SUNTEXT REVIEWS

SunText Review of Biotechnology
ISSN: 2766-5097

Open Access
Review Article
Volume 1:2

Plant Growth Promoting Rhizobacteria and their Mechanisms Involved in Agricultural Crop Production: A Review

Rehman F[1,*], Kalsoom M[2], Adnan M[3], Toor MD[4] and Zulfiqar A[2]

[1]*Department of Plant Pathology, College of Agriculture, University of Sargodha, Pakistan*
[2]*Institute of Food Science and Nutrition, University of Sargodha, Pakistan*
[3]*Department of Agronomy, College of Agriculture, University of Sargodha, Pakistan*
[4]*Department of Soil and Environmental Sciences, College of Agriculture, University of Sargodha, Pakistan*

[*]**Corresponding author:** Fazal ur Rehman, Department of Plant Pathology, College of Agriculture, University of Sargodha, Pakistan; Email: fazalurrehman107 [at] gmail [dot] com

Received date: 25 October 2020; **Accepted date:** 31 October 2020; **Published date:** 07 November 2020

Citation: Rehman F, Kalsoom M, Adnan M, Toor MD, Zulfiqar A (2020). Plant Growth Promoting Rhizobacteria and their Mechanisms Involved in Agricultural Crop Production: A Review. SunText Rev Biotechnol 1(2): 110.

DOI: https://doi.org/10.51737/2766-5097.2020.010

Abstract

On the basis of phenotypic and genetic diversity, it is very difficult to characterize the soil microbial communities. Bacteria that are associated with the plant roots and have ability to promote the growth of plant are called Plant Growth Promoting Rhizobacteria (PGPR). Firstly, these plant growth promoting rhizobacteria inhance the growth of the plant. Secondly, they have antagonistic activities as biocontrol agents. The growth of the plant is enhanced through plant growth promoting rhizobacteria directly by fixing the atmospheric nitrogen, solubilization of insoluble phosphate and secretions of hormones including IAA, kinetics and GAs. They also facilitate the plant growth indirectly by production of induced systemic resistance, production of siderophore, production of antibiotics and lytic enzymes, HCN production and regulation of stress conditions. This review article thoroughly explains the direct and indirect mechanisms of action of PGPR.

Keywords: PGPR; Phytohormones; Phosphate solubilizing bacteria; Induced systemic resistance; Siderophore

Introduction

Bacteria that have ability to colonize plant roots and promote the growth of plant are categorised as plant growth-promoting rhizobacteria (PGPR) [1,2]. Soil microbial communities are so complex and very difficult to characterize because of their immense phenotypic and genotypic diversity [3]. In recent years, a number of PGPR have been identified have a great impact of plants growth mainly because of their role as an ecological unit as in rhizospheric zone has gained importance in the functional activities of the biosphere. PGPR directly influence the growth promotion of plants by Solubilizing insoluble phosphates, fixing atmospheric nitrogen, secreting hormones which helps in regulation of plant growth [4]. PGPR indirectly benefits plant growth by Induced systemic resistance (ISR), competition for nutrients, antibiosis, parasitism and production of metabolites suppressive to deleterious rhizobacteria [5].

PGPR is highly diverse community and their effects can occur through local antagonistic action against the soil-borne pathogens and through induction of systemic resistance against pathogens in the entire plant [6]. Several substances are produced by antagonistic rhizobacteria which have ability to control the pathogen and also have indirect promotion of growth in many plants. The Induced systemic resistance (ISR) in plants resembles pathogen-induced systemic acquired resistance (SAR) under conditions where the inducing bacteria and the challenging pathogen remain spatially separated [7]. Both types of induced resistance make the uninfected plant parts more resistant to pathogen attack in several plant species. Resistance is induced by Rhizobacteria through the salicylic acid-dependent SAR pathway or through require jasmonic acid and ethylene perception from plant for ISR. Rhizobacteria belongs to the genera of Pseudomonas and Bacillus and are well known for their antagonistic effects and their ability to trigger ISR [8].

In few last years, considerable attention has been made to replace agrochemicals (fertilizers and pesticides) with to PGPR for the plant growth promotion through various mechanisms [9] that involved in formation of soil structure, recycling of essential elements, decomposition of organic matter, solubilization of mineral nutrients, degrading organic pollutants, stimulation of root growth, producing numerous plant growth regulators, crucial for soil fertility, promoting changes in vegetation and biocontrol of soil and seed borne plant pathogens.

