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RESEARCH ARTICLE

The Effect of Plant Growth Promoting Bacteria Strains on Yield and Some Quality Parameters of Eggplant (*Solanum melongena* L.)

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ABSTRACT

This research was carried out under field conditions to determine the effect of PGPB on the yield and quality of Pulsar F1 eggplant variety under Igdir ecological conditions in 2021. The experiment was conducted with 8 treatments (*Brevibacillus reuszeri* strain IT 119, *Kluyvera cyrocrescens* strain IT 160, IT 119 + IT 160, IT 119 + Fertilizer, IT 160 + Fertilizer, IT 119 + IT 160 + Fertilizer, Fertilizer and Negative Control) with 3 replications according to the randomized block design. Bacterial strains were applied by inoculating 100 ml (10^6 cfu/ml) to the root zone of the plants during seedling stage. PGPB treatments increased total yield, discard yield, marketable yield, plant height, plant stem thickness, number of leaves, plant root wet weight, plant root dry weight, stem wet weight, stem dry weight, number of fruits per plant, fruit wet weight, fruit dry weight and root length compared to negative and positive control groups. The treatments had no effect on fruit diameter. Although both strains were found to be successful, especially *Kluyvera cyrocrescens* strain IT 160 alone and in combination showed positive effects in terms of the parameters examined in eggplant plants and has the potential to be used as biofertilizer.

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1. Introduction

Eggplant is an economically important vegetable species in the Solanaceae family, grown as perennial in tropical regions and as annual in temperate regions. It is one of the most widely produced vegetables in the world and has a wide variation both genotypically and phenotypically. Today, the most widely known and cultivated eggplant species all over the world is *Solanum melongena* L. (Kassi et al., 2019).

With the emergence of many diseases in today's living conditions, great attention has started to be paid to healthy nutrition, and the consumption of products in this regard has increased rapidly. From this point of view, contrary to popular belief, eggplant is as valuable as other vegetables and it is an important part of healthy nutrition due to its vitamins, minerals, low protein, carbohydrate and fat content, fibrous structure and antioxidant source (Kocayiğit, 2010). In addition to being utilised as a vegetable in different ways, it has been used as a medicinal plant since ancient times and today it is used as an ornamental plant in the pharmaceutical sector and in landscaping (Demir, 2020).

Due to the phenolic and antioxidant compounds it contains, its importance in terms of human health has been better understood in recent years. It protects our body against chronic diseases and cleans it from harmful substances; it has painkillers, anti-inflammatory, and calming properties; and it is one of the most important vegetables used in diets in the fight against obesity with its approximately 90% water content.

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Thanks to the antioxidants it contains, it has been reported that it blocks the formation of free radicals that damage the cell membrane and cause oxidation of malignant LDL cholesterol, leading to an increased risk of heart disease and stroke. It is also used in the treatment of diabetes, arthritis, asthma, bronchitis, stomach, and liver diseases.

In fact, it has become a vegetable which is accepted as the "King of Vegetables" in India due to its economic and nutritious nature and its use in the treatment of diseases (Fategbe et al., 2013; Külahlıoğlu, 2016).

Globally, since the beginning of modern agriculture, farmers have endeavoured to improve the quality and yield of eggplant by selecting varieties and using techniques such as irrigation, fertilisation and control of pathogens/pests. However, many agricultural soils do not contain sufficient amounts of one or more of the nutrients such as nitrogen, phosphorus, potassium and iron, and therefore plant growth is insufficient. Unfortunately, farmers have become more dependent on chemical sources of nitrogen, phosphorus, etc. to eliminate this problem and to obtain higher plant yields. As a result of this, chemical fertilizers pose a great risk to human and environmental health due to both the cost of production and the decrease in non-renewable resources such as oil and natural gas used to produce them.

In order to greatly increase agricultural productivity and to do so in a sustainable and environmentally friendly manner, many of the current approaches to agriculture, including the use of chemical fertilizers, herbicides, fungicides, and insecticides, need to be reconsidered (Lucy et al., 2004). At this point, the use of plant growth-promoting bacterial (PGPB) strains as an integral component of agricultural practice is a technology whose time has come. In both managed systems and natural ecosystems, the beneficial bacteria-plant relationship plays a key role in promoting plant health and growth and increasing yields (Compant et al., 2010). Such plant growth-promoting bacteria are capable of enhancing plant growth and protecting plants from diseases and abiotic stresses through a wide variety of mechanisms.

