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Arash Gautam
Student, Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Dr. Khushboo Kathayat
Assistant Professor Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Arash Gautam
Student, Department of Horticulture, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India

Effect of plant growth promoting rhizobacteria on the production of vegetable crops

Arash Gautam and Dr. Khushboo Kathayat

Abstract
Vegetables are very vital component of human nutrition. They are key supplier of minerals, vitamins and fibers that's why they are known as protective food. Demand of vegetables increasing day by day. To increase the production of vegetables chemical fertilizers are used. But they are not good for human health as well as for the environment. They are well known to impart ill residual effects on the consumers. Rhizobacteria's can be used to reduce or substitute the usage of chemical fertilizers in production of vegetable crops. They are naturally occurring soil bacteria's which are known to fix nitrogen and to solubilize phosphorus and potash to increase their availability to the plants. They also synthesis many other growth promoting substances which are beneficial for plant growth.

Keywords: *Azospirillum Spp., Azotobacter Spp.,* Nitrogen Fixing Bacteria, Phosphorus Solubilizing Bacteria, Plant Growth Promoting Rhizobacteria, Potassium Mobilizing Bacteria. *Rhizobium Spp.*,

Introduction

Vegetables are an essential part of a stable foodstuff and work as a protective food. India is the world's second leading vegetable producer, following to China, producing 79,05000 million ton of vegetables from 46,5000 million ha with a productivity of 170 q/h (Department of Horticulture, Haryana, 2018). Unfortunately, this is far beneath then the per capita requirement (300g/capita/day) needed to meet the needs of the rising residents (Sachdeva *et al* 2013) [101]. Thus, it is a necessity to gain more crop harvest from every unit of agricultural area in an ecofriendly manner (Kumar *et al* 2013) [75, 77]. For normal growth of plant, essential plant nutrients must be in adequate and sensible amounts (Chen *et al* 2008) [32]. Many surveys have revealed that growers exposed to inorganic fertilizers are at peril of having progeny with limb defects (Sutton *et al* 2012; Engel *et al* 2000) [125, 44]. It is evaluated that about 49.9% of the fertilizer percolates into the earth, leading to disorders such as methemoglobinemia in children (Majumdar *et al* 2000) [82]. Useful microbes in biological fertilizers can hasten and improve plant growth, as well as defend plants from pests and sicknesses (El-Yazidi *et al* 2007) [43]. The importance of soil microbes in agricultural sustainability has been discussed (Lee *et al* 1992; Wani *et al* 1995) [79, 135]. Biological fertilizers are affordable, renewable supplier of nutrients to the plant that can be substitute inorganic fertilizers; a tiny dose is sufficient because each gram of carrier includes millions live cells of a particular strain (Anandhraj and Delapiere 2010) [11]. Beneficial microorganisms in liquid formulations can solubilize, fix, or mobilize important plant nutrients via bio actions (Bahadur *et al*., 2016) [17]. Rhizobacteria, also recognized as Plant Growth Promoting Rhizobacteria (PGPR), are bacteria that occupies the rhizosphere (plant roots) and have been shown to aid crop growth and development (Kloeper *et al*. 1980) [34]; Abbasi *et al*. (2011) [1]; Schroth and Hancock (1981) [106]. Actinophages, Streptomyces, Agrobacterium, *Rhizobium*, Azotobacter, Arthrobacter, Bacillus, Pseudomonas sp., Cellulomonas, Brady *Rhizobium*, Macrosporangium, Flavobacterium, Erwinia, Enterobacter, and Xanthomonas are among the species that contain PGPR (Weller, 1988) [136]. These rhizobacteria can promote crop growth by enriching soil by nutrients through activities such as phosphate solubilization, biological nitrogen fixation, siderophores production, and PGR's (Bulgarelli *et al*. 2013; Gopalakrishnan *et al*.2015) [25, 51]. The application of PGPR in farming can replace or reduce the use of synthetic fertilizer required and it will reduce the ill impact of chemical fertilizers on environment (Glick 2014, Ijaz *et al*.2019, 2020) [50, 66]. Microbial inoculation, particularly those containing PGPR, can aid in the reduction of chemical fertilizers and pesticides used in tomato agriculture (Ahmed *et al*., 2017) [9]. Symbiotic nitrogen-fixers and phosphate-solubilizing microorganisms are vital for providing phosphorus and nitrogen to the plant, allowing for more sustainable nitrogen and phosphate fertilizer use (Tambekar *et al*. 2009) [127].

Nitrogen Fixing Bacteria

Conventional producers use greater rates of chemical fertilizers to attain high yield and quality vegetables, which are costly and harmful to the atmosphere (Orhan *et al*., 2006) [88]. Over use of chemical fertilizer risks soil productiveness and vegetable output, farmers have expressed a curiosity in using ecofriendly and bearable nitrogen-fixing PGPR. (Dixits *et al*. 2007; Shuklah *et al*. 2012; Ziaf *et al*. 2016) [39, 115, 141]. Biological nitrogen fixation (BNF) can minimize the requirement for synthetic Nitrogen based fertilizer, lower crop production costs, and improve agricultural sustainability (Silva and Uchida 2000) [118]. NFB (nitrogen-fixing bacteria) that converts inert air N2 to organic molecules (Bakulin *et al*., 2007) [19]. Nitrogen is necessary for plants because it promotes quick growth, increases leaf area and quality, accelerates crop maturity, and aids in fruit and seed formation. Recent research shows that nitrogen-fixing bacteria can greatly boost plant growth and productivity (Aseri *et al*., 2008) [15].

