors together affect soil fertility and attributes [1]. In contaminated soil, beneficial microorganisms and nutrients concentration is low, however, such soil when inoculated with PGPR, they improve physicochemical and biological features of soil [2,3]. The best environmental friendly method to remediate the soil pollutants includes microbial application, which is an efficient agent for this due to their high sensitivity, tolerance and sequestration of soil pollutants [4,5]. It has been found that PGPR when applied to polluted land they escalate plant growth naturally and remove pollutants simultaneously [6]. This bioremediation technology (rhizoremediation) is now being used for the remediation of pesticides, heavy metals, polyaromatic hydrocarbons and other toxic wastes [7,8,9]. Success of rhizoremediation depends upon, pollutant type, their bioavailability, plant variety, environmental conditions and microbial activity [10]. Bioremediation of palm oil mill effluent contaminated soil and its effect on growth of *Amaranthus hybridus* L. was analysed, and it was found that application of microbes (bioinoculant) showed positive effect on its growth [11]. PGPR are also involved in remediation of petroleum products in soil along with the growth of several crops, ryegrass, cotton, alfalfa and tall fescue [12]. Hence, there are numerous PGPR which can be applied for remediating soil pollutants and escalating plant productivity.

The breakthrough in this review is that PGPR which has been introduced here as biofertilizers and biopesticides, whose global demand is hiking everyday has some other attributes too. PGPR has also been used, as denoted here, as an agent which help to increase growth of plant in adverse conditions, viz, saline stressed soil and heavy metal contaminated soil. Little has been explored in this aspect. Such PGPR would then help in bioremediation of harmful molecules and help plant to combat with stressed soil conditions and show good growth as well.

2. PGPR (BIOFERTILIZERS): AGENTS OF SUSTAINABLE AGRICULTURE

In a report of Ahmad et al*.* [13], 72 bacterial isolates were obtained from rhizospheric regions of legumes. Among 72 isolates only 11 showed multiple plant growth promoting activities. They were subjected to biochemical characterization and specific PGPR trait tests (production of IAA, ammonia production, synthesis of HCN, phosphate solubilization, siderophore production and antifungal activity). In this case *Azotobacter fluorescent, Pseudomonas* and *Mesorhizobium* produced 80% IAA and *Bacillus* only 20%. Phosphate solubilization was found in *Bacillus* (80%), *Azotobacter* (74.47%), *Pseudomonas* (55.56%) and *Mesorhizobium* (16.67%). Siderophore and antifungal activity was shown by all the isolates (10-12.77%) except for *Mesorhizobium.* 11 bacterial isolates which were separated from 72 isolates were, 7 *Azotobacter,* 3 *Pseudomonas* and 1 *Bacillus*. IAA production was highest in case of *Pseudomonas* (at all concentration of tryptophan, 50-500 microg/ml). Antagonistic activity was analysed against *Aspergillus, Fusarium* and *Rhizoctonia bataticola* on Muller-Hinton medium and results showed that *Azotobacter* (isolates AZT (3), AZT (13) and AZT (23)), *Pseudomonas* (Ps (5)) and *Bacillus* (B (1)) antagonized *Aspergillus,* one or more species of *Fusarium* and *Rhizoctonia bataticola.*

In a study of Chowdhury et al. [14], effects of isolated PGPR on root and shoot length, seed germination and chlorophyll content of Spinach (*Spinacia oleracea* L.) was analysed. PGPR were isolated from rhizospheric regions of cabbage and paddy. Serial dilution spread plate method (NAM plates) along with biochemical characterizations (Amylase test, Catalase test, Gelatin hydrolysis test etc) and PGPR specific tests (Phosphate solubilization test, IAA production test, HCN production test and Ammonia production test) were used for PGPR isolation and identification. After this, 4 PGPR designated as SIN1, SIN2, SIN3 and SIN4 (SIN= Sample Isolate Nadia) were selected for further study. Seeds of spinach inoculated with 4 PGPR, singly and in combination were sowed in pots in Kalyani University garden. Results showed that shoot length of spinach seedlings was highest (Mean shoot length >3.5 cm) in seeds inoculated with SIN1 and root length was maximum (Mean root length >2.5 cm) in seeds of bacterial treatment, SIN1+SIN2+SIN3+SIN4. The effect of SIN1 on chlorophyll content was highest (>30 mg/gm). These outcomes showed that such PGPR could be a better substitute of chemical fertilizers, not only in spinach but also in other plants if analyzed further.

