Acta Physiol Plant (2016) 38:117
DOI 10.1007/s11738-016-2133-7

REVIEW

Growth stimulation and management of diseases of ornamental plants using phosphate solubilizing microorganisms: current perspective

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Received: 12 March 2015 / Revised: 27 July 2015 / Accepted: 7 April 2016 / Published online: 20 April 2016

Abstract Ornamental plants play an important role in human society since flowers are considered a vital component due to their beauty, texture, color, shape and fragrance. To produce high quality ornamentals, growers in general have intensified the use of agrochemicals without considering their deleterious impact on floral attributes. Also, the agrochemicals (including fertilizers and pesticides) used in floriculture are expensive and their excessive application results in emergence of pathogens resistant to such chemicals. It has, therefore, become imperative to develop renewable, inexpensive and eco-friendly fertilizers without producing any disturbing impact on quality of ornamentals. In this regard, phosphate solubilizing microorganisms (PSM) among plant growth promoting rhizobacteria have been identified as an efficient alternative to agrochemicals in floriculture. Even though, there are adequate reports on the effect of PSM on growth and development of numerous plants, information on the impact of PSM on production and quality of ornamental plants is, however, critically scarce. Considering these gaps and success of PSM application in floriculture achieved so far, efforts have been directed to highlight the impact of PSM on the production of ornamentals grown distinctively in different production systems. Also, the role of PSM in the management of ornamental diseases is discussed and considered. The review will conclude by identifying several PSM for future researches aiming to improve the health and quality of ornamentals grown in different production systems. Use of PSM is also likely to reduce the use of chemicals in floriculture.

Keywords Ornamental plants · Floriculture · Phosphate solubilizing microorganisms · Disease management

Introduction

Ornamental plants in general are plants that are grown for decorative purposes, cut flowers and for aroma. Ornamental plants are also grown for showy foliage which may be deciduous, turning bright orange, red, and yellow or evergreen. Other ornamental plants are cultivated for their blooms. Due to these features, ornamental plants are considered extremely important in human society because flowers gratify humans by their beauty, texture, color, shape and fragrance. Globally, ornamental plants also serve as a main source of export materials and add value to the economy of the country. For example, *Chrysanthemums*, often called as mums or chrysanths, is one of the leading commercial flower due to its variable colors. Ornamental plants also possess medicinal value and are used to combat certain human diseases. As an example, *Chrysanthemum* tea, made from white and yellow *Chrysanthemum* flowers is used against influenza. Also, the extract of *Chrysanthemum* plants (stem and flower) have a wide variety of potential medicinal properties including anti HIV-1, antibacterial and antimycotic (Karishma et al. 2013a). Considering such an exquisite and varied importance of ornamental plants, there is need to enhance their—(1) growth, (2) flower production and (3) quality attributes such as number, longevity and size of flowers, which in effect is likely to give a significant monetary benefit to

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Communicated by A. K. Kononowicz.

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horticulturists/growers. To achieve these, high rates of various synthetic fertilizers like, nitrogen (N), phosphorus (P) and potassium (K) are used in floriculture. Of these plant nutrients, P is essentially required as sugar phosphate intermediates in respiration and photosynthesis and phospholipids of plant membranes (Shenoy and Kalagudi 2005). Also, P is essential for cell division, development of meristematic tissue and for stimulating buds and balls formation (Ahemad et al. 2009). Broadly, the basic reasons for fertilizing ornamental plants are to encourage growth, or to create healthy, vigorous and attractive plants. The exorbitant cost of chemical fertilizers together with the toxic impact of such chemicals on soil microflora and fauna and indirectly to human health, however, is the major concern for growers (Eman et al. 2008). Also, the long-term application of fertilizers destruct the soil structure (Singh et al. 2008), and hence, affects the growth and production of flowers (Torkashvand 2009). It has, therefore, become extremely difficult for growers to manage such threatening situations. To prevent or to minimize the usage of such chemicals in floriculture practices, there is an urgent need to find some viable alternative to expensive and floral disruptive chemicals. In this regard, biological preparations/formulations often called biofertilizers "a substance which contains living microorganisms which when applied to seed, plant surfaces, or soil, colonizes the rhizosphere or the interior of the plant and promotes growth by increasing the supply or availability of primary nutrients to the host plant (Vessey 2003)" including PSM have provided sound solutions to the toxic chemicals in sustainable floriculture (Karpagam and Nagalakshmi 2014; Zawadzka et al. 2013). Among biofertilizers (e.g., nitrogenous, phosphatic and potassic), PSM provides especially P to plants by transforming unavailable P to available and soluble forms (Zaidi et al. 2009). Concurrently, The PSM improves the quality and quantity of ornamental plants (Karishma et al. 2011). The major advantage of using PSM is their better rhizosphere competence, i.e., their ability to colonize, grow and develop faster in the rhizosphere soil, and hence to supply P for longer duration to plants (Sharma 2002). Apart from P, PSM also provide: (1) gibberellins, cytokinins and IAA (Priya et al. 2013; Sharma et al. 2012), (2) improve water and nutrients uptake (Khan et al. 2007), (3) release antibiotics and other inhibitory substances (Shanmugam et al. 2011; Lipping et al. 2008) and (4) produce B-group vitamins (Revillas et al. 2000). Broadly, PSM facilitate the growth of ornamental plants by providing essential nutrients (Abbasniayzare et al. 2012) and by suppressing phytopathogens (Salma et al. 2014). For example, the increase in growth characteristics like plant height, early flowering, and nutrient uptake were observed in *Azospirillum* inoculated French marigold and "rosesby" plants (Balasubramanian 1989; Preethi et al. 1999). Biofertilizers like, *Azotobacter chroococcum* and *A. lipoferum* also increased plant height, leaf area, tepal diameter, and growth and quality of tulip flower as well as bulb yield (Khan et al. 2009). Rajesh et al. (2006) also found that *Azospirillum* and phosphate solubilizing (PS) bacterium (*Bacillus subtilis*) enhanced the flower fresh weight in carnation. These and other similar studies suggest that the combination of PSM/AM fungi, PSM/endophytes and PSM/vermicompost in addition to PSM/PGPR or chemicals could very effectively be exploited for enhancing the floral quality and yield of ornamental plants.

Rationale for using phosphate solubilizing microorganisms in floriculture

The market for ornamental plants is growing rapidly due to high floral demands worldwide (Anderson et al. 2010). This increase in demand of ornamentals for example, cut flowers (e.g., the rose, chrysanthemum, carnation and lily, etc.), cut foliage, potted plants and bedding plants is primarily due to constantly increasing economy of both developed (especially US and European nations) and developing countries. Ornamental plants are generally grown in an artificial habitat because field soils are generally unsatisfactory for the production of plants in containers. This is primarily because soils do not provide the required aeration, drainage and water holding capacity. Moreover, growers generally use artificial soils instead of natural ones when good soils (nutrient rich) are not available, where maintenance of favorable soil conditions is too expensive, or where growth of high-value out-of-season crops is contemplated. Also, the chance of diseases which may develop during the growth of ornamental plants from the natural soil pathogenic microbiota is reduced while using artificial habitat. And hence, soils used to grow ornamentals may be hugely different from those of the native habitat which is used to grow normal plants. Therefore, the nutrient recycling systems of the ornamental habitat may be different. Due to these reasons, fertilizers are periodically applied to fulfill the essential mineral elements and concurrently to increase growth, flowering/fruiting, increase vigor/vitality, balance root and shoot growth, and to address a visible nutrient deficiency. Among ornamentals, some plants, such as annual flowers and roses are, however, more nutrient demanding plants than others. Globally, the commercial production of fertilizers used to facilitate the growth of flower plants requires considerable amounts of energy and is highly expensive. Also, chemical fertilizers are consistently applied in floriculture practices to attain optimum yields and quality flowers. The long term application has, however, resulted in uneven distribution of nutrients and has damaged the structure and health of soil (Younis et al. 2013).