Azospirillum spp

Azospirillum spp. are known as associative endosymbionts, and they live on the roots of grasses and other plants. They are also known to fix environmental nitrogen and provide growth hormones and vitamins to host plants. In non-leguminous crops get some of their nitrogen from associative symbiotic bacteria like Azospirillum, azotobacter. Azospirillum is thought to be more effective, and it has been observed that Azospirillum inoculation boosts crop growth, nitrogen uptake, and yield. A number of scientific studies have shown that the use of Azospirillum and other beneficial rhizobacteria's improves the plant growth and production of commercially significant crops such as tomato, brinjal, and chillies (Sukhada 1988) [124]. In tomato growth, harvest and quality indices like TSS, vit-c, and lycopene content were more in plants grown up with Azospirillum and rhizobacteria, according to Kumaran *et al*. 1998 [78]. Zeddy *et al*.,1993 [140] investigated the effects of *A. brasiliense* aggregated and single cell suspensions on plant growth. They found that inoculating maize seedlings with Azospirillum enlarged root surface area and dry weight of foliage much more than plants infected with malate produced Azospirillum or controls.

Azotobacter spp

Azotobacter is the most common type of heterotrophic free-living nitrogen-fixing bacteria. They are Gram-negative, huge ovoid pleomorphic cells with diameters ranging from rods to coccoid cells. They can be found individually, in paired or irregular clumps, or in chains of varied lengths. They develop cysts rather than endospores. They are either motile or non-motile due to peritrichous flagella. Azotobacter spp. is well known for its nitrogen-fixing capacity, but they may also create other plant growth hormones (auxins, cytokinin's and gibberellin's). Azotobacter has the ability to convert nitrogen to ammonia, which is then absorbed by plants. Azotobacter spp. has the ability to convert N_2 to ammonia (NH^{4+}), which is then absorbed by plants. Azotobacter sp. can also create antifungal chemicals, which can be used to combat a variety of pant infections. (Rao *et al*. 2014) [98].

Rhizobium spp.

Rhizobium is the most extensively used bio-fertilizer, colonizing the roots of particular pulses crop to develop tumor-like growths known as root nodules. These nodules function as ammonia (NH^{4+}) producers. The *Rhizobium* spp. and legume association can fix up to 1,00-3,00 kg N/ha in a single spell and, in some cases, can add significant nitrogen for subsequent crops. *Rhizobium* seed treatment is a popular agronomic stratagem used to assure sufficient nitrogen in legume crop rather than Nitrogen fertilizer (Gupta., 2004) [55]. The *Rhizobium* with leguminous plant symbiosis is the best investigated intracellular PGPR (Gray. and Smith.2005) [53]. The most studied illustration is the positive relationship in between the *Rhizobium* and plants in the Leguminosae family, which are the most widely utilized biofertilizer inoculants on the planet. In association, the *Rhizobium* thrives on the host plant's carbohydrates and provides fixed nitrogen for amino acid production (Brencic and Winans, 2005; Gray and Smith, 2005) [53]. *Rhizobium* and leguminous plants can fix about 460 kg of nitrogen per year through their symbiotic connection. Several studies have shown the importance of BFN by *Rhizobium*, not only for the advantages to legumes, but also for mixed and intercropping, which helps the other species planted after the leguminous cultivar (Castro *et al*. 2004; Hayat *et al*.2008) [26, 36]. The study found that synthetic *Rhizobium* inoculation had a substantial effect on harvest and other growth parameters of Haricot beans. It has been determined that inoculating Haricot beans with *Rhizobium* considerably enhanced height of the plant, pod harvest, and other harvesting components (Ahmed *et al*. 2016; Meena *et al*. 2018) [8, 84]. *Rhizobium* had a considerable impact on legume vegetable crops, increasing output by 4-13%. Mishra and colleagues 1996; Kanaujia and colleagues 1999; Choudhury and colleagues 1982) [85, 71, 34].

Phosphorus Solublizing Bacteria (PSB)

After nitrogen, phosphorus is the second limiting macronutrient required for the development of vegetable, and it is plentiful in the soil in both organic and mineral forms. Though, in most of the soils, this mineral remains only available to the crop in the form of the soluble ions H2PO4 - and HPO4-2 (Khan *et al*., 2009; Bhattacharyya and Jha., 2012) [6, 21]. It is crucial to note that a large portion of the Phosphorus added to farms as fertilizer is quickly immobilized and henceforth unreachable to plants (Otieno *et al*. 2015) [89]. Furthermore, the conventional P fertilizer manufacture process is ecologically unfavorable due to pollutants released hooked on the key product, gas stream, and byproducts, as well as the accretion of Cadmium or additional heavy metallic elements in soil and crops due to the repeated application of phosphorus-based fertilizers (Sharma. *et al*. 2013; Song. *et al*. 2008) [109, 110, 122].

The use of phosphate-solubilizing microorganisms in agriculture may supplement or replace the usage of phosphate fertilizers (Khan *et al*.2006) [73]. Bacteria are more successful than fungi at P solubilization (Alam *et al*., 2002) [10]. Phosphate solubilizing bacteria account for 1.0 to 49.9% of the total microbial population in soil, while phosphorus solubilizing fungi (PSF) account for just 0.10 to 0.50% (Chen *et al*., 2006) [32]. Bacterial solubilization of inorganic phosphorus is accomplished by the synthesis of organic acids, whereas organic P mineralization is accomplished through the development of various phosphatases that consequence in the results of phosphoric acids (Bulgarelli *et al*.2013; Glick 2012) [25, 49]. Rhizobacteria inoculated chili and brinjal increased crop growth and yield.