2.1 PGPR as Phosphate Solubilizers

Mineral phosphate solubilizing ability was analysed by Linu et al. [15] on Pikovskaya's and National Botanical Research Institute's Phosphate (NBRIP) medium. In this study, 81 phosphate solubilizing bacteria were obtained from rhizospheric area. It was concluded that most of the bacterial isolates has potent ability to solubilize hydroxyapatite in case of liquid as well as in solid media. Among these, 2 isolates showed increased solubilization in Pikovaskaya's liquid culture, of Tricalcium Phosphate. In earlier case, in liquid medium, solubilization was associated with decrease in pH of that medium. Later, 2 bacterial strains were identified on the basis of their phenotype, 16S rDNA typing, complete cell Fatty Acid Methyl Ester (FAME) profiles and Carbon Substrate Utilization (SU) using Biolog GN2 plates. And that 2 bacterial isolates were namely, *Gluconacetobacter* sp. and *Burkholderia* sp. Later, seed treatment with these 2 bacterial isolates in cowpea, enhanced root and shoot biomass, nodulation, yield of straw and grain and also absorption of minerals such as nitrogen and phosphorus. These also elevated enzyme activity of phosphatase, dehydrogenase and available content of phosphate in soil. Out of all, highest yield was due to *Burkholderia* sp.

According to Rodriguez and Fraga [16], phosphate uptake and crop yield has been enhanced when PGPR such as phosphate solubilizing bacteria are applied. Some examples of effective phosphate solubilizing strains are, *Pseudomonas, Bacillus* and *Rhizobium.* Organic acids and acid phosphatases are some important elements responsible for carrying this major process of phosphate solubilization occurring in the soil (mineralization of organic phosphorus). *In vitro* and in field conditions, tests have showed that certain strains of PGPR such as *Pseudomonas putida, Pseudomonas fluorescens* has escalated elongation of both root and shoot in plants such as tomato, lettuce, canola and productivity of plants such as rice, sugar beet, potato, radish, lettuce, citrus, apple, beans, wheat and ornamental plants. Treatment with *Azotobacter* has increased productivity of wheat crop by 30 percent and *Bacillus* in the same crop by 43 percent. There are copious studies which shows that certain bacterial genera, *Pseudomonas, Bacillus, Rhizobium, Agrobacterium, Micrococcus, Burkholderia, Achromobacter, Erwinia, Flavobacterium* and *Aerobacter* has property of solubilizing insoluble and inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, rock phosphate and hydroxyapatite. In a report of Alaylar et al. [17], P-solubilizing PGPR were chosen with the aid of traditional methods. In this the gene region i.e., pqqB was identified that occurred in P-solubilizing bacteria, cultured on Pikovskaya's agar plates. This gene region was identified by using PCR technique which had recognized specific primers (5'-AATCCAAGCCAAAGCCCGTA-3' and 5'-ATTGTCGCCATGTGGGT-3'). 16SrRNA gene region sequence analysis method was also used for its molecular characterization. On the basis of such analysis, 4 PGPR were identified and these isolates were namely, *Rhizobium* sp. (TAGEM15-70-B8), *Enterococcus* sp. (TAGEMI5-70-B22), *Bacillus cereus* (TAGEM15-70-B24) and *Acinetobacter* sp. (TAGEM15-70-B29). Due to such reasons, PGPR can be used in agricultural areas as an ecofriendly biofertilizers.

Goswami et al. [18] studied that *Kocuria turfanensis* 2M4 (PGPR) isolated from saline desert of Little Rann of Kutch, Gujurat showed phosphate solubilization (12 µg mg^{-1} phosphate) under saline and non- saline soil. It caused increase in total plant length of *Arachis hypogaea*

by 17% and 13% increase in fresh biomass under saline soil.