An understanding of both plant growth promoting rhizobacteria and their interactions with biotic and abiotic factors is very important in bioremediation techniques, energy generation processes and in biotechnological industries including pharmaceuticals, chemical and food [10]. Plant growth promoting rhizobacteria also reduce the application of chemical fertilizers and that is economically and environmentally beneficial for lower production cost as well as recognize the best management practices of soil and crop to achieve more sustainable agriculture as well as fertility of soil [11].

Mechanisms of Action of Plant Growth Promoting Rhizobacteria

Plant growth promotion is well-known and an important phenomenon done plant growth promoting rhizobacteriaand amd this growth enhancement is because of the certain traits of rhizobacteria [12]. There are a lot of mechanisms through which PGPR can enhance plant growth and development in diverse environmental conditions. Plant growth promoting rhizobacteria alter the whole microbial community in rhizospheric zone through the production of various substances [13]. Commonly, PGPR promotes plant growth directly on the bases of their ability for supply of nutrient (nitrogen, phosphorus, potassium and essential minerals) or through production of plant hormone levels. PGPR can also bring the plant growth by indirectly through decreasing the inhibitory effects of various pathogens on growth and development in the forms of biocontrol agents, environmental protectors and root colonizers [14].

Phytopathogenic microorganisms have a major and chronic threat to sustainable agriculture and ecosystem stability because they subvert the soil ecology, degrade soil fertility, disrupt environment and consequently show harmful effects on human health and contaminating ground water [15]. PGPR having direct mechanisms facilitate the plant in nutrient uptake or increase nutrient availability through the process of nitrogen fixation, mineralize organic compounds, solubilization of mineral nutrients and production of phytohormones [16]. PGPR is very important in sustainable and environmentally friendly approach to obtain sustainable fertility of the soil and plant growth indirectly. This approach results in wide range of exploitation of PGPR to decrease the need for agrochemicals including fertilizers and pesticides for improve soil fertility through a variety of mechanisms including production of antibiotics, HCN, siderophores and hydrolytic enzymes.

Direct Mechanisms

Biological fixation of nitrogen

Nitrogen is an important element for life. It is present in the structures of essential biochemicals like nucleotides and proteins [17]. Although there is a high concentration of N2 in air in gaseous form but plant cannot use nitrogen in this form [18]. Biological nitrogen fixation is the main process by N-fixing bacteria convert N2 into ammonia which can be used by plants as a nitrogen source. As there is the small quantity of fixed nitrogen that is available for plant [19]. Therefore, farmers have to apply nitrogen containing fertilizers to sustain their agriculture. This utilisation of huge amount of chemicals is not affordable for the farmers and it also have negative impacts on the environment [20]. These deficiencies can be fulfilled by using PGPR and providing needed nitrogen by the BNF. This can be an alternative way for farmers to increase agricultural yield [21].

The production of biological fixed nitrogen is not limited to the PGPR forms symbiotic nodules with legumes; it can also be produced by non-symbiotic free living nitrogen fixing bacteria such as Azospirillum, Azotobacter, Azoarcus, Bacillus polymyxa, Gluconoacetobacter, Burkholderia and Herbaspirillum [22].

Production of phytohormones

Phytohormones are the one of the most important plant growth substances. They are plant hormones that have a great influence on the responses of plant against its environment [23]. The production of these hormones occur at one location in the plant and then is transferred to the other location where they work to enhance the plant growth. The physical responses due to these hormones results in the growth of roots and leaves [24].

There are several most important types of phytohormones. These are auxins, gibberellins, ethylene, cytokinins and abscisic acid [25]. Plant growth promoting rhizobacteria usually produces these phytohormones.

Cytokinins production: Cytokinins (CK) are a class of phytohormones that have vital role in promoting the cell division in plant roots and shoots [26]. They are mainly involved in cell growth, cell differentiation, apical dominance, axillary bud growth and leaf senescence [27]. Actually this hormone is synthesized by the plant but some of PGPR and yeast strains can also prepare this hormone. Some phytopathogens can also synthesize cytokinins. Various bacteria including Azotobacter spp., Pantoea agglomerans, Rhizobium spp., Rhodospirillum rubrum, Bacillus subtilis, Pseudomonas fluorescens and Paenibacillus polymyxa are reported to produce cytokinins hormone [28].