Fertilizing with too much fertilizers for example N can lead to increased herbivory or susceptibility to insects and some disease. Excessive levels of N: (1) stimulate rapid shoot growth while slowing down root growth, (2) deplete the plant's carbohydrate reserves more rapidly, which in turn can result in less stress tolerance and slower recovery from any injury to the plant, (3) result in thinner and more succulent leaf tissue, which increases moisture loss, (4) can predispose the plant to greater insect and disease problems (e.g., necrotic ring spot disease on Kentucky bluegrass; a disease often associated with excessive N applications) and (5) leach through the soil beyond the root system potentially polluting ground water resources. Research has shown that increasing soluble N levels in plants can decrease their resistance to pests, resulting in higher pest density and crop damage. For example, increased N fertilizer rates have been found to increase the susceptibility of some crop plants to outbreaks of aphids, mites and other arthropod pests, like potato aphids, *Macrosiphum euphorbiae* (Thomas) on lettuce (http://www.extension.org/pages/18574/managing-the-soil-to-reduce-insect-pests). Similarly, with increasing N concentrations in creosotebush (*Larrea tridentate*) plants, populations of sucking insects were found to increase, but the number of chewing insects declined. With higher N fertilization, the amount of nutrients in the plant and the amount of secondary compounds that may selectively affect herbivore feeding patterns increases. Protein digestion inhibitors that accumulated in plant cell vacuoles were not consumed by sucking herbivores, but inhibited chewing herbivores (Mattson 1980). Also, the natural uptake of P from chemical fertilizers by ornamental plants is very low and approximately 75–90 % of the phosphatic fertilizers applied to soil are lost due to its rapid fixation with Fe and Al oxides in acidic soils (Goldstein 1986; Norrish and Rosser 1983) while calcium phosphate predominates in neutral or calcareous soils (Lindsay et al. 1989). And hence, plants quite often suffer from huge P deficiency in soils. The integrated usage of the nutrients to get quality product without any toxicological environmental hazard is, therefore, of prime concern. To overcome the production cost, toxic impact of agrochemicals on floral quality and to satisfy the P demands of ornamental crops, there is greater need to find an alternative technology that could solve these alarming problems. In this context, the effort is directed towards the use of PSM either alone or as mixture with fertilizers to enhance biological and physico–chemical properties of soil resulting in increased crop yields (Baloach et al. 2014). Use of PSM in general, as environment friendly biofertilizer helps to reduce the use of expensive phosphatic fertilizers (Ali et al. 2014; Dalve et al. 2009). Also, the use of PSM as bio-inoculants increases the soil P pool, reduces chemical pollution and promotes sustainable ornamental production (Reena et al. 2013). In this regard, the effects of biological and chemical fertilization in different cropping systems have been compared (Koley and Pal 2011; Jeyaraman and Purushothaman 1988). The adoption of PSM application in ornamental production systems have been found to provide a useful, efficient and economical alternative, and consequently to reduce/save the use of P fertilizers (Adesemoye and Kloepper 2009; Ekin 2011). In a recent study, Ramlakshmi and Bharathiraja (2015) have also suggested that the combination of phosphobacteria (*Paenibacillus polymyxa*) and arbuscular mycorrhizal (AM) fungi (*Glomus fasciculatum*) could reduce the use of P fertilizer by 25 % in marigold production. And hence, the integrated nutrient management (Chaitra and Patil 2007) involving the use of PSM endowed with multiple characteristics has attracted attention of floriculturists worldwide (Naqvi and Ahmad 2012; Goes et al. 2012).

Phosphate solubilizing microorganisms in addition to providing P to plants also act as biological control agents (Zaidi et al. 2014), and consequently by suppressing the phytopathogens enhance the growth and quality of ornamental plants (Basharat et al. 2011). If genuinely identified and properly applied, the PSM–plant interactions are likely to benefit floriculturists massively while reducing soil pollution which otherwise may result from excessive application of fertilizers, maintaining soil fertility and consequently enhancing the yield and various floral attributes. Moreover, the low cost technology for its mass production coupled with high cost benefit ratio are some of the reasons why the use of PSM should be promoted in floriculture practices in different production systems. Even though, there are extensive reports on the effect of PSM on growth and development of different plants (Ahmad et al. 2014; Panhwar et al. 2014), but to date, in comparison to other crops, the information on the impact of PSM on the production and quality of ornamental plants is negligible. In addition, there is still a need to address issues for example, how PSM manage floral diseases in different production systems. Considering these gaps, we highlight here the role of PSM in the production of ornamental plants. Also, the role of PSM in the management of phytopathogens, and consequently their impact on floral quality is considered and discussed.

PSM improve ornamental production

PSM: definition, origin and mechanism of P solubilization and plant growth

Phosphate solubilizing microorganisms are a group of beneficial microorganisms capable of hydrolyzing organic and inorganic phosphorus from insoluble phosphatic compounds (Chen et al. 2006a). Phosphate solubilizing microorganisms have been recovered from conventional non rhizosphere (Onyia and Anyanwu 2013) and rhizosphere soils (Qiao et al. 2013), rhizoplane (Sarkar et al. 2012), phyllosphere (Mwajita et al. 2013), rock phosphate (RP) deposit area soil (Mardad et al. 2013), marine environment (Mujahid et al. 2014) and polluted soils (Susilowati and Syekhfani 2014). Among PSM, the notable fungi belongs to genera *Penicillium* (Reena et al. 2013), *Aspergillus* (Fig. 1a) (Coutinho et al. 2012) and *Trichoderma* (Yasser et al. 2014) while bacteria includes *Achromobacter* (Ma et al. 2009), *Acinetobacter* (Gulati et al. 2010), *Sphingomonas* and *Burkholderia* (Panhwar et al. 2014; Song et al. 2008), *Bacillus* (Tallapragada and Usha 2012), *Serratia* (Fig. 1b) (Selvakumar et al. 2008), *Enterobacter* (Frank and Julius 2012), *Micrococcus* (Reena et al. 2013), *Pseudomonas* (Mehnaz et al. 2010), rhizobia (Kumar et al. 2014; Kenasa et al. 2014) and actinomycetes (Saif et al. 2014). However, while comparing the P solubilizing abilities of different P solubilizers, P solubilizing fungi (PSF) have been found better solubilizer than bacteria (Venkateswarlu et al. 1984). Among various mechanisms including mineralization of organically bound P through enzymatic degradation (Yadav and Tarafdar 2011), identified for solubilization of insoluble P by PSM, the organic acid (OA) theory is well recognized and most widely accepted mechanism of P solubilization (Khan et al. 2014). Generally, all PSM including bacteria and fungi release various organic acids (Table 1) which cause the solubilization of complex insoluble P and bring it into available form by lowering the pH of the medium. The efficiency of solubilization/mineralization, however, depends on the kind and concentration of organic acids/enzymes released into the medium. Furthermore, the quality of the acids is more important for P solubilization than the total amount of acids produced by PS organisms (Scervino et al. 2010). Additionally, the insoluble P is also transformed into soluble forms of P without OA production by microbes (Illmer and Schinner 1992; Chen et al. 2006b). Phosphate solubilizing microorganisms increases the overall performance of plants even though by providing mainly soluble P to plants, yet they also benefit plants by providing various other growth stimulating substances (Table 2).

Sustainable production of ornamentals

Development of healthy ornamental plants, increased flower production, and quality of flowers are some of the important issues in commercial floriculture technology which requires special attention. To achieve these objectives, expensive and environment disruptive chemical fertilizers are used. However, the inoculation of PSM plays a crucial role in reducing the inorganic fertilizer application and at the same time increasing the quality and yield of different ornamentals (Table 3) besides maintaining soil fertility (Baloach et al. 2014; Qasim et al. 2014).

Marigold (*Tagetes erecta* L.) is an important flower crop which can be cultivated throughout the year. Marigolds are ideal for making flower garden because of their attractive and colorful flowers. Marigold plant has got both industries and medicinal importance, and has desirable fragrance and adapts well to different environmental conditions. To assess the impact of PSM on marigold, Hashemabadi et al. (2012) assessed the effect of Barvar-2 P biofertilizer consisting of *Pseudomonas putida* and *Bacillus lentus* (Raissi et al. 2013) and different levels of P (100, 200,300 and 400 mgl^{-1}) on various attributes such as plant height, number of leaf per plant, fresh and dry weights of shoots and the content of P in shoot and flower diameter of marigold. Among various treatments, Barvar-2 in the presence of 400 mg P l^{-1} had maximum stimulatory effect on height (26.87 cm), the number of leaves per plant (56.27), flower diameter (84.42 mm), shoot fresh weight (19.94 g) and total shoot P (0.353 %) content in marigold plants. Generally, the interactive effect of biofertilizer and P was statistically not significant for any measured parameter except for total P accumulation in shoot and the number of leaf per plant. In a follow up study, Zaredost

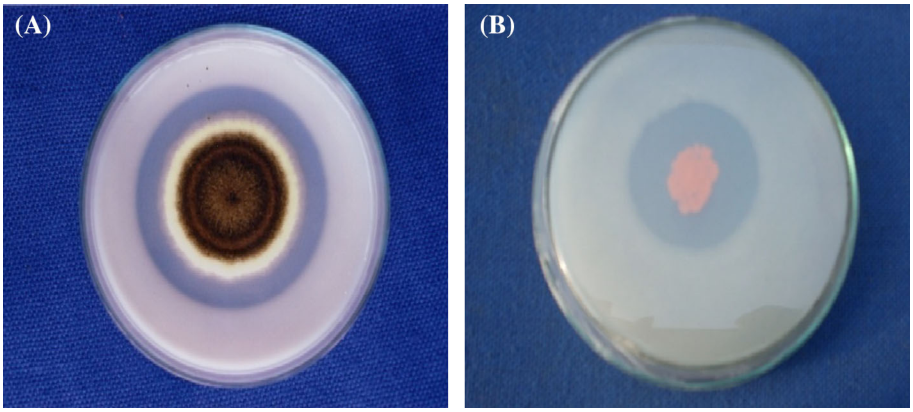

Fig. 1 Solubilization of tri-calcium phosphate on Pikovskaya plates by species of *Apergillus* (**a**) and *Serratia* (**b**)

Table 1 Organic acids produced by phosphate solubilizing bacteria and fungi

PSM	Organic acids produced	Source of insoluble P	References
Phosphate solubilizing bacteria			
Pantoea agglomerans, *Burkholderia anthina*, *Enterobacter ludwigii*	Gluconic	TCP	Walpola and Yoon (2013a)
Azospirillum, *Bacillus*, *Enterobacter*	Acetic, citric, gluconic	TCP	Tahir et al. (2013)
Enterobacter hormaechei subsp. steigerwaltii, *Bacterium* DR172	Gluconic, succinic, acetic, glutamic, oxaloacetic, pyruvic, malic, fumaric, alpha-ketoglutaric acid	TCP	Mardad et al. (2013)
Burkholderia ambifaria, *B. tropica*	Acetic, citric, gluconic, lactic, succinic, propionic	TCP	Surapat et al. (2013)
Acinetobacter rhizosphaerae	Gluconic, oxalic, 2-keto gluconic, lactic, malic, formic	TCP, URP MRP and NCRP	Gulati et al. (2010)
Fluorescent pseudomonas, *P. poae*, *P. trivialis*, *Pseudomonas* spp.	Gluconic, oxalic, 2-ketogluconic, lactic, succinic, formic, citric, malic	TCP, MRP, URP NCRP	Vyas and Gulati (2009)
Phosphate solubilizing fungi			
Aspergillus niger	Citric, gluconic, oxalic acid	Rock P	Mendes et al. (2014)
Trichoderma spp.	Citric, lactic acid, succinic acid	Rock P	Promwee et al. (2014)
Penicillium chrysogenum, *Penicillium* sp.	Citric acid, gluconic	Tilemsi RP, TCP, RP, Aluminum P	Babana et al. (2013); Chai et al. (2011)
Talaromyces flavus, *T. helices*, *P. janthinellum*, *P. purpurogenum*	Citric, valeric acid	TCP, Aluminum P, phosphorite	Scervino et al. (2010)
Absidia spp.	Citric, oxalic, gluconic acid	Rock P	Xiao et al. (2009)