2.2 PGPR as Zinc Solubilizers

Zinc is one of the most important micronutrient needed for growth and development of plants. In a study of Goteti et al. [19], solid medium and broth supplemented with zinc carbonate and zinc oxide was used. For this study 10 bacterial isolates were used and result analysis was done on the basis of formation of clear halo zones on the inoculated solid media plates. Different pH was maintained in case of broth media supplemented with different sources of zinc. Clear halo zones were observed and their diameter was recorded. In this case, bacterial isolates P29, P33 and B40 formed clear halo zones of diameter 22.0 mm on solid media supplemented with $ZnCO_3$. Along with this, bacterial isolates namely, P17 and B40 showed 31.0 mm clear zone in ZnO added solid media. Release of zinc in broth supplemented with $ZnCO_3$ (17 and 16.8 ppm) and in ZnO (18 and 17 ppm), was observed in case of bacterial isolates P29 and B40. In this different pH was maintained ranging from 3.9 to 6.1 in case of $ZnCO_3$ supplemented broth media and 4.1 to 6.4 in case of ZnO supplemented broth media. Along with *in vitro* analysis, a pot experiment was also conducted. In this, seeds of maize were inoculated with bacterial isolate P29 at 10g/kg, which showed increament in total dry mass (12.96g) and in uptake of N_2 (2.268%), K (2.0%), Mn (60 ppm) and Zn (278.8 ppm).

In a study of Gandhi and Govindaraju [20], there was 143 zinc solubilizing bacterial isolates obtained from rice rhizosphere soil samples using Tris-mineral salt growth medium supplemented with insoluble source of zinc such as ZnO and $ZnCO_3$ individually. Among the zinc solubilizing isolates, there was maximum zinc solubilizing halo zones observed with isolate AGM3 followed by AGM9, both on ZnO and $ZnCO_3$ amended solid tris mineral salt growth medium with diameter of 13.21 mm, 10.71 mm, 11.74 mm and 7.90 mm respectively. Similarly, in broth assay, AGM3 showed high value of zinc solubilization than AGM9 in both ZnO and $ZnCO_3$ supplemented medium with a value of 36.54 µg Zn ml^{-1} respectively.

Highest zinc solubilization (3.94 µg/ml) by one of rhizobacterial strain *Bacillus arybhattai* IA20 was reported by Ahmad et al. [21]. It also escalated growth of cotton under semi-arid condition.

2.3 PGPR as Indole Acetic Acid (IAA) Producers

PGPR are considered as effective IAA producers and hence they ameliorate growth and productivity of plants. Numerous works have been reported on this aspect of PGPR.

Mahmooda et al. [22], after morphological and physiological characterization obtained 7 bacterial isolates out of 63 PGPR, among which 7 were Phosphate Solubilizing Bacteria (PSB). All 7 PGPR had Indole Acetic Acid (IAA) producing ability, ranging from 5.5 mg L^{-1} to 30.6 mg L^{-1}. NFM broth medium with tryptophan (1.0 mg L^{-1}) and NH_4Cl (1 g L^{-1}) was used for IAA analysis. Bacterial cells were incubated for 72h at 26-28 ^0C in a water bath shaker. After centrifugation and evaporation, samples were evaluated by HPLC with UV-detector and Tech sphere 5-ODS C-18 column. WPR-51 (*Azospirillum* spp.) showed highest concentration of IAA. After biochemical screening 4 PGPR, WPR-32 (*Azotobacter* spp.), WPR-42 (*Azospirillum* spp.), WPR-51 (*Azospirillum* spp.) and PSM-202 (*Bacillus* spp.) were used in eight different combinations to test their effects on seed germination, seed vigor and root length of wheat (*Triticum aestivum* L.) in 6 days Petri-plates study. After *in vitro* analysis, a pot study was carried out to verify results of incubational experiment. Data were collected on root-shoot lengths and root-shoot biomass after 8 weeks of transplantation. Out of 8 treatments, co-inoculation treatment WPR-32+42+51+PSM and WPR-42+WPR-51+WPR-32+PSM showed maximum root and shoot lengths along with increased biomass than WPR-32+42+PSM and WPR-51+PSM.