Some important properties such as biological nitrogen fixation, phosphate solubilisation, 1-aminocyclopropane-1-carboxylate (ACC) deaminase activity, production of siderophores and phytohormones are considered as characteristics of plant growth promoting bacteria (Souza et al., 2015). In addition, they indirectly contribute to plant growth by showing biocontrol activity against pathogens causing diseases in plants with their enzymes, antimicrobial substances, and superiority in competition (Innerebner et al., 2011; Whipps, 2001). These two complementary properties make PGPBs valuable for agriculture. The combination of different methodologies such as identification of PGPB strains, determination of plant growth promoting properties of bacteria, seed inoculation tests under laboratory conditions and field cultivation trials are important for the development of new and effective inoculants for agriculture. Effective bacterial inoculants to be used in vegetable cultivation will contribute to reducing or eliminating the use of fertilizers, improving the physical, chemical, and biological properties of soil, promoting plant growth, overcoming food safety challenges, reducing environmental pollution, and increasing productivity.

In this study, it was aimed to determine the effects of 2 bacterial strains and chemical fertiliser on yield and quality parameters of Pulsar F1 eggplant cultivar, which is the most preferred eggplant variety by the producers in Iğdır province, under field conditions, which ranks first in eggplant production in Eastern Anatolia Region in addition to TÜİK (2019).

2. Materials and Methods

2.1. Bacteria and Plant Material Used in the Study

In the study, *Brevibacillus reuszeri* strain IT 119 isolated from the rhizosphere of *Atriplex nitens* and *Kluyvera cryocrescens* strain IT 160 isolated from the stem of tomato plant were used as plant growth promoting bacteria. The catalase test, nitrogen fixation, phosphate solubilisation and ACC-deaminase activity of both bacterial strains were found positive (Temel, 2023). Additionally, hypersensitivity tests were performed on these strains in tobacco and it was determined that they did not cause necrosis. Pulsar F1 eggplant variety was grown to determine the effect of bacterial strains on plant yield and quality parameters.

2.2. Field Trial

The experiment was established in 2021 in the Iğdır Merkez Özgür neighborhood according to the coincidence blocks experimental design with 3 replications. A total of 288 eggplant seedlings were planted with 12 plants in each replicate. Plotting was done as 60 cm above the row, 100 cm between the rows and 120 cm between the plots, and 140 cm between the treatments in the block. All cultural treatments were carried out regularly during the experiment. The water requirement of the plants was met by the drip water method.

Before the first planting, 1 ton of burnt barnyard manure was applied to a 500 m^2 area as base fertilizer. Before the first seedling planting, 5 kg of compound fertilizer 18-18-18 (N-P-K) from the Gübretaş company was applied by drip irrigation. White Lily Exelans NK liquid organomineral fertilizer was applied 3 weeks after the seedling planting during the development period of the plants. Only water was given to the plants in the negative control group.

Bacterial strains maintained at -80 °C were inoculated in Nutrient Agar medium and left to grow in an incubator set at 27 °C. After incubation, a loop of 48 hours fresh culture of the bacterial strains was taken and transferred to Nutrient Broth medium. Bacterial inoculum was prepared by incubating the liquid media containing bacteria overnight at 150 rpm/min at 27 °C on a shaker. After incubation, the bacterial solutions were diluted with water and the concentration of the mixture was adjusted to 10^6 cells/ml using a turbidimeter. The prepared bacterial solutions were inoculated 100 ml into the root zone of the seedling plants.

There were 8 treatments in the experiment: IT 119, IT 119 + Fertiliser, IT 160, IT 160 + Fertiliser, IT 119 + IT 160, IT 119 + IT 160 + Fertiliser, Negative Control (Water only) and Positive Control (Fertiliser only).

In the study, total yield (kg/parcel), discard yield (kg/parcel) and marketable yield (kg/parcel) were determined according to Başer (2015), plant height and stem thickness were determined according to Kanber (1997), number of leaves (number/plant), plant root dry weight, plant stem wet weight and plant stem dry weight were determined according to Yücel (2020) and root length was determined according to Özgen (2019). For fruit quality parameters, fruit length, fruit diameter and fruit weight were measured after each harvest during the growing season. The measurements were made on 6 randomly selected fruits from each replicate of each plot after harvest. Then, average fruit length, average fruit diameter and average fruit wet weight values were calculated by averaging the measured values. Fruit dry weight (%) was obtained by calculating the ratio of dry weight to wet weight as % after weighing the fresh weight of two fruits taken after harvesting during the vegetation period and then dried in an oven at 70 °C until the weight was constant.