Table 2 Bioactive molecules stimulating plant growth released exclusively by some important PSM

PSM	Active biomolecules	References
Phosphate solubilizing bacteria		
Sphingomonas	IAA, salicylic acid (SA), zeatin, abscisic acid (ABA)	Yang et al. (2014); Panhwar et al. (2014)
Burkholderia	IAA, siderophore, hydrogen cyanide, exopolysacharides, antifungal compounds	Zhao et al. (2014a); Stephen and Jisha (2011)
Bacillus	IAA, siderophores, lytic phosphatase, phytase enzymes, gibberellic acid	Susilowati and Syekhfani (2014); Panhwar et al. (2012)
Pseudomonas	IAA and gibberellic acid, antifungal metabolites, ACC deaminase, proteolytic enzymes, chitinase, cellulase, pectinase	Sivasakthi et al. (2013); Mehnaz et al. (2010)
Enterobacter	Siderophores, IAA, exo-polysaccharides, HCN, ammonia	Frank and Julius (2012)
Micrococcus	Auxin, ACC deaminase, siderophore	Reena et al. (2013); Dastager et al. (2010)
Phosphate solubilizing fungi		
Aspergillus	IAA, antifungal metabolites (against root and crown rot pathogen *F. Oxysporum*)	Ruangsanka (2014); Coutinho et al. (2012)
Trichoderma	IAA, antifungal metabolites (against *F. oxysporum* and *R. solani*), extracellular acid and alkaline phosphatases	Yasser et al. (2014); Yadav et al. (2011)
Penicillium	IAA, antifungal metabolites (against root and crown rot pathogen *F. Oxysporum*)	Ruangsanka (2014); Nath et al. (2012)

et al. (2014) conducted a similar experiment to evaluate the individual and combined effects of Barvar-2 and P (100, 200, 300 and 400 mg l^{-1}) on marigold. In agreement to earlier findings, the combined effect of Barvar-2 and chemical fertilizer was also insignificant for the most of the measured characteristics except for uptake of P by shoot and carotenoid content in petals. Furthermore, the lowest time to flowering (64.67 days) was obtained when seeds and transplant roots were inoculated with Barvar-2 × 400 mg P l^{-1}. Maximum display life, fresh weight, carotenoid content and concentration of P in shoots were observed in transplant roots inoculated with biofertilizer × 400 mg P l^{-1}. Ashwin et al. (2013) in other pot experiment conducted under greenhouse conditions evaluated the impact of P solubilizers *S. marcescens* and *A. awamori*, Zn-solubilizer (*A. niger*) and vermicompost on

Table 3 Examples of inoculation of some ornamental plants with P solubilizing bacteria

Host ornamentals	Botanical name	Inoculant PSM	References
Gladiolus	*Gladiolus grandiflorus*	*Serratia marcescens*, *Aspergillus awamori*, PSB	Ashwin et al. (2013); Chaudhari et al. (2013); Qasim et al. (2014)
Daisy	*Gerbera jamesoniiis*	*P. fluorescens*	Karishma et al. (2013a)
Petunia	*Petunia hybrid*	*Bacillus polymxa*	Hoda and Mona (2014)
Chrysanthemum	*Chrysanthemum* spp.	*P. fluorescens*	Kumari et al. (2014); Prasad et al. (2012);
Tuberose	*Polianthes tuberosa*	*B. polymyxa*, *Pseudomonas*	Srivastava et al. (2014); Koley and Pal (2011)
Rose	*Rosa damascene*	*Acinetobacter* sp.	El-Deeb et al. (2012)
Peace lily	*Spathiphyllum illusion*	Barvar-2	Abbasniayzare et al. (2012)
Sunflower	*Helianthus annuus*	*Azotobacter*, *Pseudomonas*, *Bacillus* sp.	Raval and Desai (2012)
Geranium	*Pelargonium graveolens*	*B. subtilis*, *P. flourescens*	Mishra et al. (2010)
Marigold	*Tagets erecta*	*Paenibacillus polymyxa*	Ramlakshmi and Bharathiraja (2015)
Bamboo	*Bambusa bamboo*	*A. chroococcum*	Sachin and Misra (2009)

marigold. The biofertilizer enriched vermicompost (EVC) significantly enhanced the growth characteristics like stem girth and bio-volume index of the plant except plant height. Plant fresh weight and dry weight was also more in EVC treatment. It was also observed that the number of flowers per plant and flower diameter was increased considerably in EVC treated plants compared to farmyard manure (FYM) and sole application of vermicompost. It was concluded that vermicompost apart from supporting as carrier material for biofertilizers also helps in stimulating the growth of plants and yield of marigold.

Abbasniayzare et al. (2012) conducted a study to compare the effects of biofertilizers and chemical fertilizers on growth indices of *Spathiphyllum illusion* including control (without fertilizer), Nitrokara (nitrogen biofertilizer), urea, Nitrokara + urea, Barvar-2 (P biofertilizer), triple super phosphate, triple super phosphate + Barvar-2 and Barvar-2 + Nitrokara. Of these treatments, triple super phosphate + Barvar 2 resulted in maximum number of leaves, dry and fresh weight of leaves and the size of spadix. Barvar-2 + Nitrokara, however, had the best impact on leaf size, height of flower stalk and chlorophyll content. Geranium is yet another ornamental which is erect and much-branched shrub with a height of up to 1.3 m and a spread of 1 m. The hairy stems of this plant are herbaceous when young but become woody with age. The deeply incised leaves are velvety and soft to the touch due to the presence of numerous glandular hairs. The leaves are strongly rose scented. The showy white to pinkish flowers is borne in an umbel-like inflorescence. Phosphate solubilizing *B. subtilis* (strain MA-2) and *P. fluorescens* (strain MA-4) have been found to increase the biomass by 9 and 27.6 %, respectively (Mishra et al. 2010). In a similar study, Raval and Desai (2012) reported a significant increase in root and shoot growth of sunflower (*Helianthus annuus*) grown in pot soils inoculated with PSB *Azotobacter*, *Pseudomonads*, and *Bacillus*. Ekin (2011) also investigated the effect of phosphate solubilizing *Bacillus* strain M-13 on seed set and filling efficiency, kernel yield and chemical composition of sunflower grown under field soils treated with three levels of P (0, 50 and 100 kg P_2O_5 ha^{-1}). The PSB application significantly enhanced the seed set by 8.2–20 %, seed filling efficiency by 1.3–1.9 %, kernel yield by 37.3–67 % and quality by reducing hull percentage by 15.2–24.3 % and improved nutrient concentration of seeds. It was concluded from this study that PSB in the presence of 50 kg P ha^{-1} can give similar seed set and kernel yield as those obtained with 100 kg P ha^{-1}. The fluorescent *Pseudomonas* positive to siderophores, IAA and HCN have also shown substantial increase in seed germination, root length, shoot height, fresh and dry weight of roots and shoots, and yield of sunflower (Bhatia et al. 2005).

Bamboo (*Bambusa bamboo*) is another ornamental plant which belongs to a group of woody perennial evergreen plants in the true grass family Poaceae, subfamily Bambusoideae and tribe Bambuseae. Bamboo is the fastest growing woody plant in the world whose growth rate [up to 1.2 m/day (1.5–2 inches/h)] is due to a unique rhizome-dependent system, which depends heavily on local soil and climate condition. Some of its members are giant bamboo. Commercially available timber is harvested from cultivated and wild stands and some of large bamboos. Some of its variety has culinary use (as edible bamboo) and some are used as medicine for treating infections. Effect of phosphate solubilizing and IAA positive gram positive bacterium *A. chroococcum* on growth of bamboo seedlings was studied by transferring 1 week old bamboo seedlings in the nitrogen free Hoagland's medium and in pot soils. It was observed that growth in the inoculated seedlings was more pronounced with profuse roots than non-inoculated seedlings. A significant increase in length and dry matter accumulation in roots and shoots of bamboo plants was observed in seedlings harvested 25 days after growth. It was suggested from this study that *A. chroococcum* could be beneficial for bamboo plantation due to their P solubilizing and IAA-producing ability (Dhamangaonkar and Misra 2009).