In a study of Park et al. [23], 5 bacterial isolates were obtained from rhizospheric region of wheat, soybean, lettuce, pepper, sesame, maize and rice. These isolates which were considered as a potential PGPR includes, *Stenotrophomonas maltophilia* (PM-1, PM-26), *Bacillus fusiformis* (PM-5, PM-24) and *Pseudomonas fluorescens* (PM-13). These isolates were characterized and identified on the basis of their morphology and 16S rDNA sequencing. Among all the bacterial isolates highest amount of IAA (255 microgml (-1)) was produced by *Bacillus fusiformis* (PM-24). Along with IAA production these isolates were also tested for nitrogenase activity.

In a work of Yousef [24] *Bacillus subtilis* showed highest yield of IAA both in pH 8, 0.5% and 1%

NaCl. And it can be opted as a potent PGPR which work under saline stressed soil.

Pal et al. [25] reported that *Lysinibacillus varians* and *Pseudomonas putida* the two potent PGPR enhanced growth of *Brassica nigra* under cadmium stressed soil. These IAA producing PGPR showed $p < 0.05$ increase in root and shoot length, germination % and chlorophyll content alongwith other growth features. So, these can be used as a potent biofertilizer who increase plant growth and ameliorate the harmful effects of cadmium.

2.4. PGPR as Siderophore Producers

Siderophore is a natural iron chelator, produced by several PGPR and it plays an essential role in analyzing the competitiveness of PGPR to dwell in rhizospheric region which excludes several plant pathogens that mainly depends on iron for their growth and survival. PGPR present in rhizospheric region can be neutral, pernicious or beneficial for plant growth.

Siderophore production by PGPR was studied by Gupta and Gopal [26], for which ten PGPR isolates were tested. Different types of culture media were used for culturing these PGPR. On King's B plates, bacterial cultures of *Pseudomonas* sp., *Pseudomonas fluorescens* and *Pseudomonas striata* were obtained. Pure colonies of *Bacillus coagulans, Brevibacillus brevis* and *Enterobacter* sp., were obtained on Sabouraud's agar plates. *Bacillus* sp., were found on Yeast Extract Glucose agar plates. Now all the bacterial cultures were transferred in their respective broths by inoculating at 10^7 cells/50 ml of the culture medium and then the broth tubes were incubated under shake culture condition at 150 rpm and temperature was 28 ± 2^{o} C for 24-48 hours. After proper incubation, the bacterial isolates were inoculated on the Chrome Azurol S (CAS) agar plates, to observe siderophore production by the isolates. CAS medium was made according to guidelines of Schwyn and Neilands but in this, in place of PIPES buffer, HEPES buffer was used and the MM9 salts was used which consisted of K_2HPO_4 (2%), KH_2PO_4 (2%), $MgSO_4$ (25%), $CaCl_2$ (12.5%) and NH_4Cl (10mM). The appearance of orange halo zones around the bacterial growth was analysed and radius of the halo zones was measured after 72 hours of proper incubation. Later on, siderophore content present in aliquot was also calculated by using formula:

Percentage Siderophore Units = Ar-As/Ar X 100

Where,

Ar = Absorbance of reference at 630 nm (CAS reagent).
As = Absorbance of sample at 630 nm.

For this analysis pre-prepared bacterial broth cultures were used, from which inoculation was done on iron free SM medium. After proper incubation and centrifugation, quantitative estimation of siderophores was done by CAS-Shuttle Assay. It was concluded, that only 6 bacterial isolates, produced siderophores and the remaining 4 isolates showed growth on CAS agar medium but did not formed orange halo zones and percentage siderophore units. It was found that highest amount of siderophore was produced by *Pseudomonas fluorescens* followed by *Enterobacter* sp., *Pseudomonas* sp., *Enterobacter* sp., *Azospirillum brasilense* and *Brevibacillus brevis*. Among all, *Pseudomonas* sp. was considered as the best PGPR and antagonistic agent (forming an iron deficient area for plant pathogens). Hence, it has been evaluated that these siderophores will enhance yield and growth of crops when added along with other biofertilizers.

Sultana et al. [27] studied that out of four salt-tolerant PGPR which produced siderophore, *Bacillus aryabhattai* MS3 exhibited highest siderophore 60% and 43% under non-saline and saline (200 mM NaCl) soil respectively.