2.3. Statistical Evaluation

The data obtained in the experiment were subjected to analysis of variance using SPSS (version 26.0) statistical package programme and the differences between treatments were determined by Duncan Multiple Comparison Test with 1% error probability.

3. Results and Discussion

3.1. Effect of Treatments on Yield Parameters of Pulsar F1 Variety

The effects of treatments on total yield, discard yield and marketable yield are presented in Table 1.

Table 1. Effect of treatments on yield parameters.

Treatments	TY (kg)	DY (kg)	MY (kg)
IT 119	59.66±0.12^{a*}	3.13±0.06^{d}	56.53±0.02^{a}
IT 119 + G	55.83±0.07^{b}	4.04±0.02^{c}	51.79±0.17^{b}
IT 160	59.77±0.07^{a}	2.97±0.01^{d}	56.80±0.23^{a}
IT 160 + G	43.95±0.12^{d}	4.09±0.05^{c}	39.86±0.02^{d}
IT 119 + IT160	39.94±0.29^{f}	3.00±0.12^{d}	36.94±0.06^{e}
IT 119 + IT160 + G	44.74^{c}±0.01^{c}	3.03±0.01^{d}	41.71±0.29^{c}
Negative Control	31.09±0.58^{g}	9.24±0.58^{b}	21.84±0.12^{g}
Positive Control	42.37±0.09^{e}	12.54±0.06^{a}	29.83±,0.58^{f}
F	1890.616**	293.238**	2527.054**

*Values are the average of three replicates. There is no statistical difference between the values shown with the same letter in the same column. ** p≤0,01. **TY:** Total yield, **DY:** Discard yield, **MY:** Marketable yield, **G:** Fertiliser.

When Table 1 was examined, it was observed that the total yield of eggplant s harvested during the vegetation period varied between 31.09 and 59.77 kg/parcel. The highest total yield was obtained in IT 160 and IT 119 treatments, while the lowest yield was determined in the plants in the negative control group. It was observed that single application of bacterial strains gave better results than the application of fertiliser and mixture of each other. During the vegetation period, it was found that the total discard yield of the eggplant s harvested from the experiment varied between 2.97 and 12.54 kg/parcel. The highest discard yield was found in the positive control group with 12.54 kg/parcel. The lowest discard yield was 2.97, 3.00, 3.03 and 3.13 kg/parcel in IT 160, IT 119 + IT 160, IT 119 + IT 160 + Fertiliser and IT 119 treatments, respectively. When the effect of treatments on marketable yield was evaluated, it was determined that marketable yield varied between 21.84and 56.8 kg/parcel. The highest yield was determined as 56.80 and 56.53 kg/parcel in plants treated with IT 119 and IT 160 strains, respectively.

The effects of treatments on plant height, plant stem thickness and number of leaves are given in Table 2.

Table 2. Effect of treatments on plant height, plant stem thickness and number of leaves.

Treatments	PH (cm)	PST (mm)	NL
IT 119	98±0.58^{c*}	15.70±0.06^{d}	250±0.58^{a}
IT 119 + G	104±2.31^{ab}	22.00±0.58^{a}	172±0.58^{f}
IT 160	100±0.58b^{c}	22.08±0.01^{a}	238±0.58^{c}
IT 160 + G	102±1.15^{abc}	21.43±0.01^{ab}	235±0.58^{d}
IT 119 + IT160	105±2.31^{a}	20.40±0.58^{c}	245±0.58^{b}
IT 119 + IT160 + G	104±1.15^{ab}	21.20±0.58^{b}	229±0.58^{e}
Negative Control	55±0.58^{d}	12.04±0.01^{f}	45±0.58^{h}
Positive Control	99±0.58^{c}	15.05±0.01^{e}	169±0.58^{g}
F	152.328**	351.187**	14472.375**

*Values are the average of three replicates. There is no statistical difference between the values shown with the same letter in the same column. ** p≤0,01. **PH:** Plant height, **PST:** Plant stem thickness, **NL:** Number of leaves, **G:** Fertiliser.