Potassium Mobilizing Bacteria (KMB)

Potash is one of the three major nutrients that plants require. Potassium (K) occupies a unique place among the three primary macronutrients, as evidenced by its involvement in enhancing crop productivity by increasing acceptance to diverse biotic and abiotic stresses. Potassium is essential for growth and yield because it is involved in the development of absorption, transport, and storage tissues. Soil bacteria have been shown to show a vital role in the natural K cycle and may act as substitute for making potassium accessible for plant uptake (Rogers.1998) [99].

There are various KSB in soil, each with a unique character and set of activities (Gromov 1957; Norkina and Pumpyansakya 1956) [54, 87]. Potash solubilizing bacteria (KSB) in soils promotes plant growth and supplies abundant nutrients to plants (Han and Lee, 2005) [57, 58]. F. aurentia, a fellow of the Pseudomonas family, was collected from agricultural soil (Banana rhizospheric soil). It boosts crop productivity by solubilizing K (Ramarthinam and Chandra, 2006) [96]. Potassium is soluble through complex formation between organic acids and metal ions such as Fe2+, Al3+, and Ca2+ (Styriakova, 2003) [123]. This solubilization action is often attributed to KSB's synthesis of sure biological acids and enzymes. Furthermore, they are known to create amino acids, vitamins, and growth stimulating compounds for example indole -3-acetic acid (IAA) and gibberellic acid (GA), which aid in growth of plant. As a result, potash-solubilizing microbes in the soil can retain current resources while avoiding atmosphere contamination perils induced by over use of chemical fertilizer. Potassium solubilizing bacteria of rhizosphere origin have the ability to solubilize insoluble forms of potassium through various mechanisms such as the production of capsular inorganic, polyoses, and carbon-based acids such as oxalic acid and tartaric acid, which primes to the solubilization of felspar and elite and the issue of potassium (Sheng and He. 2006) [113]. Treatment of seeds and seedlings of various crop plants with KSB showed positive impacts on the development of cotton and mustard (Sheng. 2005) [112] pepper and banana (Hassan *et al*., 2010) [61], tomato (Lian *et al*., 2008) [80], brinjal, chili, cucumber, ladyfinger and potato (Han. and Lee., 2005; Han and Lee., 2006; Sangeeth. *et al*. 2012; Prajapati *et al.*, 2013; Ramarethinam and Chandra 2006 and Abdel-Salam and Shams 2012) [57-59, 102, 94, 96, 2]. According to these researches, using KSB as biological-fertilizers for farming can lessen the application of agrochemicals and boost environmentally friendly crop production (Archana *et al*., 2012) [14].

Table 1: Application of beneficial rhizobacteria's among many vegetables and their effects on growth and production.

Sr. No.	Crop	PGPR Used	Effect	References
1	Asparagus	PSB	Asparagus growth characteristics were at their peak when PSB was combined with organic fertilizers.	Palande *et al*., (2017) [91]
2	Bottlegourd	Azotobacter, PSB	Azotobacter and PSB applications were both found to be extremely profitable, resulting in a high C:B ratio.	Patle *et al*., (2018) [92]
3	Brinjal	Azospirillum, Azotobacter, PSB	Growth and harvest characteristics were increased with combine application of Azospirillum+Phosphorus Solubilizing Bacteria + Azotobacter.	Solanki *et al*., (2010) [121]
4	Faba bean	KSB, Humic acid	Humic acid and potassium-solubilizing bacteria improve the soil quality, boost nutrient availability and uptake, and thus increase faba bean plant yield.	Ding *et al* 2021 [38]
5	Frenchbean	PSB, *Rhizobium*	Combine use of *Rhizobium*+ PSB leads to the maximum pod yield/ha Organic material	Thakur *et al*., (2018) [130]
6	Knol-khol	Azospirillum, PSB, Azotobacter.	Inoculation with Azospirillum, PSB and Azotobacter. Results in good harvest and biological and chemical parameters.	Choudhary *et al*., (2017)
7	Lettuce	Azotobacter, Azospirillum, Pseudomonas	Plant length, leaf count, leaf area index, and yield were all highest after Azospirillum seed inoculation.	Chamangasht *et al*., (2012) [29]
8	Okra	Azotobacter, PSB	The maximum yield metrics were obtained in the okra crop when organic manures were combined with Azotobacter and PSB.	Bairwa *et al*., (2009) [18]
9	Onion	Azospirillum, VAM, PSB	Onion seed output was highest when GA3 was combined with Azospirillum+PSB+ VAM.	Waghmode *et al*., (2010) [134]
10	Potato	Azotobacter, PSB	use of Azotobacter + PSB and carbon-based manure increased the production of potatoes.	Kumar *et al*., (2013) [75, 77]
		KMB	On a dry weight basis, KMB inoculation has a significant impact on overall tuber production.	Chaudhary *et al* (2017)
11	Radish	Azospirillum, PSB, Azotobacter	When one-fourth quantity of Azospirillum, Azotobacter, PSB and RDF were administered, growth, yield, and nutritional quality of radish were maximized.	Shani *et al*., (2017) [108]
12	Tomato	Azotobactor, Azospirilium and PSB	Fruit yield was maximized when RDF + PSB was used, however fruit quality was improved when RDF+azospirillum+PSB was used.	Kadlag *et al*., (2007) [70]
		Frateuria aurantia	The application of *Frateuria aurantia* enhanced plant growth, total and marketable yield; yields rose with higher doses.	Öztekİn *et al* (2016) [90]