Gibberellin production: Gibberellins (GAs) are hormones produced in plants that regulate various process of development in plant. They play vital role in stem elongation, dormancy, germination, flowering, flower development and leaf and fruit senescence. GAs are one of the most important class of plant hormone. Gibberellins are involved in the process of breaking dormancy and other aspects of germination. Gibberellin is most important phytohormone that is synthesized by some cytokinin-producing PGPR [29]. The gibberellin and cytokinin mechanisms for bacterial production and regulations are of the great importance.

Indole-3-Acetic Acid Production: IAA is one of the most important phytohormone produced by plants and PGPR. It has vital role in plant cellular responses including cell division, gene expression, organogenesis, pigment formation, root development, seed germination, stress resistance of plants, tropic responses and photosynthesis [30]. IAA can work both as inhibitors and stimulators. The required amount of IAA for the plant growth promotion is greatly influenced by plant species and bacterial species. Since Indole-3-Acetic Acid is responsible for root formation and lengthening. IAA is widely produced by the activity of PGPR [31].

Ethylene production: Ethylene is a plant growth hormone produced by almost all plants and plays a vital role in many of physiological changes in plants at molecular level. The production of ethylene is stimulated by plant responses to biotic and abiotic stresses that have adverse effects of on root growth and as a result on the whole plant growth [32]. PGPR have certain enzyme such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase, that have ability to regulates ethylene production. PGPR Inoculation is very helpful to maintain the plant growth and development under stress conditions.

Abscisic acid production: Abscisic acid is the plant growth hormone that is synthesized by plants when it is under abiotic stresses like stresses due to drought, salt stress, cold or soil pollution etc. It activates the stress resistance genes. Several strains of PGPR synthesize Abscisic acid [33]. When plants are inoculated with Abscisic acid-producing strains i.e. Bacillus licheniformis Rt4M10, Azospirillum brasilense Sp 245, Pseudomonas fluorescens Rt6M10, the internal content of ABA is increased. Thus the plant becomes more resistant to drought. Thus PGPR helps the plant to regulate the growth.

Phosphate solubilizing bacteria

Nitrogen is not the only important element for life of which unavailability can limit the plant growth. Phosphorus is also an important for the plants. Soil has large amounts of phosphate, but it is found in insoluble form that can not be utilized by the plants for growth. Some PGPR have ability to solubilize the phosphate in the soil by the mechanism of acidification, chelation, or enzymatically [34]. For example, Gluconacetobacter diazotrophicus is a PGPR present in sugarcane and can solubilize phosphate through acidification.

Indirect Mechanisms

Antibiotics and lytic enzymes production for biocontrol

It is well known that there is a great compitition between microorganisms for nutrients and colonization sites in their natural environments. Many PGPR species have ability and have evolved various mechanism to reduce competition by releasing of antibiotics, lytic enzymes or weak organic acids to their environment [35]. Due to this, PGPR is a valuable tool and can be used against plant pathogens. The increased use of antibiotic producing bacteria can result in development of resistant strain of pathogens. The enzymes secreted by PGPR are utilized to eliminate pathogens [36] like Botrytis cinerea, Fusarium oxysporum, Sclerotium rolfsii, Phytophthora spp., Pythium ultimum and Rhizoctonia solani. These secreted enzymes are cellulates, chitinases, lipases and proteases.

Production of induced systemic resistance (ISR)

Systemic acquired resistances and Induced systemic resistance are evolved mechanisms of response in plants against pathogens. Systemic acquired resistance is a resistance that is triggered when a pathogen infects a plant and Induced systemic resistance is a resistance that is triggered by the PGPR. ISR appears to be same as of systemic acquired resistance (SAR) [7]. When the inoculum of PGPR is applied to the plant, the PGPR induce a resistance in that plant against many of the bacterial pathogens. It results in induced systemic resistance.

Siderophore production

Iron is another important nutrient for plants. In aerobic conditions, iron is present as Fe^{3+} form which is not soluble to be used by microorganisms and plants. Some microbes produce and secrete low mass iron chelators. These chelators are known as siderophores. They have high affinity for iron. They work as solubilizing agents for Fe^{3+} in limiting conditions. Fe^{3+} becomes Fe^{2+} which is then unbind from the siderophores inside the cell [37]. Siderophore production works as a biocontrol mechanism, since with this process, plant growth promoting rhizobacteria derives other microorganisms from iron [38]. PGPR also use siderophores to obtain other heavy metals from the soil and prevents the heavy metal to cause toxicity in plants. It can be used for bioremediation of the heavy metal toxic soil.