Examples of single and interactive (composite) effects of PSM on some ornamentals

Gladiolus (Gladiolus grandiflorus Ness) Gladiolus belonging to the family *Iridaceae* and subfamily Ixioideae (Goldblatt 1991) is an important ornamental and commercial bulbous flower known as queen of the bulbous plants. The name gladiolus is derived from the Latin word "*gladius*" meaning sword from the shape of its leaves. Gladiolus among cut flowers is an economically important ornamental crop grown for its: (1) elegant appearance, (2) attractive multi-colored spikes and (3) long vase life (Sajjad et al. 2014; Anderson et al. 2012). It is perhaps the second most popular cut flower after rose accounting for about 60 % of the total turnover of cut flowers (Naqvi and Ahmad 2012). It is grown both as potted and esthetic cut flower and is considered a profitable floricultural crop (Riaz et al. 2007). Good quality spike, corms and cormels in gladiolus are produced following consistent application of chemical fertilizers. On the other hand, Ali et al. (2014) evaluated the impact of "biopower" which consisted of *Azotobacter* and *Azospirillum* (free living N_2 fixers), *Rhizobium* (symbiotic N_2 fixer) and P solubilizing bacteria, purchased from the National Institute for Biotechnology & Genetic Engineering (NIBGE) Faisalabad, Pakistan, on growth and flower quality of *Gladiolus*, grown under greenhouse conditions. The measured vegetative and reproductive growth parameters were increased substantially due to bacterial applications. Among microbial cultures, *Azospirillum* used alone, showed maximum increase in plant height, florets spike, spike length, florets fresh weight and resulted in earlier sprouting than other treatments. Also, the monoculture of *Azospirillum* was superior in terms of cormels per plant (31.95 corm plant^{-1}) with their higher weight (9.65 g), longest vase life (11.6 days) and better macro nutrient uptake percentage (4.76 % N, 0.43 % P and 3.63 % K) over control plants. A significant increase in both number and weight of cormels could possibly be due to better availability of P, which is required especially for corm growth. The better cormels production in inoculated plants also had more carbohydrates which were due to effective photosynthesis. And hence, it was considered that the increase in corms weight might be due to storage of carbohydrates and N compounds in the corms. In a follow up study, Meenakshi et al. (2014) assessed the effect of three different biofertilizers like *Azotobacter*, phosphate solubilizing bacterium (PSB) and potassium solubilizing bacterium (KSB) along with varying levels of inorganic fertilizers: applied both singly and in combinations. Phosphate solubilizing bacteria in association with *Azotobacter* and KSB most effectively and profoundly increased the weight (corm/plant) and size of corm of gladiolus plants when grown in soils treated with 3/4th N, P and K. This microbial combination also enhanced water uptake, available N and K content in soil. However, the maximum number of florets opened per spike and available P content in soil were recorded for 1/2 N, P and K + *Azotobacter* + PSB + KSB application. Maximum fresh and dry weight of spike was observed for treatment containing 3/4th N, P and K + *Azotobacter* + KSB. Among all treatments, 3/4th N, P and K + PSB + KSB showed maximum vase life whereas, 3/4th N, P and K + *Azotobacter* + PSB produced maximum number of corms and cormels/plant. In a similar investigation, Qasim et al. (2014) conducted a field experiment to assess the effect of PSB, *Rhizobium*, *Azotobacter* and *Azospirillum* on growth and production of *Gladiolus* cultivar White Prosperity under field conditions. The microbial cultures were applied one at planting time using the dip method and the other before planting. Bacterial cultures, in general, significantly improved the vegetative and flowering traits, corms productivity and chemical composition of *Gladiolus* foliage. Of the treatments, *Azospirillum* in particular had the maximum positive stimulatory effect both on vegetative and reproductive attributes. Also, significant increase in total chlorophyll content, protein contents, total soluble sugars and accumulation of nutrients (N, P and K) in gladiolus plant was observed due to inoculation with *Azospirillum* which was followed by *Azotobacter* application. Apart from the use of microbial cultures only, *Azotobacter* and PSB in the presence of N (120 kg per ha^{-1}), P (65 kg per ha^{-1}) and K (62.5 kg per ha^{-1}) markedly enhanced the vegetative and floral characteristics of *Gladiolus* plants (Srivastava and Govil 2005). Srivastava and Govil (2007) in a follow up study evaluated the effect of PSB, *Azotobacter*, AM fungi and farmyard manure (FYM) on growth and flowering of *Gladiolus* cv. American Beauty. The biofertilizers were applied twice; one at the time of planting and the other before planting. Vegetative and floral characters, in general, were significantly improved following biofertilizers application relative to control. Among bacterial cultures, *Azotobacter* had the maximum positive effect on vegetative growth while PSB enhanced maximally the quality of spikes. Moreover, the treatment of the corms with the biofertilizers increased the total rhizosphere bacterial populations and maximum population (148.2 cfu/g soil) was recorded for *Azotobacter* (at 100 g/l) treatment with respect to control (70 cfu/g soil). This study suggested that the improved characters of gladiolus plants were possibly due to the growth promoting activities of inoculated bacteria. Single and combined effect of selected biofertilizers such as those prepared from *Azotobacter* and *Azospirillum* on growth, flowering and yield of gladiolus, grown in soil treated with different levels of NPK was variable (Dalve et al. 2009). However, the biofertilizers in the presence of reduced doses of N significantly influenced the growth, flowering and yield of gladiolus. Other growth attributes of *Gladiolus* such as number of leaves, plant height and flowering parameters like days required for: (1) emergence of spikes, (2) opening of first pair of florets, (3) 50 % flowering, yield factors namely number of: (a) florets per spike, (b) spikes per plant, (c) spikes per plot and per hectare, and corms and cormels per plant and per hectare were positively influenced by the application of both the biofertilizers in combination with N. However, the measured parameters were maximum under 75 % N + 100 % PK (375:200:200 kg NPK ha^{-1}) + *Azotobacter* + *Azospirillum* which was at par with the treatment containing 100 % NPK (500:200:200 kg ha^{-1} + *Azotobacter* + *Azospirillum*). It was concluded from this study that 25 % of N could be saved by applying biofertilizers in *Gladiolus* farming. In other study, Dongardive et al. (2007) evaluated the effects of organic fertilizers on the performance of *Gladiolus* cv. White Prosperity using NPK (500:200:200 kg/ha), FYM (4t/ha), vermicompost (8t/ha), neem cake (6t/ha), FYM + *Azotobacter* (5 kg/ha), vermicompost + *Azotobacter* (5 kg/ha), neem cake + *Azotobacter*, FYM + PSB (5 kg/ha), vermicompost + PSB, neem cake + PSB, FYM + *Azotobacter* + PSB, vermicompost + *Azotobacter* + PSB, and neem cake + *Azotobacter* + PSB. The NPK resulted in the lowest number of days to corm sprouting, number of days to 50 % spike initiation and number of days to opening of the first two florets, and greatest plant height, leaf length, number of leaves per plant, spike length, number of spikes per plant, number of florets per spike and floret diameter. This was followed by vermicompost + *Azotobacter* + PSB treatments which showed maximum increase in *Gladiolus* performance.

Daisy (Gerbera jamesonii) Daisy Bolus ex. Hook (family Asteraceae) quite often called as Transvaal daisy or Barberton daisy is a tender perennial possessing intensely colored disc-shaped hard flowers and leafless stems. Gerbera is very popular and widely used as a decorative garden plant. Commercially, Gerbera is most important ornamental plant ranking fifth among the cut flowers in the world (Parthasarathy and Nagaraju 1999). The flowers are hard and stand the rigorous transportation. The long vase life fetches a good market price. Therefore, the improvement in quality attributes such as number of flowers, longevity and flower size are important economic concerns. Karishma et al. (2013a) in a pot experiment assessed the effect of mixture of PSB (*P. fluorescens*) and AM fungi (*G. mosseae* and *Acaulospora laevis*) on the performance of *Gerbera*, grown with varying levels, i.e., low (20 kg/ha), medium (40 kg/ha) and high (80 kg/ha) of superphosphate. While comparing the effects of all inoculations, mixture of three cultures (*G. mosseae* + *A. laevis* + *P. fluorescens*) in the presence of lower concentration (20 kg/ha) of superphosphate had the maximum positive impact on root length, root biomass, percent root colonization, AM spore number, number of flowers, P content and phosphatase activity. Also, maximum increase in leaf area and shoot biomass was found in *G. mosseae* + *P. fluorescens* inoculated plants grown in pots treated with lower concentration of superphosphate. This study suggests that the combined inoculation of PSB and AM fungi could serve as a commercially potent biofertilizer for enhancing the overall performance of *Gerbera* plants while substantially reducing the chemical inputs.