Effect of beneficial rhizobacteria's on important Vegetable crops

Spinach

Spinach is a useful leafy vegetable and a yearly member of the Chenopodiaceae family. Chlorophyll is abundant in spinach which gives it dark green color, high quality, and popularity among consumers. Additionally, spinach is a less calorie vegetable with particularly high levels of mineral deposits like Fe, Ascorbic acid, and vit-A, which provide it nutritional worth. To improve quality, yield, seed output, and growth Fertilizers high in nitrogen and phosphorus are regularly used on spinach. However, like many other vegetables, spinach suffers from the uncontrolled application of these fertilizers in terms of both quantity and quality. Thus, like many other vegetable crops, the usage of biological fertilizers has been advocated as a low-cost and practical method for improving the productivity of spinach. For instance, the use of PGPR that fixes nitrogen for example phosphorein and Azotobacter spp. whether applied separately or together with various N and P fertilizer rates had varying effects on growth, yield, and spinach plants of the cv. Dokki variety's male-female ratio and seeds' harvest and superiority (El-Assiouty and 2005's Abo-Sedera) [42]. 300 g of phosphorein inoculum per feed. seed inoculation in the presence of 15.0 or 7.50 kg P/fed and 40.0 kg N/fed (100% of the permissible Nitrogen dosage). (66.7 or 33% of the required P2O5 dosage) and 300 g of inoculated seeds. Azotobacter inoculum with the complete P2O5 dose (22.0 kg P2O5/fed.) plus 50.0% of the total amount of nitrogen (20.0 kg/feddan) showed the best results. Rhizobacteria that Promote Plant Growth by fixing nitrogen. Good seed production with the good value compared to control (fed with 40.0 kg N and 22.0kg P2O5) in Sustainable effect on growth and development, Male: Female ratio, and harvest. Application of 40 kg Nitrogen + 15 kg P2O5 + 0.3 kg phosphorein enhanced plant fresh production by 27.0 and 42.2% and seed harvest by 16.2 and 10.5% over control in the both spells, respectively, among all treatments.

Broccoli

Broccoli is a popular cool spell vegetable crop that is grown in various countries of the world. It is a cabbage family Brassicaceae edible green vegetable with a huge floral head that is consumed as a vegetable. It is abundant in vit-A, B1-B6, C and E, Calcium, Magnesium, Zinc, iron and antioxidants (Talley 2001; Rangkedilok *et al.*, 2002; Rozek and Wojciachowska 2005; Wojciachowska *et al*., 2005) [126, 97, 100]. Broccoli is high in sulphoraphane, a powerful anticarcinogenic chemical. It is minimal in sodium, fat, and calories (Decoteau 2000) [37]. Broccoli has gained popularity in recent years due to its versatile application and high nutritional value. More amount of plant nutrients is used to improve broccoli growth, production, and head quality (Brahma and Phookan 2006) [23]. Abou El-Magad *et al.,* 2014; directed two field researches in afresh reclaimed soil in Egypt in two different winter spells to evaluate the impact of *A. chroococcum* and *A. brasilense* and various levels of inorganic Nitrogen i.e. 59.9kg, 90.0kg and 121 kg N per feddan on vegetative stage, harvest, and quality of broccoli. Rhizobacteria Azospirillum and Azotobacter spp. treated plants grew faster in terms of plant height, leaf count, weight of green leaves and whole plant. In PGPR treated broccoli plants, dry matter accretion in heads and leaves, head quality along with Nitrogen, Phosphorus, and potassium contents of leaves and heads, were higher than in untreated control plants. *A. chroococcum* was the more effective of the two inoculants. Superior and resulting in a significant rise in vegetative growth, primary head N, P, and K content, as well as harvest and head quality of broccoli when compared to *A. brasilense* or a uninoculated control plants. However, the impact of different quantities of N on the evaluated parameters of broccoli differed statistically. Amongst different Nitrogen doses, 120 kg Nitrogen/fed (0.42ha) produced the most vegetative growth, followed by 90.0 kg N/fed. However, 60.0 kg Nitrogen/fed treatment resulted in the lowermost vegetative growth, primary head harvest, head quality. The current findings demonstrated that the combined usage of nitrogen fixing rhizobacteria and inorganic nitrogen had a statistically significant favorable impact on broccoli vegetative growth, yield, and nutrient uptake of broccoli. However, the combined application of 120 kg Nitrogen/fed with Azospirillum. *brasilense* caused in the maximum vegetative growth, harvest, and biochemical composition of broccoli among all single or repeated inoculation treatments. On the other hand, Yildirim *et al*., 2011 [139] studied the impact of root inoculations with *B. cereus* (N- fixing), *B. reuszeri* (P-solubilizing), and *Rhizobium rubi* (both N-fixing and P-solubilizing) on growth, nutrient acceptance, and harvest in soil inoculated with manure and some fertilizers. rhizobacteria inoculation with compost boosted broccoli harvest, chlorophyll content, head diameter, plant weight and Nitrogen, potash, Calcium, Sulphur, Phosphorus, Magnesium, iron Manganese, Zinc, and Copper levels much more than controls. Manure containing solitary cultures of *B. cereus*, *B. reuszeri and R. rubi* enhanced harvest by 17.0, 20.3, and 24.4%, respectively, and chlorophyll by 14.6, 14.0 and 13.6%, as compared to uninoculated. This research revealed that seedlings treated with *B. reuszeri) (*Phosphorus solubilizing) and *R. rubi* (both Nitrogen-fixing and Phosphorus-solubilizing) bacteria might be used as an option to decrease the usage of expensive fertilizers in broccoli production. Biofertilizers derived from *Azotobacter spp., Azospirillum spp.,* PSB, and Vascular Arbuscular Mycorrhiza, when used solo or in combination with or without chemical fertilizer, exhibited varying effects on broccoli production and qualitative value (Singh *et al.*, 2014) [120]. The results also suggested that a 100% application of rhizobacteria's performed better than the prescribed amount of fertilizer. Other treatment mixtures, with the exception of *Azospirillum + Azotobacter spp.* (50.0% each), achieved worse than the suggested amount of fertilizer. The coculture of *Azospirillum* and *Azotobacter (*50.0% each) enhanced the protein and lipid profile, as well as the phosphate and sulphate content of broccoli head. In conclusion, the combined inoculation of. *Azotobacter + Azospirillum* at a 50.0% concentration was shown to be more effective in increasing broccoli curd production and active biomolecules.

