Review Article

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Role of Plant Growth-Promoting Rhizobacteria (PGPR) and Bio-Control Agents (BCAs) in Crop Production

Sujata Kumari, Narender K. Bharat and Ashok K. Thakur

Dept. of Seed Science and Technology, Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan. H.P. (173 230), India

Corresponding Author

Sujata Kumari
e-mail: sujatasst1990@gmail.com

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Abstract

The bioagents like Plant Growth Promoting Rhizobacteria (PGPR) and Biocontrol Agents (BCAs) play a crucial role in plant growth promotion, nutrient uptake and suppression of biotic and abiotic stresses. Different researchers have applied these bioagents by various means either through seed treatment or through soil application to prevent various plant diseases. Thus, these non-chemical environment friendly tools can be exploited to enhance crop production.

Keywords: BCAs, Rhizobacteria, seed and soil application

1. Introduction

The world population is increasing rapidly and feeding this huge population is a real challenge in upcoming time, an endeavor that requires resolving the issue is increased agricultural productivity. Besides, now-a-days people are more aware chemical hazards and benefits of organic produce on their organoleptic and nutritional properties. Hence, use of non-chemical environmental friendly tools for crop production and plant disease management became more popular in agriculture.

PGPR (Plant Growth Promoting Rhizobacteria), a group of plant-beneficial rhizobacteria, potentially beneficial for stimulating plant growth and increasing crop yields. In the last few years, the number of PGPRs has been found to increase mainly due to their role in the rhizosphere. Various species of bacteria such as *Pseudomonas*, *Azospirillum*, *Azotobacter*, *Klebsiella*, *Enterobacter*, *Alcaligenes*, *Arthrobacter*, *Burkholderia*, *Bacillus* and *Serratia* have been reported to enhance the plant growth and suppress phytopathogens (Saharan and Nehra, 2011). Another group of beneficial microbes are fungal species (*Trichoderma*) well-known biological control agents (BCAs) and are now formulated and used extensively to prevent several soil borne plant diseases. *Trichoderma* species are successful antagonists having biocontrol abilities against economically important plant parasitic soil-borne pathogens and present abundantly in almost all type of soils (Kushwaha and Verma, 2014; Olabiyi and Ruocco, 2013; Shahid et al., 2014).

Biocontrol antagonists played important role in the management of plant diseases and parasitic microorganisms (Alwathnani and Perveen, 2012; Hajieghrari et al., 2008; Zhang et al., 2013). *Trichoderma* attacked other plant pathogenic fungi and promotes plant and root growth. It uses different mechanisms for the control of plant pathogenic pathogens including antibiosis, mycoparasitism, the induced resistance of host cell and competition for nutrient and space. Species of *Trichoderma* can control and antagonize broad range of economically important postharvest phytopathogenic fungal pathogens and plant-pathogenic fungi as well as also control bacteria and viruses (Harman 2006; Yedidia et al., 2003). *Trichoderma* spp. also enhances plant growth and root development (biofertilizer) and stimulates plant defense mechanisms (Harman et al., 2004). Some *Trichoderma* strains have been shown to penetrate the epidermis and establish robust and long lasting colonization of root surfaces.

2. Effect of Seed Treatment with PGPR and BCAs on Crop Production

Plant growth, yield as well as seed quality parameters viz., germination, seedling vigour index, plant height, plant dry weight, number of fruits/plant, fruit weight and fruit yield (1080.00 g plant^{-1}) in chilli was enhanced with PGPR application (Kanchana et al., 2014). The indigenous isolates of PGPR showed significant plant growth promotion with respect to increase in root and shoot length and number of secondary roots as compared to control under glasshouse