Rose (Rosa spp.) Rose is a woody perennial belonging to genus *Rosa* within Rosaceae family. Over 100 species and thousands of cultivars of roses are known. Most species are native to Asia, while some are native to Europe, North America, and northwest Africa. Plants are erect shrubs, climbing or trailing with stems that are often armed with sharp prickles. Rose plants range in size from compact, miniature roses, to climbers that can reach seven meters in height. Flowers vary in size and shapes and are usually large and attractive in colors ranging from white through yellows and reds. Roses are widely grown for their beauty and are often fragrant. Even though there are numerous reports on the prevalence of PSM inhabiting different habitat, little is, however, known about the bacterial communities associated with the rose plants being grown in dry desert ecosystems. Extremes of temperature, water scarcity, nutrient deficient soils, high velocity winds and land degradation are, however, some of the fundamental problems for growing rose plants in arid ecosystems. Also, plant communities in arid habitat are controlled by the interaction between biotic and physicochemical components of the desert matrix (Read 1998). Interactions with microbes appear crucial in obtaining inorganic nutrients or growth-influencing substances. To unravel such difficulties, El-Deeb et al. (2012) conducted a study to isolate and characterize endophytic bacteria from different organs of surface sterilized rose plants collected randomly at flowering stage from rose farm in the hill mountain outside Taif City, Saudi Arabia; an elevation of around 2000 m above sea level. Root, stem, leaves and flower of each plant were kept in a plastic bag in a cooler, stored at 4 °C and analyzed thereafter. Endophytic bacteria were recovered from healthy roots, stems, leaves, and flowers of rose plants, with a significantly higher density in roots, followed by stems, leaves, and petals. During this experiment, a total of 38 bacterial endophytes were isolated and were identified to genus level using 16S rRNA sequence analysis. The selected isolates were found closely related phylogenetically to *Acetobacter*, *Acinetobacter*, *Methylococcus*, *Bacillus*, *Micrococcus*, and *Planococcus*. These bacterial cultures were tested further for their plant growth promoting activities and demonstrated phosphate solubilizing activity, produced IAA and siderophore. Also, the six endophytic bacteria produced hydrolytic enzyme such as cellulase, xylanase, pectinase, amylase, protease, lipase, and chitinase. However, the concentration of these enzymes varied among six bacterial genera. Generally, the hydrolytic enzymes of endophytes have been found to play an important role in the colonization of plant roots (Quadt-Hallmann et al. 1997; Reinhold-Hurek and Hurek 1998; Sakiyama et al. 2001) which has further been supported by the release of cellulolytic and pectinolytic enzymes by other endophytic bacteria such as *Rhizobium* sp. (Al-Mallah et al. 1987). In addition to affecting colonization, such hydrolytic enzymes also help bacteria to enter the interior of the roots by hydrolyzing wall-bound cellulose, auxin-induced tumors, water flow and wounds, or where the lateral roots branch (Al-Mallah et al. 1987). Therefore, the secretion of seven enzymes by the six endophytic PSB in this study could be of greater importance in colonization of ornamental plants by PSB. Since phosphate solubilizing bacteria have now been isolated from rose plants, they have also been tested to assess their impact on the performance of rose plants. For example, response of integrated nutrient management on growth and flowering in rose. cv. Gruss-an-Teplitz grown under field experiment was observed (Singh 2007). For this experiment, the treatments were (g/m^2): (1) 50 N, (2) 40 P, (3) 30 K chemical fertilizers, (4) 4 kg farm yard manure (FYM) + remaining required dose of NPK, (5) 4 kg FYM + remaining required dose of NPK + *Azotobacter*, (6) 4 kg FYM + remaining required dose of NPK + PSB, (7) 2 kg poultry manure (PM) + remaining required dose of NPK, (8) 2 kg PM + remaining required dose of NPK + *Azotobacter*, (9) 2 kg PM + remaining required dose of NPK + PSB and (10) one control (without manure and fertilizers) were used. Maximum leaf biomass production and dry matter accumulation in leaves were recorded with treatment containing 4 kg FYM + remaining required dose of NPK + PSB while lateral shoots/plant was maximum at 4 kg FYM + remaining required dose of NPK + *Azotobacter*. The flowering attributes such as number and weight of flowers/plant, diameter of flowers and number of petals/flower were highest on plants grown with NPK (50, 40, and 30 g/m^2). The measured parameters were also statistically at par with 4 kg FYM + remaining required dose of NPK + *Azotobacter*. In the presence of 4 kg FYM + remaining required NPK, *Azotobacter* showed maximum flower yield and dry weight of flowers/plant. However, the two treatments did not differ significantly in terms of flowering and yield attributes. It was concluded from this study that half dose of chemical fertilizers can be saved by applying *Azotobacter* with 4 kg FYM + remaining required NPK.

Petunia (Petunia hybrida), the common garden petunia, *Petunia hybrida*, is derived from *P. integrifolia* and *P. axillaris* that are two of many species endemic to South America. It is sun and heat-loving annuals or tender perennials herbs, up to 1 m tall. It has erect, ascendant, decumbent or procumbent stems. The leaves are sessile or petiolate with blades elliptic, ovate or obovate, more rarely rounded or linear, membranaceous, somewhat juicy, flat and usually without marked venation. Petunia is cultivated in flower beds and pots and requires full sunlight to produce plants and flowers with bright attractive colors. They grow in nutrient rich soil and require regular fertilization for best blooming. The effect of different combinations of vermicompost and two biofertilizer on growth, yield and quality of petunia was evaluated by Moghadam and Shoor (2013). Among all treatments, the mixture of *Azospirillum* sp. + PSB + vermicompost + 25 % of recommended dose of NPK resulted in maximum plant height, number of branches, plant spread, leaf area index, dry matter accumulation and yield attributes such as number of flowers per plant, number of flowers per plot, flower yield/plant, flower yield/plot. This combination of *Azospirillum* sp. + PSB + vermicompost + 25 % of recommended dose NPK caused early flower bud initiation, produced 50 % flowering, enhanced the duration of flowering and significantly improved flower diameter. In a follow up study, Hoda and Mona (2014) conducted two field experiments during two successive seasons of 2011 and 2012 to assess the impact of biological and synthetic fertilizers on growth, flowering and chemical characteristics of petunia (cv. Bravo white). The biological cultures used to spray *Petunia* plants included *B. polymyxa* (P dissolving bacteria, PDB) and one nitrogen fixing *A. lipoferum*. These cultures were used both separately and in combination in the presence or absence of a complete fertilizer: 19 N:19P_2O_5:19K_2O. The solo and co-culture of the two bacterial inocula significantly increased the vegetative growth (plant height, branches number, leaf area, dry weights of shoots and roots) and flower characteristics (such as flowering date, number of flowers/branch and flowering period) relative to control. Furthermore, the mixture of *Azospirillum* sp. with *Bacillus* sp. and 5 g plant^{-1} of the chemical fertilizer demonstrated maximum increase in growth, flowering attributes and chemical characteristics for example, chlorophyll, total carbohydrates, and N and P contents, over control. It was clear from this study that the tested biofertilizers apart from improving the nutrient pool of soil also increased the efficiency of added chemical fertilizer. And hence, the rate of chemical fertilizer for high quality *Petunia* plants could be reduced to half when grown in the presence of PDB and N_2 fixing bacteria. Furthermore, the half dose of fertilizer plus composite culture of each organism yielded results comparable to those observed with recommended dose of chemical fertilizers.

Chrysanthemum (Chrysanthemum indicum) Chrysanthemum indicum (L.) is popularly known as Gul-e-Daudi or ‘Glory of the East’ and belongs to the family Compositae (Asteraceae). Generally, *Chrysanthemum* is considered one of the most widely cultivated garden flowers and ranks probably next to rose. It produces mostly showy flowers with wide range of shapes, size and color and is highly suitable for pot culture and bedding purposes. The problems associated with production of *Chrysanthemum* are, however, the use of expensive chemical fertilizers, poor soil health, and lack of modern technology (Kumari et al. 2014). To avoid chemical usage and to identify a suitable microbial pairing for *Chrysanthemum* production, a study involving the use of *G. mosseae* and *A. laevis* (AM fungi) and *P. fluorescens* (PSB) with different levels of superphosphate (SP), i.e., medium concentration is the recommended one (40 kg/ha), lower (20 kg/ha) and higher (80 kg/ha) was designed and executed in a pot trial experiment and different plant growth parameters were measured (Prasad et al. 2012). Here, the biofertilizers inoculated plants grown in the presence of recommended dose of SP (40 kg/ha) had significantly better growth. Among various treatments, inoculation with *A. laevis* + *P. fluorescens* at medium concentration (40 kg/ha) of SP resulted in maximum height, fresh and dry root weight, AM root colonization, AM spore counts, alkaline and acid phosphatase activity, and accumulation of P in shoot and root of *Chrysanthemum* plants. In contrast, root length was maximum in *G. mosseae* + *A. laevis* + *P. fluorescens*. Leaf area and fresh and dry shoot weight were maximum when plants were inoculated with *G. mosseae* + *A. laevis* + *P. fluorescens* and grown in soil amended with lower concentration of SP. The overall increase in the performance of this plant was attributed due to the maximum nutrient acquisition mediated by AM fungi and other growth enhancers released by PSB. Similarly, to optimize the production of flowers in annual chrysanthemum, Meshram et al. (2008) conducted a study with graded doses of NPK and *Azospirillum* sp., *Azotobacter* sp., and PSB (bio-inoculants). Interestingly, the initiation of first flower, days to 50 % flowering, diameter of fully opened flower, longevity of flower intact on plant and yield attributes like number of flowers/plant, yield of flowers/plant (g) and yield of flowers/ha (q) with high biological: chemical (B:C) ratio were significantly maximum with treatments receiving 80 % NPK + *Azospirillum* sp. + *Azotobacter* sp. + PSB at 5 kg/ha each followed by the treatment involving 80 % NPK + *Azospirillum* sp. + PSB at 5 kg/ha each over control and other treatments.