Radish

Radish, a root vegetable inborn to Asia and Europe (Gill 1993**)** is a frequently cultivated member of the Cruciferae family. It is cultivated virtually everywhere in many nations, including India, all year. Radish fusiform roots are consumed uncooked. as salad or as prepared veggie. Its leaf includes minerals as well as vit-A and vit-C. It can also be prepared as a green leafy vegetable. Growth and development of several nonlegumes Some nitrogen-fixing PGPR also impact radish growth. For Antoun examined 266 PGPR strains, including B. japonicum strain Soy 213. Antoun *et al.*, (1998) demonstrated the greatest impact on the radish plant. A total of B. japonicum produced a 60% rise in stimulatory effect, whereas in average, 25% of all rhizobia and brady rhizobia strains improved radish growth. by a factor of two or more. Also, B. japonicum strain Tal-629 dramatically enhanced in a second plant inoculation, the dehydrated matter harvest of radish increased by 15.0% over the control. These investigations revealed that *Rhizobium*, like several other bacteria, could also be used as a PGPR to boost vegetable yield. Basavaraj *et al*. 2002, testified the impact of self-sufficient bacteria in a follow-up investigation. C1 and C2 *Azotobacter* strains on germination and seedling Radish development under regulated settings. Over the uninoculated control, strain C2 of *Azotobacter. chroococcum* increased germination by 9.32%, length of radical by 90.40%, and length of plumule by 54.38%. Moreover, *Azotobacter* treatment of radish seeds increased height of plant, leaf count, area of leaf, girth of root, length of root, fresh and dehydrated root weight and root and leaf nitrogen composition superior then the untreated control. Though, *Azotobacter spp.* was found to be more beneficial with 75% of the necessary nitrogen dosage per ha, reducing reliance on nitrogen-based fertilizers while keeping good harvests. Shukla *et al*., (2012) tested chemical fertilizers and biological fertilizers like *Azospirillum spp.*, PSB, and AM fungus on radish cv. Chinese pink. A. strain C2 had the highest seed output (10.2 q per ha) and 1000. The combined treatment of *Azospirillum* + prescribed NPK rates resulted in the maximum seed weight and seedling vigor index-II. Ziaf and colleagues (2016) [141] assessed the result of nitrogen-fixing bacteria's such as *Azotobacter spp.*+ Ger (a synthetic germination and early growth stimulant) and Phosphorus Solubilizing Bacteria + Ger in conjunction with complete (suggested fertilizer dosage), 50%dosage of Nitrogen and a 50% dosage of Phosphorus on the produce of radish variety "Mino Early". The findings discovered that *Azotobacter spp.* increased plant and harvest characteristics, whereas germinator It had a bad impact on them. The combination of PSB and the required fertilizer dose give rise to the maximum leaf count per plant, fresh weight of root, and merchantable output. On the other hand, the use of Azotobacter with 50% dosage of Nitrogen and 50% dosage of Phosphorus resulted in the highest weight of green(fresh) leaves, carbon-based harvest, agronomic efficiency, and yield response. Furthermore, when Phosphorus Solubilizing Bacteria or *Azotobacter spp.* was sprayed with the suggested quantity of fertilizer, root diameter rose, and plants inoculated with *Azotobacter spp.* and a 50% dosage of Phosphorus had the lengthiest roots. Correlation investigation found that radish merchantable produce was affected by fresh weight of root.

Okra

Okra is a is a seasonal vegetable grownup for its eatable pods, which can be eaten as fresh or dehydrated all over the world. The nutrient composition of eatable okra pods is as follows: 88% H_2O, 2.1% protein, 0.2% fat, 8.0% carbs, 1.7% fiber, and 0.20% ash (Tindall. 1983). Aside from these, of okra provides minerals and vitamins. It needs nutrients such as N, P, K etc. for growth and maintenance (Hooda *et al*., 1980; Ahmed *et al*., 2015) [63, 7]. Any of these nutritional deficiencies caused in deprived growth and a decreased output (Shukla. and Nalk. 1993) [114]. As a result, a combined approach incorporating bacterial/bio-fertilizers and chemical fertilizers has been used for of okra production over the years (Singh *et al*.,2010) [119]. Dawar *et al*. (2008) [36] assessed the biotic potential of various bioagents such as B. thuringiensis, nitrogen-fixing rhizobacteria *Rhizobium melilot, Aspergillus spp.,* and *Trichoderma spp.* in suppressing Root rotting fungal spp. that cause damage to plants of sunflower and okra. When compared to the control, all biocontrol agents increased growth characteristics of both of helianthus and *Abelmoschus esculentus*. When seeds of helianthus and *Abelmoschus esculentus* were treated with *Rhizobium*. melilot and Bacillus. thuringiensis, the length and weight of the shoot and root rose dramatically.

Additionally, *Rhizobium* administered alone as seed dressing increased plant development and lowered disease intensity in plants. When *Rhizobium melilot* applied to plants, it significantly decreased the attack of *R. solani* on plants of okra (Tariq *et al*., 2007) [129]. *Rhizobium*, which are beneficial rhizosphere organisms for both leguminous and non-leguminous plants, are thought to protect roots against pathogenic fungi by covering and parasitizing the fungus's hyphal tips.