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conditions (Kumar et al., 2011) as well as plant growth and yield attributes such as total number of fruits and fruit weight under field conditions in chilli (Datta et al., 2011). Similarly, indigenous PGPR were efficacious as seed treatment in capsicum w.r.t. improvement in yield and soil health (Gupta et al., 2015). In bell pepper, Mandyal et al. (2012) observed highest shoot length, plant biomass, root biomass, number of fruits/plant and yield after seed inoculation with a *Bacillus* isolate (PM9) over untreated control. The seed treatment not only improved plant growth and yield but also reduced the incidence of major diseases of chilli crop plant. *Bacillus subtilis* KP07 elicited induced systemic resistance (ISR) against *Colletotrichum acutatum* and recorded minimum disease severity when compared to chemical control, whereas the disease severity of *Phytophthora capsici* was recorded 60% in KP07 treated plants when compared to chemical control (80%) (Suh et al., 2011). PGPR mixed bioformulation, *Pseudomonas fluorescens* 1+*B. subtilis* + neem + chitin as the best treatment for reducing the fruit rot incidence besides increasing the plant growth and yields parameters under both greenhouse and field conditions in chilli. There was manifold increase in chitinase, *β*-1, 3 glucanase, peroxidase, polyphenol oxidase, phenylalanine ammonia lyase and phenol accumulation in plants treated with mixed formulation (Bharathi et al., 2004). The incidence of *Fusarium* wilt in red chilli (*Capsicum annuum* L.) seedlings was observed relatively reduced due to chitinolytic bacteria as a biocontrol agent (Suryanto et al., 2010). A rhizobacterial isolate AB17 induced the greatest increase in plant height, root length, shoot fresh weight and root biomass under greenhouse conditions when applied as seed treatment @ 10^8-10^9 in pepper (Lamsal et al., 2012). The PGPR strains viz., *Bacillus amyloliquefaciens* IN937a, *B. subtilis* GBO3 and *Brevibacillus brevis* IPC11 showed enhancement in the seed quality parameters like seed germination and seedling vigor and reduction in bacterial canker disease when applied as seed treatment (Girish and Umesha, 2005). Inoculation with *B. subtilis* BEB-lSbs (BS13) increased fruit weight and length, yield and enhanced texture of tomato fruits (Violante and Portugal, 2007). Whereas, Mangmang et al. (2014) reported that PGPR inoculate @ 10^{-11} cfu ml^{-1} in tomato and lettuce seeds produced longer and heavier roots with superior germination and vigor. The lipopeptides, especially surfactin and fengycin produced by *Bacillus subtilis* strains are able to stimulate bean and tomato plants and also decreased the impact of subsequent pathogen infection (Jourdan et al., 2007). *Pseudomonas syringae* pv. *tomato* (bacterial speck of tomato) and *Azospirillum brasilense* resulted in decreasing the population of *Pseudomonas*, eliminating disease development and improving the plant growth (Bashan and Bashan, 2002) The application of biofertilizers, *Rhizobium*, *Azotobacter* and phosphate solubilizing bacteria (PSB) increased plant height (45.26 cm), number of nodules/plant (38.46), yield of grain and straw of field pea (Rather et al., 2010). PGPR inoculation as seed coating @ 1.5 x 10^9 cfu ml^{-1} in runner bean increased photosynthesis, transpiration, water use efficiency and leaves chlorophyll content and grain yield (Stefan et al., 2013). Whereas, Amin et al. (2014) reported that seed treatment with *Pseudomonas fluorescens* (talc formulation 10 g kg^{-1} to soak the seeds in 1 litre of water for 24 hrs) decreased anthracnose symptoms in common bean and consequently achieved greater yield. Rhizobacterial inoculants (*Pseudomonas putida* NWU12, *P. fluorescens* NWU65, *Vibrio fluvialis* NWU37 and *Ewingella americana* NWU59) when applied as seed treatment @10^6 cfu ml^{-1} increased plant height in spinach and pepper over the control (Hou and Oluranti, 2013). Application of three PGPR strains (*Azotobacter* sp., *Nitrobacter* sp. and *Nitrosomonas* sp.) was found to increase seed germination, plant height, stem width and root length in *Piper nigra* plants (Ibiene et al., 2013).

Bacillus megaterium with *B. megaterium* TV-91C @ 1 × 10^8 cfu ml^{-1} in cabbage increased fresh and dry shoot and root weight as compared to untreated control (Turan et al., 2014). Khalid et al., 2004 reported that seed inoculation with selected PGPR isolates exhibited stimulatory effects on grain yields of wheat with 7% increase over control in pot and up to 5% increase over control in field experiments. Seeds of wheat inoculated with 8N-4 isolate of *Bacillus pumilus* @ 10^6–10^7 cfu ml^{-1} recorded maximum increase in shoot biomass, root length, total nitrogen and phosphorous contents (Hafeez et al., 2006). Similarly, seed inoculation of bacterial strains (*Pseudomonas putida* and *Azospirillum lipoferum* @ 10^8 cfu ml^{-1}) significantly enhanced seed germination and seedling vigour, plant height, 100 seed weight, number of seed/ear and leaf area and shoot dry weight in maize (Gholami et al., 2009). *Pseudomonas fluorescens* and *Pseudomonas putida* in maize increased germination percentage, vigor index, plants circumferences, number of leaves and the leaf area and aerial dry matter (Noumavo et al., 2013). Two isolates of PGPR (*Bacillus* and *Azotobacter*) increased seed germination, number of leaves and seedling vigour in maize when applied as seed treatment @ 10^8 cfu ml^{-1} (Sengupta et al., 2015). Inoculation of *Azospirillum* increased maize productivity and cob length (Casanovas et al., 2000). Whereas, a combined inoculation of *Pseudomonas* and *Bacillus* @ 10^8 cfu ml^{-1} as seed treatment increased plant height and dry weight in maize plants (Jarak et al., 2012). Bacterial isolates of *Agrobacterium*, *Bacillus*, *Enterobacter* and *Pseudomonas* inhibited mycelia growth of *Phytophthora cactorum* and *P. fragariae* var. *fragariae* in strawberries (Hessenmeller and Zeller, 1996). Dual inoculation of PGPR strains improved growth and tuber yield of potato under field conditions (Sunaina and Ajay, 2005). Application of *Azospirillum* + Phosphobacteria recorded less number of days to appearance of first female flower and narrower sex ratio as compared to control in cucumber (Nirmala et al., 1999). *Azospirillum* strains viz. ACD-15 and ACD-20 significant increased grain yield in sorghum over the control (Alagawadi and Krishnaraj, 1998). Inoculation of soybean plants with PGPR in the presence of