Regulation of stress conditions

Ethylene is a phytohormone. It is also secreted in the response of biotic and abiotic stresses from salt, drought or pathogenic bacteria. Although it promote the growth of plant and help in ripping of fruits, the high amounts ethylene also have harmful effects on the plant. Many PGPRs synthesis an enzyme i.e. ACC deaminase [39]. This enzyme destroys the precursor of ethylene and which is 1-aminocyclopropane-1-carboxylate. It results in decreasing the ethylene levels that relieve the stress of the plant.

HCN production

The harmful rhizobacteria can work as biocontrol agents of weeds. They colonize plant root surfaces and suppress their growth. Cyanide are toxic and are produced by many of microorganisms including bacteria, algae, fungi and plants. They work as a means of survival by competing with counterparts. There is no any negative impact on the host plants by inoculation with cyanide-producing bacterial strains [40]. The host-specific Rhizobacteria can work as biological weed control agents. Many of the secondary metabolite are also produced which act as an effective agent for the biocontrol of weeds. HCN is mostly synthesized by Pseudomonas and Bacillus species. HCN inhibits electron transport chain and energy supply to cell [41]. This disturbance results in the death of cells.

Competition

PGPR often compete with the many of the harmful microbes for the nutrition uptake. These nutrients are present in trace amount, therefore, they can limit the disease causing agent [42]. When there are abundant non-pathogenic microbes present in the soil and rapidly colonize the surfaces of plants and also utilize nutrient available. This utilization of nutrients will inhibit the growth of pathogenic microbes. These mechanisms are difficult to study in the system. The competition for the nutrient between PGPR and pathogens is one of the important interaction that indirectly supports the growth of the plants by inhibiting the growth of pathogens [43].

Future Prospects of PGPR and Challenges

PGPR is one of the most important and safe means of agriculture to increase the yield. It is a promising solution to meet the requirements of higher yield [44]. The most important thing is that it protects plants from chemicals that are applied to control the pests and also cause harmful impacts on the ecosystem. PGPR can also improve the yield by controlling various plants diseases and pests as diseases are responsible for huge losses of plant yield. PGPR have beneficial effects on laboratory as well as greenhouse experiments [45]. Genetic engineering is an emerging field to improve and explore the uses of PGPR strains. Besides all the advancements, there are some environmental barriers and adverse conditions that greatly influence the activity of PGPR. The problems of varying efficacy of PGPR can be improved by strain mixing, using improved inoculation techniques and gene transfer of active genetic source of antagonists to the host plant. Various diverse conditions can also influence the PGPR action as biocontrol because biocontrol agents need specific ecological environment for growth and survival. Hence under diverse ecological niche, the efficacy of biocontrol agents could be changed by the usage of compatible mixed inoculum of biocontrol agents. Other then these beneficial aspacts, there are several challenges faced by PGPR [46]. The natural variation is a main problem because it is difficult to predict how bacteria will act in laboratory and what will be it's action when placed in field. These variations can affect the whole experiment. Another challenge is that the propagation of PGPR to regain their viability and biological activity e can vary according to the plant type and season [47].

Conclusion

The use of PGPR has resulted in significant improvement in growth, health and yield of plants. The PGPR can stimulate the improvements in growth, health and yield of plants by direct or indirect mechanism of PGPR action. PGPR can also improve growth of plant by reducing the activities of phytopathogens which reduce the yield and growth. The result of PGPR inoculation can vary according to the plant age and the chemical, physical and biological properties of the soil. There are several challenges for making their commercial uses. This can be overcomed by using advance techniques and applying biotechnology to reduce the challenges faced by PGPR. Hence one day the use of PGPR will replace the use of chemical fertilizers.

References

1. Vessey JK. Plant growth promoting rhizobacteria as biofertilizers. Plant Soil. 2003; 255: 571-586.
2. Lugtenberg B, Kamilova F. Plant-growth-promoting rhizobacteria. Annual Rev Microbiol. 2009; 63: 541-556.
3. Jha CK, Saraf M. Plant growth promoting rhizobacteria (PGPR): a review. J Agri Res Develop. 2015; 5: 108-119.
4. Bhattacharyya PN, Jha DK. Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture. World J Microbiol Biotechnol. 2012; 28: 1327-1350.