Tuberose (Polianthes tuberose) Tuberose belonging to the family Amaryllidaceae is one of the most important commercial cut flowers which are famous for their sweet fragrance in many countries. It is a perennial self perpetuating bulb. The aerial portion consists of a rosette of leaves, which are narrow, linear and light green. Inflorescence is known as spike and bears the florets in pairs. The spikes are used as cut flowers for vase decoration and bouquets, while individual flowers are used for making garland, button holes and extracting essential oils. To optimize the cut spikes production, progressive farmers often use a higher quantity of chemical fertilizers which of course over a period of time reduces soil fertility. And hence, to increase the growth and quality of tuberose plants, the field growers should adopt a safer strategy like they should use biofertilizers (Srivastava et al. 2014). In this context, an experiment was conducted to assess the effect of both N fertilizer and PSB on different traits of tuberose. Urea was used as N source at 0, 50, 100 and 200 kg/ha while PSB was added at 0, 5 and 10 kg/ha to the experimental soil. Soil was treated with PSB before planting while split application was followed for N: one after emergence of the bulbs and second 20 days after the first application. The measurable features of plants were height, length of florescence, stem and floret diameter, number of leaves and florets, and fresh and dry weights of aerial parts and roots. Application of N fertilizer significantly increased the measured parameters except stem and floret diameters. In comparison, PSB enhanced all growth parameters except dry matter accumulation in upper organs of inoculated plants. While comparing the effect of each level of N and microbial culture on tuberose plants, 200 kg N/ha and 10 kg PSB/ha was found superior and produced highest yield and quantitative traits of tuberose plants (Taher et al. 2013). Kashyap et al. (2014) in a field trial evaluated the effect of biofertilizers including asymbiotic nitrogen fixer (*Azotobacter*) and PSB along with different levels of chemical fertilizers on growth and flowering attributes of tuberose. Basal dose (5 kg/m^2) of farm yard manure (FYM) was also used along these treatments. The growth characteristics such as plant height, number of leaves per plant and days taken for emergence of bulbs of biofertilizer inoculated tuberose plants were increased significantly with increasing levels of chemical fertilizers. Among various single and composite treatments, biofertilizers in the presence of 15, 11.2 and 9.3 g/m^2 of N, P and K, respectively, showed the highest stimulatory effect and enhanced the measured parameters dramatically. The increasing levels of N, P and K alone and in combination with biofertilizers increased the per cent sprouting of bulbs to 100 % relative to. Also, the maximum number of leaves (72.56) was observed with *Azotobacter* + PSB + N, P and K (15, 11.2, 9.3 g/m^2, respectively) compared to control (56.53/plant). The increase in the overall performance of tuberose plants was suggested due to the availability of P (PSB) and N (*Azotobacter*) and some other growth stimulating factors released both by PSB and *Azotobacter* (Khan et al. 2010). This study suggested that the higher dose of N, P and K used in tuberose production could be reduced by 25 % by applying biofertilizers either alone or in combination with chemical fertilizers. Pandhare et al. (2009) in a field trial evaluated the effect of bio-inoculants with reduced doses of inorganic fertilizers on flower quality and yield of tuberose grown during *kharif* (monsoon) season which lasts between April and October depending on the area. Bio-inoculants in the presence of lower than recommended doses of inorganic fertilizers (200:300:200 kg/ha NPK) affected the formation of spikes and quality of tuberose plants. The bio-inoculant (*Azotobacter* and PSB) applied pre planting with 75 % NP (150:225 kg ha^{-1}) and 100 % K (200 kg ha^{-1}) considerably enhanced the yield and yield related characters such as number of florets per spike and per plant, weight of loose flowers per plant and floret size. In other experiment, *B. polymyxa* (PSB), *A. brasilense* (N_2 fixer), and *A. chroococcum* (N_2 fixer) and certain inorganic nutrients were applied both as solo application and as mixture to assess their impact on growth and flowering of *Tuberose* cv. Prajwal (Koley and Pal 2011). Biofertilizers in the presence of chemical fertilizer significantly increased the height, number of leaves, spike length, spikes clump^{-1} of tuberose plants. Among different biofertilizers, *Azotobacter* in the presence of NPK (10:8:10 g m^2) showed the maximum (68.95 cm) plant height which was statistically at par with [NPK (10:0:10 g m^2 + PSB)] while PSB in the presence of NPK (10:4:0 g m^2) produced lowest (59.91 cm) plant height. Maximum number (65.45) of leaves were recorded when PSB was used with NPK (10:0:10 g m^2) which were statistically at par with NPK (10:4:10 g m^2) + *Azotobacter*) while NPK (5:8:10 g m^2) along with PSB produced minimum leaves (53.48) on tuberose plants. The increase in number of leaves was suggested probably be due to the release of growth promoting substances such as IAA or GA like substances, Vit B12, thiamine, riboflavin (B2), etc., by PSB, *Azotobacter* or *Azospirillium* when used alone or in combination. The combination of *Azotobacter* and NPK (10:8:10 g m^2) produced maximum (92.5 cm) spike length while *Azotobacter* in the presence of 10:4:10 g m^2 NPK resulted in maximum florets per spike formation (54.61). Conclusively, the tested biofertilizers expressing growth promoting activities as observed here may be incorporated into the nutrient schedule of tuberose production. Similar report on growth of inoculated tuberose plant is reported by Wange and Patil (2007). The influence of N, P and biofertilizers (*Azotobacter*, PSB and vesicular arbuscular mycorrhiza, VAM) on growth and bulb production in other study on tuberose was variable (Chaudhary 2007). Application of biofertilizers in combination with N at the rate of 100 kg per hectare and P at the rate of 50 kg per hectare proved to be equally effective to N at the rate of 200 kg/ha and P at the rate of 100 kg/ha in increasing the plant height, number of leaves per plant, number of bulbs/plant and advancing the sprouting of bulbs. The higher dose of N and P independently did not affect the growth, sprouting of bulbs, and bulb production in tuberose.

Tulip (Tulipa gesneriana L.) Tulips are a perennial, bulbous plant/an herbaceous herb with showy flowers in the genus *Tulipa* belonging to family Liliaceae. They are spring blooming plants that grow from bulbs. Depending on the species, tulip plants can be between 4 inches (10 cm) and 28 inches (71 cm) high. The tulip's large flowers usually bloom on scapes with leaves in a rosette at ground level and a single flowering stalk arising from among the leaves. Plants typically have 2–6 leaves while some species have up to 12 leaves. Most tulips produce only one flower per stem, but a few species produce multiple flowers. The generally cup or star-shaped tulip flower has three petals and three sepals which are often termed tepals because they are nearly identical. The effect of bio-inoculants on growth, flower quality and bulb yield of 'Apeldoom' tulip was assessed in Kasmir by Khan et al. (2009). For this experiment, three treatments containing biofertilizers included *A. chroococcum* and *A. lipoferum* and without biofertilizer, and four levels of N [0, 50, 75 and 100 % of recommended dose (75 kg/ha)] of urea as N were tested in a randomized block design with three replications. Urea was added to experimental soil at planting. Healthy and uniform sized (10–12 cm) bulbs were dipped in thick slurry of carrier based *A. chroococcum* and *A. lipoferum* cultures for 30 min and dried in shade for 30 min. Bioprimed bulbs were planted for two consecutive years in beds maintaining 40 bulbs/m^2. Among two bacterial cultures, *Azotobacter* was found superior and significantly increased the height (38.9 cm), wrapper leaf area (lower most leaf) (143.39 cm^2), tepal diameter and bulb yield of tulip plants. Among different level of N, a consistent increase in N from 0 to 100 %, though enhanced the growth and bulb attributes but delayed flowering in tulip. While comparing the interactive effect of bio-inoculants × N fertilizers, the interaction of *A. chroococcum* × 100 % N was though found most effective and dramatically increased the growth, quality of tulip flower and yields of bulb, but was statistically at par with *A. chroococcum* + 75 % N.

Peace lily (Spathiphyllum illusion) Peace lily belonging to family Araceae is a very popular indoor flower grown in many tropical regions of America and Southeast Asia. *Spathiphyllum* is an important ornamental foliage which has a beautiful large leaves (12–65 cm long and 3–25 cm broad) and white spadix. The plant does not need large amounts of light or water to survive. Abbasniayzare et al. (2012) studied the effects of biofertilizers and chemical fertilizers both separately and jointly on growth indices of *S. illusion*. The treatment used in this study were: (1) Barvar-2 (P biofertilizer), (2) Nitrokara (N biofertilizer), (3) urea (N fertilizer), (4) nitrokara with urea, (5) triple super phosphate (TSP; chemical P fertilizer), (6) TSP with Barvar-2 and (7) Barvar-2 with Nitrokara. Among all treatments, the phosphate solubilizing bacterial preparation "Barvar 2" in the presence of TSP substantially enhanced number, dry and fresh weight of leaves and the size of spadix. In addition, "Barvar-2 with nitrokara" was found superior combination and showed greatest positive impact on foliage size, height of flower stalk and chlorophyll content. However, maximum accumulation of N was obtained when plant was grown with urea.

Interactive effect of PSM and AM fungi on ornamental plants

Phosphate solubilizing microorganisms can also be used in association with AM fungi for enhancing the quality and yield of ornamental plants. Arbuscular mycorrhizal fungi (AMF) acts as biofertilizer and facilitate plant growth by enhancing nutrient (especially P) uptake, increasing chlorophyll content (Demir 2004), and providing tolerance to plant against different stresses (Aggarwal et al. 2012; Tanwar et al. 2013). The growth stimulatory effects of AM fungi on ornamental plants (Banuelos et al. 2014; Prasad et al. 2012) such as *P. hybrida*, *T. erecta* and *Chrysanthemum morifolium* (Gaur and Adholeya 2005; Sohan et al. 2003) have been reported. Likewise, Long et al. (2010) observed increase in number and size of *Zinnia* flower when inoculated with efficient strain of AMF. The interactive effect of PSM and AM fungi on ornamental plants is, however, negligible. However, in some instances for example, increase in carnation plant height due to AM fungi and PSB is reported by Bhatia et al. (2004). In a polyhouse experiment, the impact of two AM fungi (*Funneliformis mosseae* and *A. laevis*) along with *T. viride* and *P. fluorescens* on growth and flowering of *Chrysanthemum* was assessed (Karishma et al. 2013b). The measured growth parameters of inoculated plants increased significantly after 120 days of inoculation over control. Shoot height, number of flowers, P uptake (both in shoot and root) and total chlorophyll content were recorded highest in triple inoculation of (*F. mosseae* + *A. laevis* + *T. viride*) while fresh and dry shoot weight and stomatal conductance was found highest in plants inoculated with dual combination of (*F. mosseae* + *T. viride*). Single inoculation of *F. mosseae* maximally increased the leaf area while in the presence of *T. viride* it enhanced some growth parameters but when applied with *A. laevis* and *T. viride*, it was found as a superior combination for growth and flowering of *Chrysanthemum*. Kumari et al. (2014) in a pot experiment investigated the effect of PSB (*Pseudomonas* sp.) and mycorrhiza (*Glomus* sp.) and different levels of P on growth, yield and quality of *Chrysanthemum*. The combined effect of PSB and different levels of P was found to be significant and maximum plant height, fresh weight of plant and dry weight of plant were recorded with PSB + 15 P g/m^2. The minimum number of days for bud initiation, number of days to first flowering, maximum number of buds per plant, number of flowers per plant and the longest flower stalk were also obtained with PSB + 15 P g/m^2. Ramlakshmi and Bharathiraja (2015) in a recent study reported that the growth and yield of marigold was significantly enhanced by the co-inoculation of AM fungi (*G. fasciculatum*) and phosphobacteria (*Paenibacillus polymyxa*) with 75 % of P and 100 % NK fertilizers and was followed by AM fungi + phosphobacteria and 50 % P and 100 % NK fertilizers. From this study, they suggested that the combined application of AM fungi and phosphobacteria could help to reduce the use of phosphatic fertilizers by 25 % in marigold production.