B. japonicum increased grain yield, grain protein yield, and total plant protein production under short season conditions in Canada (Dashti et al., 1997). Seed inoculation with *T. viride* showed the highest germination (96.29%) and the rate of seedlings emergence (5.73) as compared to control in sweet pepper under greenhouse conditions (Diniz et al., 2009). Among the five *Trichoderma* strains, *T. harzianum* gave the highest germination percentage both in laboratory and field conditions in chilli (Asaduzzaman et al., 2010). Sriram et al. (2009) reported that the elicitor treatment as seedling dip reduced *P. capsici* infection to 23% compared to control (93%) in chilli. Mehetre and Kale (2011) recorded 83.16% inhibition of disease with respect to infected control pots. *T. atroviride* and *T. harzianum* @ 2.5×10^6 conidia ml^{-1} had higher emergence percentage and lower disease incidence (Olawumi et al., 2016). The combination of *Pseudomona fluorescens*+*T. harzianum* as a better seed bio-priming option for increasing growth and reducing damping off in capsicum nursery (Kumar et al., 2010).

Seed treatment with *P. fluorescens* and *T. harzianum* were more effective in increasing the seed germination and vigour and reducing anthracnose disease in capsicum even than the fungicide seed treatment (Raj and Christopher, 2009). Duc et al. (2017) reported that combined inoculation of PGPR (10^8 cfu ml^{-1}) and *Trichoderma* (10^7 cfu ml^{-1}) at seedling stage improved yield parameters of three pepper varieties (Karpex, Karpia and Kaptur) under field conditions.

3. Effect of Soil Application with PGPR and BCAs on Crop Production

The effect of soil application with PGPRs on plant growth, yield and disease management has also been observed by various workers. Kokalis et al. (2002) evaluated tomato and pepper transplants amended with formulations of several PGPRs and found improved seedling growth, vigour and survival of such plants in the field. The artificial inoculation of rhizobacteria, *Azospirillum* caused a positive effect on tomato plant growth and yields (Glala et al., 2010). The incidence of diseases i.e. powdery mildew, leaf spot, wilt and dieback was significantly reduced in PGPR treatment @ 10^8 cfu ml^{-1} as compared to un-inoculated ones in chilli (Naik et al., 2011). The direct promotion of plant growth by soil application of PGPR generally entails providing the plant with a compound that is synthesized by the bacterium or facilitating the uptake of nutrient from the environment (Glick, 1995). *P. fluorescens* strains increased the root length and root area in the treated by producing plant growth hormone viz., IAA and GA (Dibypaul et al., 2005). Soil treatment with *Azospirillum* (2 kg ha^{-1}) along with nitrogen took less number of days for first flowering compared to application of N alone in rice (Balasubramaniam and Kumar, 1989). *T. harzianum* inoculated chilli plants showed significant increase in plant growth parameters like shoot length, root length, dry weight of shoot and root, number of leaves and number of branching as compared to control (Bhuvaneswari et al., 2014). Soil application with *T. harzianum, P. fluorescens* and *T. harzianum* resulted in highest seedling emergence, vigour index, minimum pre emergence rot and post emergence damping off in chilli (Kabdal et al., 2010). Bharathi et al. (2004) reported that mixed bio-formulation of *P. fluorescens* (pf1) + *B. subtilis*+neem+chitin was found to be the best for reducing the fruit rot incidence of chilli besides increasing the plant growth and yield parameters under both greenhouse and field conditions. The treatment combination of *T. viride+P. fluorescens* was most effective in reducing the incidence of seedling rot and increasing plant growth and yield in chilli grown under greenhouse as well as field conditions (Ngullie and Daiho, 2013). Similarly, combined application of bioagents like *Serratia quinivorans*, *Enterobacter ludwigii*, *Lysinibacillus sphaericus*, *Aeromonas media* and *Pseudomonas poae* increased plant height, diameter of the stem, number of fruits in capsicum (Vyas and Vyas, 2014; Avendano et al., 2014). Indigenous isolates of *T. viride* -16 and *T. viride* were best in terms of disease suppression without affecting germination of seeds (Rani et al., 2009). Plant height, top root length, stem girth and weight of coffee seedlings increased upon combined inoculation of bioagents like *Azospirillum brasilense*, *Glomus fasciculatum* and P-solubilizing *Pseudomonas striata* and *Serratia* spp. as compared to un-inoculated control (Salakinkop et al., 2003). Plant growth, yield and nutrient uptake of wheat plants increased due to the synergistic effects of *Bacillus* sp. *Azotobacter chroococcum* and *Glomus fasciculatum* (Khan and Zaidi, 2007). Dual inoculants i.e. *Bacillus megaterium* and *Trichoderma viride* showed maximum shoots and roots dry matter, increased root length and seedlings height in chilli and tomato (Hayyan et al., 2009; Morsy et al., 2009).