3. PGPR AS BIOCONTROL AGENTS (BIOPESTICIDES)

Plant Growth Promoting Rhizobacteria has been used as a biocontrol agent. There are several methods by which PGPR, act as such agent. Some of the methods include local antagonism to soil-borne pathogens and initiation of systemic resistance against pathogens. For inhibiting growth and survivability of pathogens, PGPR produces several types of compounds such as antibiotics and siderophores. PGPR induces systemic resistance against plant pathogens, mainly by salicylic acid- dependent SAR pathways, or needs jasmonic acid and ethylene pathway, in plants for Induced Systemic Resistance (ISR). Among PGPR Induced Systemic Resistance is mainly stimulated in case of plants by genera of *Pseudomonas* and *Bacillus.* An emphasis has been laid, that

resistance-inducing and antagonistic rhizobacteria should be used as a biocontrol agent, applied to crops in microbial inoculant form [28].

Antagonistic activity of bacteria isolated from rhizospheric region of pigeonpea (*Cajanus cajun*) was analysed by Dual plate method. In this study of Tiwari et al. [29] 5mm diameter mycelial disc of *Fusarium udum* was transferred in centre of PDA plates. Then 48 hours old bacterial isolates were streaked 2cm away from the margins of PDA plates running perpendicular to the fungi. The inoculated plates were incubated for 5-7 days at 25^{o} C. Here, control plates containing only fungal culture were also used. After proper incubation and growth, plates showed that 6 bacterial isolates (PN10, PN11, PN13, PN14, PN15 and PN18) had antagonistic activity against *Fusarium udum*. Among all the 6 bacterial isolates, highest inhibition was shown by PN14 and it was also determined that siderophore produced by all the isolates was responsible for antagonistic activity of these PGPR against *Fusarium udum.* The percent inhibition (PI) of radial growth of fungus was calculated by the formula:

PI= (R-r)/R X 100

Where,

PI= Percent Inhibition.
R= Radial growth of pathogen in control plate.
r = Radial growth of the fungal colony interacting with antagonistic bacteria.

Plant Growth Promoting Rhizobacteria (PGPR) were chosen by Gul et al. [30] in order to observe their ability to stimulate growth of plant and for the biological control of crown and root rot diseases caused by pathogen *Fusarium oxysporum* f. sp. *radicis-lycopersici* (FORL). They were tested on the production of tomato plant in perlite condition. In this study 4 PGPR isolates namely, TR2/1: *Pseudomonas fluorescens* bv 3, TR18/1: *Pseudomonas fluorescens,* TR21/1: *Pseudomonas putida,* 14/1y: *Pseudomonas fluorescens* bv 5 were selected. These 4 PGPR isolates were chosen on the basis of *in vitro* and *in vivo* tests results analysis from a group of 50 PGPR, that were compared with control (non-PGPR inoculated strains). In this, a resistant and a susceptible variety of tomato, against inoculation was grown in healthy conditions needed for good flourishment of tomato. For this purpose, sowing of seeds was done on 11th January 2010 and its transplantation was done on 26th February 2010. Harvesting of the plants was done from 24th May to 2nd July 2010. For result analysis measurements was done every week. In this cumulative fruit weight and fruit number was measured. Finally, it was observed that after 4 weeks of harvesting period, tomato plants treated with PGPR gave increased yield than to the control.

Soylu et al. [31] reported antagonistic effects of 113 selected bacterial isolates obtained from rhizospheric region of Amik plain, Turkey. These were screened on a selective medium under laboratory condition. They were tested against 2 soil-borne root infecting fungal pathogens, namely, *Sclerotinia sclerotiorum* and *Rhizoctonia solani*, with Dual Culture test. In this test, most of the bacterial isolates produced inhibition zones by checking growth of fungal pathogens hyphae. In this most potent result was observed in case of two bacterial isolates, *Bacillus* spp. and *Pseudomonas* spp. Among the potent isolates, AKB50 and AFP104 isolates were most effective against the growth of hyphae of the pathogens taken into consideration i.e., 75.3% for *Sclerotinia sclerotiorum* and 83.3% in case of *Rhizoctonia solani.* Hence, these bacterial isolates can be considered as a potent biocontrol agents against particular fungal pathogens.