The effects of treatments on plant height, stem thickness and number of leaves were found statistically significant (p≤0.01). As a result of the treatments, the longest plant height (105 cm) was obtained in IT 119 + IT 160 treatment, while the shortest plant height (55 cm) was measured in the negative control group. Table 2 shows that the stem thickness of eggplant plants varied between 12.04and 22.08 mm. The highest plant stem thickness was obtained in plants inoculated with IT 160 bacteria alone and IT 119 strains together with fertiliser. When the values of the number of leaves were analysed, the highest number of leaves (250) was determined in the IT 119 application and the lowest number of leaves (45) was determined in the plants in the negative control group.

The effects of the treatments on plant root wet weight, root dry wet weight, plant stem wet and stem dry weights were found statistically significant (p≤0.01) and the results are presented in Table 3.

Table 3. Effect of treatments on plant height, diameter and number of leaves.

Treatments	PRWW (gr)	PRDW (gr)	PSWW (gr)	PSWW (gr)
IT 119	97±0.58^{e*}	32.8±0.12^{e}	901±0.12^{f}	313.3±0.58^{c}
IT 119+G	233±0.58^{b}	90.3±0.17^{a}	1597±0.17^{a}	448.1±1.15^{a}
IT 160	153±0.58^{c}	28.8±0.12^{e}	1002±0.12^{e}	346.3±0.58^{bc}
IT 160+G	236±0.58^{a}	88.2±0.58^{b}	1103±0.58^{d}	362.5±1.15^{b}
IT 119 + IT160	128±0.58^{d}	46.2±0.12^{d}	1197±0.12^{b}	362.3±1.15^{b}
IT 119+IT160+G	78±0.58^{f}	65.0±0.46^{c}	1159±0.46^{c}	359.8±1.15^{b}
Negative Control	46±0.58^{h}	15.3±0.12^{g}	195±0.12^{h}	147.4±0.58^{e}
Positive Control	71±0.58^{g}	24.6±0.35^{f}	679±0.35^{g}	250.8±1.15^{d}
F	15731.786**	8946.604**	177166.640**	58.766**

*Values are the average of three replicates. There is no statistical difference between the values shown with the same letter in the same column. ** p≤0,01. **PRWW:** Plant root wet weight, **PRDW:** Plant root dry wet weight, **PSWW:** Plant stem wet weight, **PSDW:** Plant stem dry weight, **G:** Fertiliser.

When Table 3 is examined, the highest root wet weight (236 g) was determined in the plants where IT 160 strainin was applied together with fertiliser. The lowest root wet weight (46 g) was measured in the plants in the negative control group. Similarly, the highest root wet weight (233 g) was determined in the plants in which IT 119 strain was applied together with fertiliser. The highest root dry weight (90.3 g) was measured in IT 119 + fertiliser application. Again, the second highest value (88.2) was obtained in the plants where IT 160 strainin was applied together with fertiliser. Compared to the negative control, all of the treatments had a positive effect on root dry weight. It was observed that the results of plant stem wet weight varied between 195 and1597 g. It was determined that the best treatment result belonged to IT 119 + Fertiliser treatment. The highest plant stem dry weight (448.1 g) was obtained from the plants in which IT 119 strain was applied together with fertiliser. IT 160 + Fertiliser, IT 119 + IT 160 and IT 119 + IT 160 + Fertiliser treatments were in the same group and gave good results.

The effect of the treatments on the number of fruits per plant is presented in Table 4.

Table 4. Effect of treatments on number of fruits per plant and root length.

Treatments	**FNP (Number)**	**RL (cm)**
IT 119	18.0±0.57^{a*}	36±0.58^{b}
IT 119 + G	17.8±0.11^{a}	28±0.58^{d}
IT 160	18.0±0.57^{a}	43±0.58^{a}
IT 160 + G	18.5±0.29^{a}	31±0.58^{c}
IT 119 + IT160	19.3±0.11^{a}	36±0.58^{b}
IT 119 + IT160 + G	19.5±0.29^{a}	32±0.58^{c}
Negative Control	13.0±0.57^{b}	20±0.33^{f}
Positive Control	14.0±0.57^{b}	25±0.58^{e}
F	30.602**	164.753**

*Values are the average of three replicates. There is no statistical difference between the values shown with the same letter in the same column. ** p≤0,01. **FNP:** Fruit number per plant, **RL:** Root length, **G:** Fertiliser.