4. Effect of PGPR and BCAs as Seed Treatment and Soil Application on Crop Production

Application of bioagents through seed treatment as well as soil application has also been advocated as a better option over the single method of their inoculation. Raja et al. (2013) have observed that the combination of *T. harzianum* + *P. fluorescens* and *T. harzianum*+*T. viride* were more effective in reducing disease incidence. Highest plant height in chilli was recorded in *T. harzianum* as compared to other treatment combinations and untreated control in chilli (Kavitha et al., 2005). Seed treatment (talc formulation 10 g kg^{-1} of seed), seedling root dip (talc formulation 20 g l^{-1}) and soil application (talc formulation 2.5 kg ha^{-1}) significantly improve plant growth due to ISR (Induced Systemic Resistance) in chilli (Sundaramoorthy et al., 2012). *T. harzianum* (TR20)+*P. fluorescens* (P28), was most effective in reducing disease incidence and recorded highest yield/plant followed by *T. pseudokoningii* (TR17) + *P. fluorescens* (P51) in chilli (Rini and Sulochana, 2006). Use of talc formulation of *B. subtilis* as soil application, seed treatment, foliar spray and root dip treatment recorded considerable enhancement of all biometric parameters (plant fresh weight, dry weight and root length) and reduced disease incidence compared to the untreated control in chilli (Narasimhan and Shivakumar, 2016). Isolates of PGPR applied as seed soaking (1×108 cfu ml^{-1} for 30 min prior to planting), soil drench (5 ml ×108 cfu cup^{-1}), spray on the surface of soil and adding with irrigation water increased seed germination and seedling height in pepper (Almaghrabi et al., 2014). Whereas, Sang et al. (2012) reported that biocontrol strains (*Pseudomonas otitidis* YJR27, *P. putida* YJR92, *Tsukamurella tyrosinosolvens* YJR102 and *Novosphingobium capsulatum* YJR107) effectively controlled *Phytophthora* blight, anthracnose occurrence and enhanced fruit yield in pepper plants under field conditions. *Pseudomonas fluorescens* strains applied to seed, soil and foliage or as a seedling dip significantly reduced Tomato Spotted Wilt Virus, with a concomitant increase in growth promotion in both under glasshouse and field conditions in tomato (Kandan et al., 2005). PGPR strains (*Bacillus megaterium* TV-3D, *B. megaterium* TV-91C, *Pantoea agglomerans* RK-92, *B. subtilis* TV-17C, *B. megaterium* TV-87A, *B. megaterium* KBA-10) when applied twice as drench into root zone after germination of seed at one week intervals @ 10^{8} cfu ml^{-1} showed increased plant growth parameters such as fresh shoot weight, dry shoot weight, root diameter, root length, fresh root weight, dry root weight, plant height, stem diameter, leaf area and chlorophyll contents of cauliflower transplants (Ekinci et al., 2014).

5. Conclusion

The ability of PGPRs, BCAs and antibiotics produced by them to suppress phytopathogens can be of significant agronomic importance. These might be useful in formulating new inoculants, offering an alternative of eco-friendly biological control of plant diseases and improving crop production.

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