Table 1. Representing PGPR effective against various plant diseases [32]

PGPR	Antagonistic against diseases
Bacillus spp.	Blight of bell pepper (*Capsicum annuum*), Blight of squash
Bacillus subtilis and *B. pumilus*	Downy mildew of pearl millet (*Pennisetum glaucum*)
Pseudomonas fluorescens	Sheath blight disease and leaf folder insect in rice (*Oryza sativa*), Reduce the Banana Bunchy Top Virus incidence
Burkholderia	Maize (*Zea mays*) rot
Fluorescent *Pseudomonas* spp.	Rice sheath rot (*Sarocladium oryzae*)

4. GLOBAL MARKETING AND APPLICATIONS OF PGPR

Application of PGPR in field, work as a supplement for soil and plants, they nourish soil and flourish plant growth and yield. They play paramount role in improving plant growth by dealing with soil fertility, soil stress and soil degradation. The most extensive uses of PGPR are, as biofertilizers and biopesticides [33,34,35].

4.1 PGPR as Biofertilizers

In current era, biofertilizers are playing vital roles in agricultural field, which are aiding in crop enhancement and development [36]. Biofertilizers are also known as biostimulants and these can be any material of biological origin including microbes, which when applied to plants, seeds or soil they improve crop quality, stress tolerance activation and nutrient uptake efficiency [37]. Biofertilizers are considered as a formulation of microbe or consortia of microbes which when applied in soil they colonize in rhizospheric region of plants and work for betterment of plant yield [38]. Biofertilizers act as a crucial portion of integrated nutrient management in soil and nurtures the plant by playing a very active role in nutrient cycling between soil, plant roots and microbes [39,40].

The first commercially available biofertilizer which was introduced to the world and since then biofertilizers are being used worldwide in agricultural field was, 'Nitragin' [41]. It has been determined that Rhizobia-based biofertilizers are being used from more than 100 years [42,43]. In a research report of BCC (2014) [44], it has been analysed that biofertilizers contribute to 5% in a total fertilizer market and also more than 150 microbes-based products are registered for agricultural uses. Several types of biofertilizers which are used most widely, includes, phosphate solubilizers, nitrogen fixers, zinc, boron and sulphur solubilizers. Among nitrogen fixers (Cyanobacteria, *Azospirillum, Rhizobium, Azotobacter* and *Azoarcus*) and phosphate solubilizers (*Pseudomonas* sp. and *Bacillus megaterium*) are having worldwide commercial demand (Fig: 1) [45].

Along with nitrogen fixer and phosphate solubilizers, zinc, sulphur and potash based biofertilizers are also gaining popularity, globally [46,47]. As reported, nitrogenous biofertilizers can increase the crop yield by up to 15-25% of total crop yield by adding 20-200 kg N/ha/year, on the other hand, increase of 10-20% of crop yield by application of PSB-based biofertilizer in the field at rate of 20-200 kg N/ha/year [48]. There lies a broad range of biofertilizers available in global market but, among all, rhizobia formulated biostimulants, shares approximately 78%, followed by phosphate based biofertilizers (PSB) (15%) and other biostimulants (7%) [49,50]. Another type of biofertilizers which act as plant growth regulators are also used globally, to enhance plant growth and development in an effective way [51,52]. Presently, worldwide demand and growth of biofertilizers market is showing drastic increase (Fig. 2), to meet the need of global food supply. A report shows that biofertilizer market was valued at USD 946.6 million, [53]. And this market is supposed to show a cumulative annual growth rate of 14.08% from 2016 to 2022 to attain USD 2305.5 million.

4.2 PGPR as Biopesticides

It has been determined that various plant pathogens reduce yield of crops by one-third, at global range [54]. And is has been estimated that about 25% of crop yield is reduced per annum due to phytopathogens, worldwide [55]. Therefore, PGPR showing biocontrol attributes, are used to tackle this problem and they are designated as biopesticides. They are also considered as a better option to deal with weeds and pests [56]. Biopesticides are sharing 2.5% portion in entire pesticides market, globally [57]. There are wide range of biopesticides, such as, living organism's products (microbial products and phytochemicals), and byproducts (semiochemicals) [58]. Among all, microbial biopesticides contributes 30% share in global market [59,60].