The highest plant height was reported when seeds of sunflower and okra were layered with *T. harzianum*. specifically, *Macrophomina phaseolina*, *Rhizoctonia solani*, and Fusarium spp. *T. harzianum* was found to be the most efficient microbial opponent in the suppression of root-rotting fungi, followed by *Bacillus thuringiensis, Rhizobium meliloti*, and *Aspergillus niger*.

Similarly, Ehtisham-Haque and Ghaffir (2008) found that R. melilot repressed the growth of *Macrophomina spp.*, *Rhizoctonia spp*. and *Fusarium spp.,* whereas *Bacillus japonicum* hindered the growth of *M. phaseolina* and *Rhizoctonia spp.* in root zone.

In the field, *Rhizobium meliloti, Rhizobium leguminsarum, and Bacillus japonicum* used as seed dressing or soil drench reduced *Macrophomina phaseolina, Rhizoctonia solani,* and Fusarium spp. infection in both leguminous (soya and green gram) and non-leguminous (helianthus and *Abelmoschus esculentus*) plants. Tariq *et al*. (2007) [129] investigated the antagonistic effects *of Bacillus subtilis, Bacillus thuringiensis, Bacillus cereus*, and *Rhizobium melilot* on the control of root-infecting fungus on mash bean and *Abelmoschus esculentus*. Following the application of *Bacillus spp.* and *Rhizobium melilot*, sprouting of seeds, length of root and shoot, and weight of root and shoot of *Abelmoschus esculentus* and green gram were greatly enhanced. *Rhizoctonia solani* infection was greatly reduced on okra when *Rhizobium melilot* was treated at 1.0% w/w, but all biocontrol bacteria, including *Bacillus spp*. and *Rhizobium meliloti,* totally blocked *Rhizoctonia solani* and *Macrophomina phaseolina* infection on green gram bean.

Cabbage

Cabbage is one more major vegetable that needs adequate amount of nutrition for growth. As a result, nutrient management incorporating the usage of synthetic fertilizers used together with low-cost biological fertilizers and ecologically harmless carbon-based composts in a well-adjusted ratio may be successful in increasing the production of cabbage (Hussein and Joo 2011) [64].

Sharma. 2002 [111]; studied the effect of N_2 fixing Rhizobacteria (*Azotobacter spp.* and *Azospirillum spp.*) and varied levels of Nitrogen i.e. 30 kg, 45 kg, and 60 kg N/hectare on cabbage development and harvest in a field experiment.

The usage of *Azospirillum spp*. enhanced the weight and count of unwrapped leaves per plant, diameter of head, weight of head/plant, fresh weight of whole plant and harvest (ton/hectare) considerably. Likewise, Nitrogen at 60 kg/ha generated the most unwrapped leaves/plant, diameter of head, weight of head/plant, fresh weight of whole plant and harvest (ton/hectare). Furthermore, *Azospirillum spp*. with 60 kg N/ha yielded the highest yield/ha with a BC ratio of 2.90.

Likewise, Sarkar *et al*. 2010 [105]; evaluated the effect of different Nitrogen dosages i.e. 0, 60, 80, and 100 kg/ha and biofertilizer (*Azotobacter*) dosages on cabbage growth and harvest at the Research Station of BKV, Nadia, West Bengal.

he used both Nitrogen and biological fertilizer in overall had a substantial effect on cabbage growth and produce parameters.

In terms of plant improvement, it was discovered that 100 kg N/ha was best, followed by 80 kg N/ha. *Azotobacter spp.* treated plants of cabbage outperformed untreated plants, with observed statistical differences.

except for the count of outer leaves. *Azotobacter spp.* treated plants Has a greater head production of 31.77 t/ha than untreated plants.

The increased growth of plants was linked to the fact that Nitrogen rises the leaves chlorophyll content, resulting in the generation of more carbohydrates and, as a result, quicker the development and output of cabbage heads (Lop andic and Zaric 1997; Sharma 2002) [81, 111].

Azotobacter spp. may also have aided in the growth and development of cabbage through the creation of auxin, vitamins, growth compounds, antifungals, and antibiotics.

The improved outcomes attained as a result of *Azotobacter spp.* treatment is similarly supported through the conclusions of Jeeva Jothi *et al*. (1993) in cabbage, where they testified that growth promoting substances released by PGPR may have resulted in improved root growth, H_2o transportation, nutrient appraisal and deposition.

However, the collective usage of Nitrogen and biological fertilizer lead to a considerable increase in Cabbage head weight and yield. The composite application of 100 kg Nitrogen/hectare and bacterial fertilizers resulted in the greatest cabbage harvest of 37.8 ton/hectare, which was substantially more than the previous year.

Verma *et al.* 1999; made similar observations. cabbage has the maximum vegetable and seed output as a result of the usage of 60.0 kg N/ha along with the addition of *Azotobacter spp.* These findings imply that *Azotobacter spp.* combined with 100 kg N/ha may be the greatest possibility for maximizing yield of cabbage.

Sharma *et al.* 2013 [109, 110]; investigated the impact of solo and multiple *Azospirillum spp*., *Azotobacter spp.* and Vascular Arbuscular Mycorrhiza composite culture on plants of cabbage. When compared to other dosages, the 4.0 kg/ha dosage of each biofertilizer resulted in the greatest plant height, number of leaves per plant, diameter of stem, length and width of longest leaf, and plant spread.

Azospirillum spp. was found to be superior amongst biofertilizers, considerably increasing the growth and weight of fresh leaves/plant by 25.80 and 15.23% over *Azotobacter spp.* and Vascular Arbuscular Mycorrhiza, respectively.