5. Goswami D, Thakker JN, Dhandhukia PC. Portraying mechanics of plant growth promoting rhizobacteria (PGPR): A review. Cogent Food Agri. 2016; 2: 1127500.
6. Barriuso J, Solano BR, Lucas JA, Lobo AP, García-Villaraco A, Mañero FJ. Ecology, genetic diversity and screening strategies of plant growth promoting rhizobacteria (PGPR). J Plant Nutri. 2008; 4: 1-7.
7. Rehman F, Kalsoom M, Nasir TA, Adnan M, Anwar S, Zahra A. Chemistry of Plant–Microbe Interactions in Rhizosphere and Rhizoplane. Ind. J. Pure App Biosci. 2020; 8: 11-19.
8. Annapurna K, Kumar A, Kumar LV, Govindasamy V, Bose P, Ramadoss D. PGPR-induced systemic resistance (ISR) in plant disease management. InBacteria in Agrobiology: Disease Management. Springer, Berlin, Heidelberg. 2013; 405-425.
9. Gupta G, Parihar SS, Ahirwar NK, Snehi SK, Singh V. Plant growth promoting rhizobacteria (PGPR): current and future prospects for development of sustainable agriculture. J Microb Biochem Technol. 2015; 7: 096-102.
10. Kalsoom M, Rehman F, Shafique T, Junaid S, Khalid N, Adnan M, et al. Biological importance of microbes in Agriculture, Food and Pharmaceutical Industry: A Review. Innove J Life Sci. 2020; 8: 1-4
11. Babalola OO. Beneficial bacteria of agricultural importance. Biotechnol Lett. 2010; 32: 1559-1570.
12. Arora NK, Tewari S, Singh S, Lal N, Maheshwari DK. PGPR for protection of plant health under saline conditions. InBacteria in agrobiology: stress management. Springer, Berlin, Heidelberg. 2012; 239-258.
13. Nihorimbere V, Ongena M, Smargiassi M, Thonart P. Beneficial effect of the rhizosphere microbial community for plant growth and health. Biotechnologie, Agronomie, Société et Environnement. 2011; 15: 327-337.
14. Gouda S, Kerry RG, Das G, Paramithiotis S, Shin HS, Patra JK. Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. Microbiol Res. 2018; 206: 131-140.
15. Vejan P, Abdullah R, Khadiran T, Ismail S, Nasrulhaq Boyce A. Role of plant growth promoting rhizobacteria in agricultural sustainability -A review. Molecules. 2016; 21: 573.
16. Khan N, Bano A, Shahid MA, Nasim W, Babar MA. Interaction between PGPR and PGR for water conservation and plant growth attributes under drought condition. Biologia. 2018; 73: 1083-1098.
17. Bazely DR, Jefferies RL. Goose faeces: a source of nitrogen for plant growth in a grazed salt marsh. J Applied Ecol. 1985; 693-703.
18. Ingestad T. Nitrogen and plant growth; maximum efficiency of nitrogen fertilizers. Ambio. 1977; 146-151.
19. Huebert B, Vitousek P, Sutton J, Elias T, Heath J, Coeppicus S, Howell S, Blomquist B. Volcano fixes nitrogen into plant-available forms. Biogeochem. 1999; 47: 111-118.
20. Matthews E. Nitrogenous fertilizers: global distribution of consumption and associated emissions of nitrous oxide and ammonia. Global Biogeochemical Cycles. 1994; 8: 411-439.
21. Chen WX, Chen WF. Exertion of Biological Nitrogen Fixation in Order to Reducing the Consumption of Chemical Nitrogenous Fertilizer. Rev China Agri Sci Technol. 2004; 6: 3-6.
22. Dobereiner J, Campelo AB. Non-symbiotic nitrogen fixing bacteria in tropical soils. Plant Soil. 1971; 35: 457-470.
23. Gaspar T, Kevers C, Penel C, Greppin H, Reid DM, Thorpe TA. Plant hormones and plant growth regulators in plant tissue culture. *In vitro* Cellular DevelopBiol Plant. 1996; 32: 272-289.
24. Santner A, Calderon-Villalobos LI, Estelle M. Plant hormones are versatile chemical regulators of plant growth. Nature Chem Biol. 2009; 5: 301-307.
25. Wong WS, Tan SN, Ge L, Chen X, Yong JW. The importance of phytohormones and microbes in biofertilizers. InBacterial metabolites in sustainable agroecosystem. Springer, Cham. 2015; 105-158.
26. Sachs T, Thimann KV. The role of auxins and cytokinins in the release of buds from dominance. Am J Botany. 1967; 54: 136-144.
27. Khan AA. Cytokinins: permissive role in seed germination. Science. 1971; 171: 853-859.
28. Morris RO. Genes specifying auxin and cytokinin biosynthesis in phytopathogens. Annual Rev Plant Physiol. 1986; 37: 509-538.
29. Joo GJ, Kim YM, Kim JT, Rhee IK, Kim JH, Lee IJ. Gibberellins-producing rhizobacteria increase endogenous gibberellins content and promote growth of red peppers. J Microbiol. 2005; 43: 510-515.
30. Spaepen S, Vanderleyden J, Remans R. Indole-3-acetic acid in microbial and microorganism-plant signaling. FEMS microbiology Rev. 2007; 31: 425-448.
31. Lwin KM, Myint MM, Tar T, Aung WZ. Isolation of plant hormone (indole-3-acetic acid-IAA) producing rhizobacteria and study on their effects on maize seedling. Eng J. 2012; 16: 137-144.
32. van Loon LC, Geraats BP, Linthorst HJ. Ethylene as a modulator of disease resistance in plants. Trends Plant Sci. 2006; 11: 184-191.
33. Karadeniz A, Topcuoğlu ŞF, Inan S. Auxin, gibberellin, cytokinin and abscisic acid production in some bacteria. World J Microbiol Biotechnol. 2006; 22: 1061-1064.