Management of ornamental diseases using PSM-A general perspective

Soil borne pathogens capable of inflicting losses to ornamental plants are a major threat to floriculture industry. Among pathogens, *Fusarium* species namely *Fusarium oxysporum* f. sp. *gladioli*, *F. solani*, *F. moniliforme* and *F. roseum*, for instance, causes yellowing and corm rot (Tandon and Bhargava 1963; Sarabhoy and Agarwal 1983), browning of foliage and wilting in *Gladiolus*, and concurrently reduces the quality, yield and market value of *Gladiolus*. Of these fungal species, *F. oxysporum* f. sp. *gladioli* (Massay) Snyder and Hansen are common and distributed worldwide. Following infection, the corms show tissue discoloration and become softened, wrinkled and mummified in storage. Different management practices used to control phytopathogens include chemical applications (Fulsundar et al. 2009), use of resistant cultivars (Mørk 2011), cultural practices (Riaz et al. 2009) and integrated biotechnological approaches (Salma et al. 2014; Sharma et al. 2005). As an example, to manage diseases for example powdery mildew of roses caused by *Sphaerotheca pannosa*, ornamental growers use expensive pesticides such as mancozeb. Generally, pesticides are highly specific chemicals used to control dangerous pests. Among other fungal diseases of ornamental plants, leaf spots caused by bacteria (pathovars of *P. syringae* and *Xanthomonas campestris*) and fungi [*Alternaria*, *Cercospora*, *Colletotrichum* (anthracnose) and *Myrothecium*], molds, downy mildews, rusts and blights are highly common. Considering the incredible disease threats to ornamentals, two approaches are frequently employed to control fungal diseases: (1) protectants and (2) eradicants. Of these, protectants are used to foliage to control disease from occurring. Some of the common protectants are mancozeb (highly effective against fungal leaf spots, blight and rusts) and chlorothalonil and triforine (controls black spot) while myclobutanil protects against powdery mildew on ornamentals such as crape myrtle, roses and snapdragons. Eradicant, in contrast, are fungicides that kill pathogens after they infect plants. And hence, eradicants should be applied immediately after the first visible sign of disease to avoid further plant damage. The repeated and excessive application of pesticides (protectants or eradicants) has, however, resulted in the emergence of pathogens resistant to such chemicals (Hobbelen et al. 2014; Rivero et al. 2010). Additionally, the consistent accumulation of pesticides in soil decreases the quality of soil due to the damaging effect of such agrochemicals on: (1) the structure, composition and functions of beneficial soil microflora (Ahemad and Khan 2012; Ahemad and Khan 20 10) and (2) soil problems such as structural degradation, reduction of organic matter and soil colloidal content. Moreover, some of the chemicals for example, methyl bromide (MB) used for preplant soil fumigation for the production of fruit and vegetables, orchards and vineyards, and nursery crops, to control a broad spectrum of pests, has been found as extremely toxic and ozone depleting substances (ODS). And hence, considering the high toxicity of MB to crops and ground water, the Montreal Protocol in 1997 suggested to reduce the use of MB in many countries (Gullino et al. 2003). The global phaseout schedule adopted by the Montreal Protocol provided renewed and stronger impetus to search for chemical alternatives (Katan 2000). Thus, the production cost, destructive environmental impact, emergence of resistant pathogens and perhaps lack of resistant ornamental plant varieties have generated interest among ornamental growers in employing biotechnological applications including the use of inexpensive PSM in the management of phytopathogens (Orberá et al. 2014; Postma et al. 2013). For instance, some of the more promising strains of the biocontrol agents have been developed and marketed as a powerful alternative to traditional chemical based fungicides for their use against pathogens (Chandel and Deepika 2010). Such biocontrol products are introduced on regular basis for a wide variety of plant pathogenic organisms, some of which remain active for years while others show its activity for a very short period. The disease suppressing/controlling ability and other simultaneous plant growth promoting properties of PSM are, therefore, considered best practical option for enhancing ornamental production in different agro-ecological niches.

Without doubt, no substantive efforts have, however, been made toward exploring the enormous potential of PSM in the management of ornamental diseases.

Mechanism of disease suppression: an overview

The control of phytopathogens via PSM (Zaidi et al. 2014) is accomplished through synthesis of secondary metabolites like: (1) siderophores (Ahmad et al. 2013), (2) antibiotics (Raaijmakers and Mazzola 2012), (3) lytic enzymes (Ruchi et al. 2012), (4) cyanogenic compounds (Walpola and Yoon 2013a) and (5) induction of systemic resistance (ISR) (Choudhary and Johri 2008). Siderophores, a low molecular weight iron (Fe) chelating compounds, are produced by PS bacteria under iron starved conditions at neutral to alkaline pH (Sharma and Johri 2003). Many workers have reported the release of siderophores by PS bacteria belonging to the genera *Pantoea* and *Burkholderia* (Walpola and Yoon 2013b), *Bacillus* (Sivasakthi et al. 2013), *Acinetobacter* (Zhao et al. 2014b) and *Pseudomonas* (Noori and Saud 2012), etc. Siderophores prevent phytopathogens from acquiring sufficient amounts of iron thereby limiting their ability to proliferate (Kloepper et al. 1980). This biocontrol mechanism adopted by PS bacteria has been found more effective than fungal P solubilizers because bacterial siderophores, in general, have greater affinity for iron than do fungal pathogens (Schippers et al. 1987). As a result, due to iron limitation near root zone, fungal pathogens fail to proliferate. In contrast, the growth of plants is generally not adversely affected by the complexation of iron with siderophores since majority of plant species are able to grow even at lower iron concentrations than do the microorganisms (O'Sullivan and O'Gara 1992). Evidences suggest that the siderophores do play an important role in suppression of fungal pathogens of ornamental plants. For example, Salma et al. (2014) assessed the biological control efficiency of certain rhizobacterial strains for suppression of *Fusarium* wilt disease in *Gladiolus*. Of the total 25 rhizobacteria selected, strains of *Pseudomonas* and *Bacillus* inhibited maximally the *F. oxysporum* f. sp. gladioli. Furthermore, the solo application of *Pseudomonas* strain HCS2 showed maximum increase in plant height (66.7 cm) and produced superior floral attributes over control under pot house conditions. The co-inoculation of HCS2 with pathogen, however, completely suppressed the disease without any wilting symptoms. In a similar study, of the 63 different

Bacillus isolates used by Karuppiah and Rajaram (2011), six species inhibited the growth of *Penicillium*, *Cercospora* sp. and *F. oxysporum*. The inhibition of fungal pathogens was found due to the production of siderophores, antibiotics, and hydrolytic enzymes released by PSB (Ruchi et al. 2012).

Production of antibiotics by PSM is considered yet another most powerful tool for controlling phytopathogens of ornamental plants. Many antibiotics, for example, butyrolactones, zwittermicin A, kanosamine, oligomycin A, oomycin A, phenazine-1-carboxylic acid, pyoluteorin, pyrrolnitrin, viscosinamide, xanthobaccin, and 2,4-diacetyl phloroglucinol (2,4-DAPG) produced by PSM (Mazurier et al. 2009; Trujillo et al. 2007) have been found effective against phytopathogens (Loper and Gross 2007; Velusamy et al. 2006). The serious problem in relying heavily on antibiotic positive bacteria is, however, that with the regular use of such strains there is every chance for phytopathogens to develop resistance against antibiotics (Gayathri et al. 2010). To counteract this problem, researchers have suggested to use antagonist strains for example *Bacillus* and *Pseudomonas* (Schippers et al. 1990; Bakker and Schippers 1987) that synthesizes simultaneously both HCN and one or more antibiotics. This approach looks attractive since if HCN fails to exhibit biocontrol activity by itself, it is likely to act synergistically with bacterially encoded antibiotics (Haas and Keel 2003). A variety of other microbial compounds involved in disease suppression includes defense enzymes, such as, cellulases and chitinase (Ramyasmruthi et al. 2012; Kim et al. 2008), β-1,3-glucanase (El-Sayed et al. 2014), peroxidise (Maria et al. 2010) and protease and lipase (Gajera and Vakharia 2012). These enzymes have shown biocontrol activity against a range of pathogenic fungi including the genera *Botrytis* (Nabti et al. 2014), *Fusarium* (El-Sayed et al. 2014), *Sclerotinia* (El-Sayed et al. 2014), *Alternaria* (Ramyasmruthi et al. 2012), *Phytophthora* spp. (Stephen and Jisha 2011), *Rhizoctonia* (Nagarajkumar et al. 2004) and *Pythium* (Frankowski et al. 2001). As an example, *P. putida* demonstrated antifungal activity against phytopathogenic fungi (*A. alternata*, *F. oxysporum* and *R. solani*) in Petri dish assays (El-Mehalawy et al. 2007) by producing chitinase, β-1,3-glucanase, salicylic acid, siderophore and HCN (Selvakumar et al. 2009). Another bacterial species for instance, *B. subtilis* with PS activity showed antagonistic activity against *Phytophthora capsici*.