In addition, *Azospirillum spp*. considerably increased overall production of cabbage by 7.05% when compared to *Azotobacter spp.* application. Among the numerous biofertilizer doses tested, the 4.0 kg/hectare dosage of each biofertilizer had the most beneficial effect on field-grown crops than a 2 kg/ha or even a 6 kg/hectare dosage of *Azospirillum spp*. and *Azotobacter spp.* Ishfaq *et al*., (2009) [67] used and Azotobacter (0.0, 5.0, and 10 kg/hectare) and vermicompost (0.0, 5.0, and 10 t/ha) in cabbage variety “Pride of India”. Vermicompost application at 10 ton/hectare give rise to the highest plant length, greatest plant spread, largest head size, and maximum harvest of heads/plant/ha. The count of leaves per plant and wrapper leaves/head were, however, limited to 5 ton vermicompost /ha. Amongst the several levels of biofertilizer injection, 10 kg/ha Azotobacter application give rise to the greatest height of plants and length and width of head, the greatest number of leaves/plant, and the greatest number of wrapper leaves/head, while 5 kg Azotobacter/ha resulted in the greatest head length and head harvest/plant.

Both bacterial and fungal inoculation enhanced dehydrated and hydrated weight, as well as leaf area. However, NPK chemical fertilizer reduced soil microflora, but effective microorganisms such as fungi or bacteria boosted microbial density dramatically. The count of leaves/plant and wrapping leaves/head, however, were limited to 5-ton Vermicompost/hectare.

Amongst the several treatments of biofertilizer inoculation, 10 kilograms per hectare Azotobacter application give rise to the greatest height of plants and head diameter, the more leaf count/plant, and the greatest count of wrapper leaves per head, while 5 kg Azotobacter/ha resulted in the greatest head length and head harvest/plant.

Hussein. and Joo. (2011) [64] discovered that treating seedlings with bacteria (*A. chroococcum*) and fungal effective microbes increased growth of Chinese cabbage considerably.

dehydrated and green shoot weight, as well as leaf area, increased dramatically. This study suggests that both bacterial and fungal EM are useful for improving the growth of Chinese cabbage and enhancing soil microorganisms.

Potato

Potato is a starch containing tuber vegetable belonging to the nightshade family. The fourth-most produced vegetable, the potato is a high-yielding, heavy feeder, and transient crop. In order to produce potatoes at their peak potential, higher fertilizer rates of nitrogen and phosphorus are needed (Igual *et al*. 2001) [65]. Because of this, nitrogen-fixing PGPR have been used in potato cultivation as a biofertilizer or as a bacterial inoculum to reduce fertilizer use (Sidorenko *et al*. (1996) [116]; Kumar *et al*. (2001) [76]; Shafeek *et al*. (2004) [107]. Chaudhary *et al.* (2019) [30] evaluated the result of potassium mobilizing bacteria (KMB) on potato (*Solanum tuberosum* L.) growth and harvest during the Rabi season of 2017-18. They tested eight treatments: T1 (1,00% RDK T2 (75% RDK) T3 (75.% RDK + tuber inoculation with potassium mobilizing bacteria (Enterobacter asburiae) T4 (75.% RDK + tuber inoculation with potassium mobilizing bacteria (Frateuria aurentia) T5 (75% RDK + seed tuber treatment with potassium mobilizing bacteria (Enterobacter asburiae) + potassium mobilizing bacteria (Frateuria aurentia) T6 (75% RDK+ soil application of potassium mobilizing bacteria (Enterobacter asburiae) T7 (75% RDK + soil inoculation of potassium mobilizing bacteria (Frateuria aurentia) T8 (75% RDK + soil application of Enterobacter asburiae + potassium mobilizing bacteria (Frateuria aurentia) and Kufri pukhraj variety of potato. Their research found that potassium mobilizing bacteria treatment had a big effect on potato haulm yield. T7 (75% RDK and soil application of potassium mobilizing bacteria (Frateuria aurentia.) given highest haulm yield. The haulm production increased by 7.94% compared to T1 (1,00% RDK). Potassium mobilizing bacteria inoculation also had a large impact on total tuber production. T7 (75% RDK and soil application of KMB (Frateuria aurentia)) had the best total tuber yield, which was the same as T1 and T8. T2 (75% RDK) had the lowest overall tuber yield.

Brinjal

Brinjal is an important member of the Solanaceae or night-shade family, it is also known as an eggplant (Kantharajah *et al*. 2004) [72]. listed in the top ten vegetables farmed worldwide. It is raised in several warm regions of world despite being of foremost commercial status in Africa, Asia and subtropics (India, Central America) (Sihachkr *et al*. 1993) [117]. All over the world, there are farmers that are growing eggplant. It is a rich in fiber, less calorie foodstuff that is also high in nutrients, with various health advantages including reducing the risk of cardiac disorders, management of diabetes and body weight (Gürbüz *et al*., 2018; Naeem. and Ugur. (2019) [56, 86]. Jabin and Ismail (2017) [68] conducted a pot culture experiment to analyze the impact of certain capable microbial isolates for potash solubilization in soil, over and above their outcome on growth and harvest qualities of brinjal. Different stock cultures were taken based on their potash solubilizing capability in laboratory condition and used for pot culture. The results showed that the inoculation of KSB inoculants pointedly improved the growth parameters and potash content in eggplant as equated to the control. Height of plant and number of leaves improved significantly after inoculation with Pseudomonas spp. (KSB-PD-1-A), which was comparable to the bacterial strains Pseudomonas spp. (KSB-M-1) and (KSB-M-1).