34. Rodríguez H, Fraga R. Phosphate solubilizing bacteria and their role in plant growth promotion. Biotechnol Advan. 1999; 17: 319-339.
35. Tariq M, Noman M, Ahmed T, Hameed A, Manzoor N, Zafar M. Antagonistic features displayed by plant growth promoting rhizobacteria (PGPR): a review. J Plant Sci Phytopathol. 2017; 1: 38-43.
36. Kenneth OC, Nwadibe EC, Kalu AU, Unah UV. Plant growth promoting rhizobacteria (PGPR): A novel agent for sustainable food production. Am J Agric Biol Sci. 2019; 14: 35-54.
37. Qi W, Zhao L. Study of the siderophore-producing Trichoderma asperellum Q1 on cucumber growth promotion under salt stress. J Basic Microbiol. 2013; 53: 355-364.
38. Gupta A, Gopal M. Siderophore production by plant growth promoting rhizobacteria. Indian J Agri Res. 2008; 42: 153-156.
39. Saleem M, Arshad M, Hussain S, Bhatti AS. Perspective of plant growth promoting rhizobacteria (PGPR) containing ACC deaminase in stress agriculture. Jindustrial Microbiol Biotechnol. 2007; 34: 635-648.
40. Schippers B, Bakker AW, Bakker PA, Van Peer R. Beneficial and deleterious effects of HCN-producing pseudomonads on rhizosphere interactions. Plant Soil. 1990; 129: 75-83.
41. Lieberei R, Fock HP, Biehl B. Cyanogenesis inhibits active pathogen defence in plants: inhibition by gaseous hcn of photosynthetic co~ 2 fixation and respiration in intact leaves. J Applied Botany. 1996; 70: 230-238.
42. Martínez-Viveros O, Jorquera MA, Crowley DE, Gajardo GM, Mora ML. Mechanisms and practical considerations involved in plant growth promotion by rhizobacteria. J Soil Sci Plant Nutri. 2010; 10: 293-319.
43. Nelson LM. Plant growth promoting rhizobacteria (PGPR): prospects for new inoculants. Crop Manag. 2004; 3: 1-7.
44. Orhan E, Esitken A, Ercisli S, Turan M, Sahin F. Effects of plant growth promoting rhizobacteria (PGPR) on yield, growth and nutrient contents in organically growing raspberry. Scientia Horticult. 2006; 111: 38-43.
45. Burdman S, Jurkevitch E, Okon Y. Recent advances in the use of plant growth promoting rhizobacteria (PGPR) in agriculture. Microbial Interactions Agri Forestry. 2000; 2: 229-250.
46. Prasad M, Srinivasan R, Chaudhary M, Choudhary M, Jat LK. Plant growth promoting rhizobacteria (PGPR) for sustainable agriculture: perspectives and challenges. In PGPR Amelioration in Sustainable Agriculture. Woodhead Publishing. 2019; 129-157.
47. Saraf M, Rajkumar S, Saha T. Perspectives of PGPR in agri-ecosystems. InBacteria in Agrobiology: Crop Ecosystems. Springer, Berlin, Heidelberg. 2011; 361-385.