Examples of phosphate solubilizers as potential ornamental disease control agents

Phosphate solubilizing microorganisms involving bacteria (Zaidi et al. 2014), fungi (Khan et al. 2010) and actinomycetes (Saif et al. 2014), etc., have been used as antagonists to combat phytopathogens affecting ornamental plants (Table 4). For example, *Gladiolus* among

Table 4 Examples of PSM acting as biocontrol agent against ornamental diseases

Ornamental plants	Ornamental diseases	Growth inhibition of causal organisms	PSM as biocontrol agent	Possible active principle	References
Gladiolus	Corm rot disease	*F. oxysporum* f. sp. gladioli	*Pseudomonas fluorescens*	HCN, siderophore	Naqvi and Ahmad (2012); Basharat et al. (2011)
	Disease complex	*Meloidogyne incognita*, *F. oxysporum* f. sp. gladioli (Masey)	*P. putida*, *Paecilomyces lilacinus*	ND	Sowmya and Rao (2012)
	Vascular wilt and corm rot	*F. oxysporum* f. sp. gladioli (FOG)	*Bacillus atrophaeus*, *Burkholderia cepacia*	ND	Shanmugam et al. (2011)
Dianthus	Carnation wilt	*F. oxysporum* f. sp. dianthi	*Trichoderma* spp.	Lytic enzymes, chitinases and β-1, 3-glucanases	Shanmugam and Sharma (2008)
	Vascular wilt	*F. oxysporum* f. sp. dianthi	*P. fluorescens*	Mycolytic enzymes, chitinases	Ajit et al. (2006)
Sunflower	Collar rot	*Sclerotium rolfsii*	*P. flourescens*	Siderophore;HCN	Bhatia et al. (2005)
Coleus	Root rot	*M. phaseolina*	*P. agglomerans*, *P. putida*	Lipase, catalase, protease	Damam et al. (2015)
Chir pine	Seedling death	*M. phaseolina*	*P. aeruginosa*, *B. subtilis*	Chitinase, HCN β-1,3-glucanase	Singh et al. (2010)
Geranium	Leaf blight	*Alternaria alternate*	*B. subtilis*	ND	Mishra et al. (2011)
	Anthracnose	*Colletotrichum acutatum*	*P. fluorescens*	ND	

ND indicates not detected

floricultural crops is most prone to attacks from phytopathogens. The most damaging disease of *Gladiolus* recognized worldwide is *Fusarium* wilt caused by *F. oxysporum* f. sp. gladioli. *Gladiolus* suffers serious losses due to wilt and storage rot caused by *F. oxysporum* f. sp. gladioli. It is reported that the losses caused by this pathogen in different parts of the world ranges between 30 and 80 % (Maurhofer et al. 1995). Corm rot disease caused by *F. oxysporum* f. sp. gladioli is another destructive disease of *Gladiolus*, and is a serious limiting factor in the commercial production of *Gladiolus*. The disease is reported to occur both in storage and in the field causing huge losses up to 60–80 % in highly contaminated areas (Tomar 1997). Even though chemical control is used on regular basis to offset phytopathogens attacks, pollution problem, residual effects, emergence of resistance among pathogen and altered soil microbial compositions, are some of the major problems in prolonged usage of fungicides. Therefore, the use of P solubilizing *P. fluorescens* to control fusarium corm rot pathogen *F. oxysporum* f. sp. gladioli was assessed by Naqvi and Ahmad (2012). The strains of *P. fluorescens* significantly inhibited the growth of *F. oxysporum* f. sp. gladioli which was due to the release of HCN and siderophores by the test bacterium. Furthermore, the talc based formulations of *Bacillus atrophaeus* and *Burkholderia cepacia*, developed for corm dressing and soil application in gladiolus were found inhibitory to the growth of *F. oxysporum* f. sp. gladioli. Also, the mixture of strains recorded maximum spike and corm production of 100 and 150 %, respectively, with less vascular wilt and corm rot incidences of 73.6 and 54.8 % reduction over the pathogen control in greenhouse when inoculated with *F. oxysporum* f. sp. gladioli. Reduction in disease incidence under greenhouse conditions occurred through the induction of defence gene products such as chitinase, β-1,3-glucanase, peroxidase and polyphenol oxidase. Besides disease suppression, treatment with mixed cultures enhanced corm and cormel production and flowering. In field experiments, the strain mixture recorded less vascular wilt and corm rot incidences of 48.6 and 46.1 % mean reduction over the non-bacterized control, and was almost comparable with that of fungicide. The treatment also increased spike and corm yield by 58.3 and 27.4 %, respectively, relative to the control (Shanmugam et al. 2011). Similarly, Sharma and Chandel (2006) reported biological control of gladiolus wilt caused by *F. oxysporum* f. sp. gladioli using different methods. The soil placement method proved effective compared to the corm dip method. *T. harzianum* in comparison to *T. viride* performed better against wilt pathogen and resulted in minimum disease incidence in addition to improvement in growth parameters of gladiolus.

Coleus (*Coleus forskohlii* Briq) is yet another important cultivated ornamental whose production suffers heavily from fungal diseases. Among various diseases, root rot disease caused by *M. phaseolina* is the most damaging ones, which causes reduction in the tuber yield, forskolin content, and finally the death of the plant. Generally, the root rot disease is controlled by chemical pesticides. Such pesticides are, however, not considered effective and practicable for *Coleus* production due to their cost and health and environmental hazards. And hence, considering the disease threats to *Coleus* production, Akkim et al. (2013) conducted an experiment to evaluate the antagonistic potential of P solubilizing fluorescent pseudomonads against root rot pathogen *M. phaseolina* under glasshouse and field conditions. *P. fluorescens* was found effective in reducing mycelial growth of the pathogen. The fungal inhibition was attributed to the production of siderophore, lytic enzymes, hydrocyanic acid, volatile metabolites, fluorescein and pyocyanin. Plants treated with talc based formulation of *P. fluorescens* (stem cuttings dip + soil application) significantly increased the activity of defence related enzymes viz., peroxidase and poly phenol oxidase in coleus plants when compared to untreated control and enhanced the growth and yield parameters under both glass house and field conditions. In a follow up experiment, Damam et al. (2015) used *Pantoea agglomerans*, *P. putida*, *Pseudomonas* sp. and *B. subtilis* to test their biocontrol efficacy against *M. phaseolina* under in vitro, glasshouse and field conditions. Among all treatments, the composite application of *P. agglomerans*, *P. putida*, *Pseudomonas* sp. and *B. subtilis* produced maximum plant height, number of branches, fresh and dry weight and total biomass with least disease severity. The study revealed that the bioformulations influenced the plant growth promotion and induced systemic resistance (ISR). The biocontrol agents controlled dry root rot and promoted plant growth which gives them an advantage over the use of chemical fungicides against root rot in disease management. Seed bacterization with PS strains of fluorescent *Pseudomonas* have also been found to reduce the incidence of collar rot in *Sclerotium rolfsii* infested soil, making the organism a potential biocontrol agent against collar rot and simultaneously enhancing the growth and yield of sunflower grown under field conditions (Bhatia et al. 2005). In other study, a total of 28 isolates of *Trichoderma* belonging to four different species were screened in vitro for their antagonistic ability against *F. oxysporum* f. sp. dianthi causing carnation wilt. Three different levels of antagonism observed in dual plate assay were further confirmed by cell-free culture filtrate experiments. Isolates showing class I level of antagonism produced maximum lytic enzymes, chitinases and beta-1,3-glucanases (Shanmugam and Sharma 2008).

Conclusion

Without doubt, appreciable amounts of research towards understanding the mechanism of growth stimulation and management of plant diseases by PGPR have been reported. The role of PSM among PGPR in the sustainable production of ornamental plants has, however, been critically inadequate. Hence, their development as explicit inoculant for ornamental production remains a huge challenge. Yet, different PS bacteria endowed with multiple growth stimulating characteristics have been tried which have shown positive impact on quality and production of flower crops such as rose, tuberose, carnation, marigold, aster, jasmine. These beneficial microbes improve the uptake of nutrients and by providing other growth promoting hormones, and acting as antagonists enhance the quality of ornamentals at considerably lower cost. However, to be considered and used as potential and successful inoculants, a greater knowledge and deeper understanding of their ecophysiology is desired. Exploration and identification of traits involved in growth stimulation and management of deadly phytopathogens using inexpensive and environmentally benign PSM is, therefore, urgently required to produce problem free and safe ornamental products. Moreover, there is need to popularize the use of multifaceted PSM in floriculture practices.

Author contribution statement Each author listed here has contributed immensely in developing this review article. Almas Zaidi: genesis of ideas, data compilation, table preparation, and critical editing of the whole manuscript. Md. Saghir Khan: language editing, photography, subject expert reviewing and article formatting. Ees Ahmad: data/literature collection. Saima Saif: reference collection and formatting to the style of journal. Asfa Rizvi: proofreading and cross matching/data checking of the whole manuscript. Mohammd Shahid: reference checking and double checking.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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