Tomato

Wolf apple (Lycopersicon esculentum) is one of the world's most widely farmed and consumed horticulture crops (Grandillo *et al*., 1999) [52]. The name tomato comes from the South American word "Xitomate or Zitomate." Tomato is a member of the Solanaceae family, with diploid chromosomes (2n=2X=24), the genus Lycopersicon, and the subfamily Solanoidae. Tomatoes were first farmed as wild forms in South America's Peru-Ecuador-Bolivia region. India ranks second only to China in tomato production (182.26 lakh MT). Tomatoes are only second to potatoes in terms of global production of all horticulture vegetables (Tan *et al*., 2010) [128]. Tomato and tomatoes food product provide a number of nutrients as well as several health benefits to the human frame (Willcox *et al*.,2003) [137]. Chemical fertilizers and pesticides used in tomato farming can be reduced with the use of microbial inoculations, especially those that contain PGPR (Ahmed *et al*., 2017) [9]. Kumaran *et al*. (1998) [78] found that plants grown with phosphobacteria and Azospirillum had higher tomato growth, yield, and quality indicators like TSS, ascorbic acid, and lycopene content. In an experiment, Ztekin *et al*. (2016) [90] examined the effects of Symbiont-K, a bio-fertilizer comprising of Frateuria aurantia, on tomato plants (cv. Naram F1) cultivated in greenhouse settings. They also examined the effectiveness of various Symbion-K doses. Symbion-K was used in three different doses: the recommended dosage (D, 0.3 l da-1), half the recommended dose (D/2, 0.15 l da-1), and two times the recommended dose (D 2, 0.6 l da-1). Non-inoculated plants (0.0 l da-1) served as the control group. On January 1st, 2014, all plants were transplanted at a density of 2 plants per m2. During production, Symbion-K was sprayed twice via irrigation lines: once at transplanting time and once 15 days later. The findings demonstrated that the application of bio-fertilizer improved plant growth and total and marketable yield; yields rose with higher doses. The use of 0.3 l da-1(D) was determined to be the best suitable dose in expressions of economic usage due to the fact that D and D 2 treatments produced outcomes that were identical to or close to many measured parameters.

Broad Bean

In developing nations, the Broad bean (*Vicia faba*e L.) is utilized as a human foodstuff. In the Europe, Asia, and east Africa, it can be eaten as fresh and processed (Duke, J.A., 1981; Bond *et al*1985) [40, 22]. Ding *et al* 2021 [38] directed an experiment to decrease the suggested dosage of potassium (K) for Broad bean by using KSB and HA. They studied the effect of the treatments i.e., 50 and 100% of suggested K dose with or without KSB (potassium solubilizing bacteria) and 40 kg of humic acid ha^{-1}. They applied treatments to Broad bean ((*Vicia faba* L., cv. Giza 843) plants sown in sandy loamy soil for two succeeding seasons. In their research they found that the highest potash use efficiency (40%) was obtained in the soil treated with HA and KSB while the lowest one (13.9%) was found in treatment of full recommended dose of mineral form. HA (humic acid) and KSB were given as treatment to the plants fertilized with 49.9% of the recommended dose gave the maximum growth and yield. HA and KSB improved the soil cation exchange capacity (CEC) by 5.9% and the soil organic matter (SOM) by 11.9%. Chlorophyll and carbohydrates content of the leaves were improved by 35.9% and 49.9%, consistently, overhead the control, as the results of the use of humic acid and KSB.Applying half of recommended dose of K for broad bean in a inorganic form with 40 kg of humic acid and KSB led to 13.9% and 18.9% heightened the seed and crop residue yield compared to the complete synthetic fertilizer application without bacterial inoculation. Result showed that HA and KSB can be inoculated to increase the level of soil health and improves the accessibility and reception of nutrients, and thus helps to improve the harvest of broad bean plants.

Conclusion

In current scenario the application of PGPR's is very important for sustainable agriculture as they are naturally occurring renewable supplier of plant nutrients which shows no residual effect on the produce and no ill effect on the environment. PGPR's promote crop growth by enriching soil by nutrients through activities such as biological nitrogen fixation, phosphate solubilization, siderophores synthesis, and growth regulators. Similar results were reported by Gopalakrishnan *et al.* (2015) [51]; Bulgarelli *et al.* (2013) [25]. The application of PGPR's in agriculture can replace or reduce the amount of chemical fertilizer required and it will reduce the ill impact of chemical fertilizers on environment (Glick 2014; Ijaz *et al*., 2019, 2020) [50, 66]. Symbiotic nitrogen-fixers and phosphate-solubilizing microorganisms are vital for providing nitrogen and phosphorus to the plant, letting for more ecofriendly nitrogen and phosphate fertilizer use (Tambekar *et al*., 2009) [127]. BNF (Biological nitrogen fixation) can minimize the requirement for synthetic N fertilizer, lower crop production costs, and improve agricultural sustainability (Silva and Uchida 2000) [118]. NFB (nitrogen-fixing bacteria) that converts inert air Nitrogen(N_2)

to ammoniacal form (Bakulin *et al*. (2007) [19]. The use of PGPR's in agriculture may supplement or replace the usage of phosphate fertilizers (Khan *et al*. (2006) [73]. They are extra successful than fungi at phosphorus solubilization (Alam *et al*. (2002) [10]. Phosphate solubilizing bacteria (PSB) account for 1 to 49.9% of the total microbic inhabitants in soil, while phosphorus solubilizing fungi (PSF) account for just 0.10 to 0.49% (Chen *et al*. (2006) [32]. They have been shown to play an important part in the environmental K cycle and in making potassium accessible for plant nutrition (Rogers (1998) [99].

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