'Sporeine' (obtained from *Bacillus thuringiensis* (Bt)) was first commercially available microbial biopesticide, but major development, registration and marketing of microbial biopesticides started in 1961, with a product named, 'Thuricide' (made from *Bacillus thuringiensis* (Bt)). Biopesticides are such formulation, which are eco-friendly, target-specific and efficacious elements applied for treatment of plant pathogens causing serious diseases and damage to the plant [61,62]. This formulation is used to protect a multifarious range of plants, such as, flowers, legumes, cereals, fruits and ornamentals, from pathogenic diseases. Currently these are having great global demand than chemical pesticides [63].

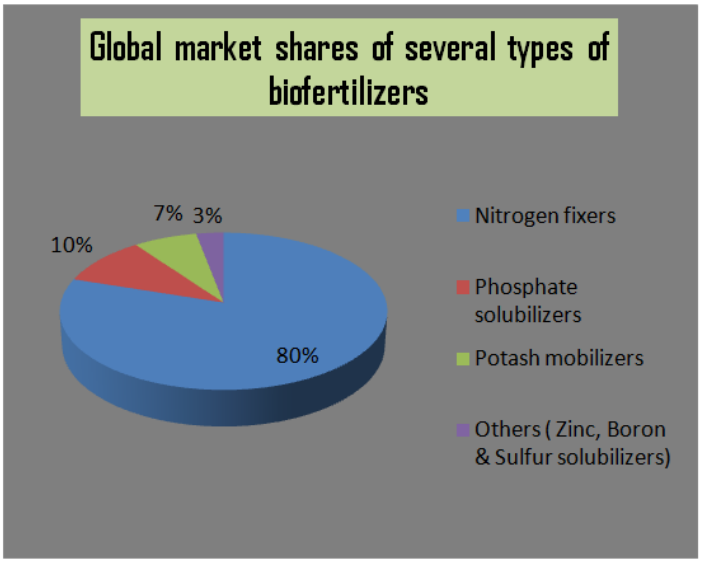

Fig. 1. Global market shares of several types of biofertilizers

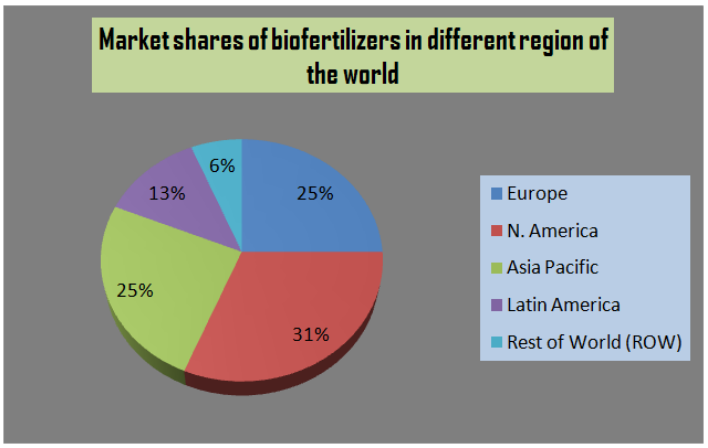

Fig. 2. Market shares of biofertilizers in several regions of world

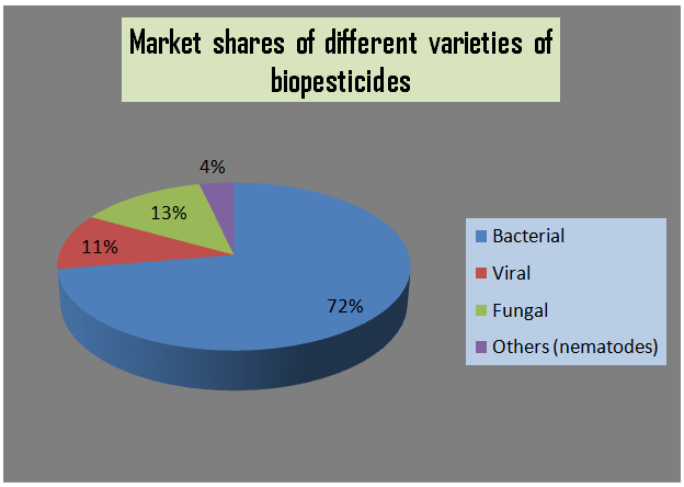

Fig. 3. Market shares of different varieties of biopesticides

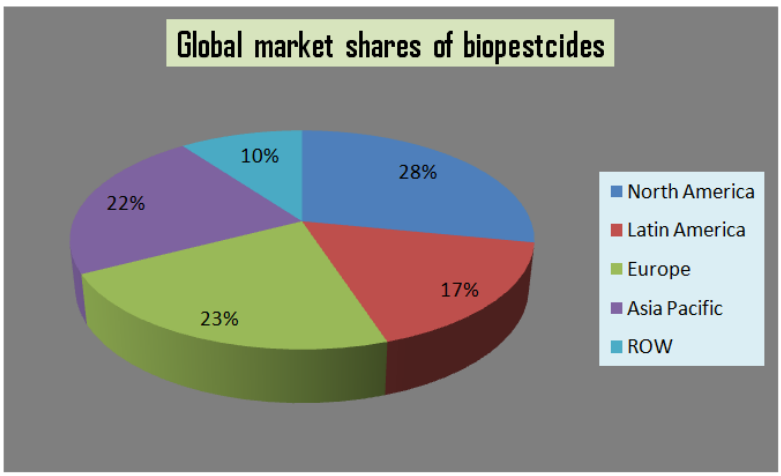

Fig. 4. Global market shares of biopesticides [73]

In global market among all types of microbial biopesticides, bacterial biopesticides occupy major portion (Fig. 3) [64].

Bacillus and *Pseudomonas* are two most popularly used bacterial strains, for biopesticide [65]. The most widely used biopesticide is prepared from *Bacillus thuringiensis* (Bt), which covers about 95% of total market share of all biopesticides [66]. It is mainly used to control insect pests [67]. Some other species of *Bacillus* which are applied as biopesticides include, *Bacillus pumilus, Bacillus licheniformis* and *Bacillus subtilis* [68]. *Pseudomonas* species which are mainly fluorescent in nature are considered as an effective biocontrol agent for plants [69]. Some other commercially available bacterial biopesticides include, *Azospirillum, Agrobacterium, Streptomyces* and *Burkholderia* [70].

In today's world, biopesticides are being used worldwide, and their global distribution is represented in the Fig. 4. It has been shown in the global market report of BCC Research that the total sale of biopesticides in 2008 was $ 1.2 billion and in year 2009, it elevated to $ 1.6 billion [71]. It was reported by PR Newswire (2017) [72], the global biopesticides market in 2015 was $ 3.7 billion and it escalated about $ 4.0 billion in 2016. It is estimated that market is subjected to rise at cumulative annual growth rate of 14.1% from 2016 to 2021 and shall reach $ 7.7 billion by 2021.