It was observed that the application of the strains both with each other and as a mixture with fertiliser gave the best results. The highest number of fruits per plant was obtained as 19.5 in IT 119 + IT 160 + Fertiliser treatment. It was determined that root length varied between 20 and 43 cm in the experiment. The longest root length (43 cm) was measured in IT 160 bacteria treatment. The shortest root length (20 cm) was recorded in the plants in the negative control group.

3.2. The Effect of Applications on Fruit Quality Parameters

The effects of treatments on fruit length, fruit diameter, fruit wet weight and fruit dry weight are given in Table 5.

Table 5. Effect of treatments on fruit length, fruit diameter, fruit wet weight and fruit dry weight.

Treatments	**FL (cm)**	**FD (cm)**	**FWW (gr)**	**FDW (%)**
IT 119	17.0±0.58^{ab*}	2.2±0.58$^{n.s.}$	135±0.58^{c*}	19±0.58^{c}
IT 119+G	15.5±1.15^{abc}	2.1±0.58	141±0.58^{b}	18±0.58^{cd}
IT 160	16.0±0.58^{ab}	2.1±0.58	143±0.58^{a}	26±0.58^{a}
IT 160+G	14.8±1.15^{bc}	2.2±0.58	111±0.58^{e}	21±0.58^{b}
IT 119+IT160	18.5±0.58^{a}	2.3±0.58	103±0.58^{g}	21±0.58^{b}
IT 119+IT160+G	18.0±1.15^{a}	2.1±0.58	113±0.58^{d}	17±0.58^{de}
Negative Control	13.0±0.58^{c}	2.2±0.58	70±0.58^{h}	16±0.58^{e}
Positive Control	17.0±1.15^{ab}	2.2±0.58	107±0.58^{f}	19±0.58^{c}
F	3.863**	1.500	1762.232**	29.089**

*Values are the average of three replicates. There is no statistical difference between the values shown with the same letter in the same column. **p≤0,01. **FL:** Fruit length, **FD:** Fruit diameter, **FWW:** Fruit wet weight, **FDW:** Fruit dry weight, **G:** Fertiliser, **n.s.:** Insignificant value.

The effect of bacterial treatments on fruit length was found to be statistically significant at p≤0.01 level (Table 5). It was determined that fruit length varied between 13-18.5 cm. As a result of IT 119 + IT 160 and IT 119 + IT 160 + Fertiliser treatments, the longest length measurement was recorded as 18.5 and 18.0 cm, respectively. The shortest fruit length was determined in the plants in the negative control group. The effect of bacteria treatments on fruit diameter was found statistically insignificant. The highest fruit wet weight was 143 g in IT 160 treated plants, while the lowest fruit wet weight was 70 g in the negative control group. Fruit dry weight percentage varied between 16 and 26 in the experiment.

In this study, the effect of single and multiple inoculation of *B. reuszeri* strain IT 119 and *K. cryocrescens* strain IT 160 on the growth of Pulsar F1 eggplant variety was evaluated. Single inoculation of bacterial strains resulted in the highest values for total yield, marketable yield, number of leaves, root length, fruit wet weight and fruit dry weight, while the highest values were obtained for root wet weight, root dry weight, stem wet and dry weight when bacteria were applied together with fertilizer. The maximum value for plant height was measured in plants where two bacterial strains were applied together. It was found that single bacterial inoculation and bacteria + fertilizer application increased plant stem thickness. The longest fruit length was obtained as a result of the combination of both bacterial strains with each other and with fertilizer. When the results were evaluated in general, it was seen that bacteria treatments gave better results than fertilizer applications and bacteria increased the effectiveness of fertilizer. Similar data to the findings of this study were obtained as a result of different PGPR applications to eggplant plants. In a study conducted by Consentino et al. (2022), it was concluded that in eggplant inoculated with *Azospirillum brasilense*, total yield increased by 5% and marketable yield increased by 9% compared to the control, and the bacteria treatment significantly affected the average mass of marketable fruit. In the study conducted by Guedes et al. (2018), longer plant height was obtained in eggplant inoculated with *Pseudomonas fluorescens* compared to plots with barnyard manure. Castro et al. (2005) observed a positive correlation between bacterial application and eggplant growth and determined that bacterial applications contributed to plant growth rate and increased stem diameter. *Pseudomonas putida* SAB10 and *P. palleroniana* SAW21 inoculated eggplant plants increased plant height, stem wet weight and stem dry weight compared to the control group (Fathalla & Sbary, 2020). Saputri et al. (2023) reported that PGPR applied together with barnyard manure caused faster decomposition of organic matter in barnyard manure, which increased the growth and yield of eggplant plants. It was found that the biopreparation formulated with a cellular concentration of 10^7 CFU mL-1 of *Brevibacillus borstelensis* B65 had properties that stimulated the growth of eggplant grown in a mixture of soil and humus, and the physiological activity of bacterial strains stimulated the growth of the root system of plants. It was also found that *B. borstelensis* B65 treatment increased the mass of eggplant roots, stems and leaves, causing a highly significant increase in root and leaf weight (Vinent et al., 2014). Fu et al. (2010) revealed that high salinity in the root medium was detrimental to the growth and development of eggplant, but eggplant inoculated with *Pseudomonas* showed a positive effect on plant growth under salt stress.