5. CONCLUSIONS AND FUTURE PROSPECTS

There is a great demand of food, worldwide, and to fulfill this, there is need of such measure which will cause benefit on economic basis as well as is eco-friendly. To have a good and sustainable agricultural future, there is need to produce agricultural crops in abundance, which would also fulfill three attributes, stress tolerance, disease resistance and good nutrient amount. Hence, PGPR are seen as one of the best option for this. They play very effective role for bright agricultural future, as they work like, biofertilizers, biopesticides, biofortification and bioremediation agents.

Although, PGPR application globally is quiet limited and it is basically used as biofertilizers and a bit as biocontrol agent, but there is need to increase its productivity and hence by introducing several latest technological tools, like, proteomics, nanotechnology, metabolomics and genomics, one can elevate and satisfy its global demand, to increase crop yield. Several approaches have been suggested with respect to PGPR to elevate crop yield. It has been reported that integrated use of PGPR with organic farming techniques, appears to be an effective approach in this concern. There is also need of proper registration, regulation and delivery system other than discovering and selecting potent PGPR. And most important aspect is that we should draw attention of farmers towards these bio products of agro world, which would be cost-effective, easy and reliable for them to apply in their fields.

The limitations of this study is that one need to explore the bioformulation, carrier molecules and method of fermentation which could help in large scale production and field application of potent PGPR. Such formulations would hence increase life span of PGPR in the field as they are

sensitive to conditions, viz, heat. Also bioremediation aspects of PGPR need to be explored more.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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