The effect of the bacteria in the study on the growth of different plant groups was tested and similar successful results were obtained. *K. cryocresscens* strain RCK-113C treatment was found to maximally increase the chlorophyll content (50.02), leaf length (26.03 cm), leaf area (268.38 cm^2), flower wet and dry weight (15.54 g and 0.88 g) of hyacinth. In addition, maximum onion diameter (42.57 mm), onion length (40.01 mm) and onion weight (12.01 g) were determined. The reasons for the increases in plant growth were attributed to increased nutrient uptake, provision of plant growth hormones, improvement of chlorophyll content and organic acids by bacterial treatments (Parlakova Karagöz et al., 2019). It was reported that *K. cryocresscens* treatment was more effective on leaf width and plant height of hyacinth plant compared to control and fertilizer treatments, the harvest period was prolonged and maximum leaf length was obtained as a result of the application (Bintaş et al., 2021), while the same bacterial strain increased magnesium and potassium content in leaves and onions (Bintaş et al., 2020). Parlakova Karagöz (2020) concluded that the bacterial formulation consisting of a combination of *B. megaterium* TV-91C, *P. agglomerans* RK-92 and *K. cryocresscens* TV-113C strains can be successfully used to improve plant growth and plant aesthetics in poinsettia cultivation. It was observed that the application of nitrogen-fixing and phosphorus-solubilizing *K. cryocresscens* strains to Ceyhan 99 bread wheat variety at different salt concentrations increased both phosphorus and nitrogen amounts in the soil (Söğüt & Çığ, 2019). *K. cryocresscens* M7 strain isolated from industrial wastes was found to be resistant to the antibiotics vancomycin, ampicillin, carbenicillin and streptomycin and was also found to be a beneficial bacterium capable of removing nickel from soil (Bisht & Kumar, 2023). *Enterobacter cloacae*, *Klebsiella pneumoniae* and *K. cryocrescens* strains were found to have promising potential as seed inoculants for African Cabbage (*Cleome gynandra* L.) (Shipoh, 2021). It has been stated that *K. cryocrescens* strain may have potential for biofertilizer production required in organic agriculture due to its ability to make water-insoluble phosphates soluble and directly promote plant growth through biological N2 fixation (Parlakova Karagöz et al., 2019). *K. cryocrescens* has been found to be able to dissolve tricalcium phosphate $Ca_3(PO_4)_2$ and hydroxyapatite $[Ca_{10}(PO_4)_6(OH_2)]$ (Sharma et al., 2013; Vazquez et al., 2000) and has the capacity to produce siderophores. Therefore, it was emphasized that *K. cryocrescens* not only promotes growth, but also antagonistic to phytopathogenic microorganisms, so it can be used as a potential candidate for developing bacterial inoculants (López et al., 2019).

Brevibacillus reuszeri is a spore-forming bacterium (Sano & Anraku, 2018) with high chitinase activity (Gürkök & Görmez, 2016). Bacteria in the genus *Brevibacillus* are one of the most common gram-positive bacterial species recorded from various environmental habitats (Allan et al., 2005) and have been found to produce many bioactive metabolites (Bartel et al., 2019). Strains belonging to the genus *Brevibacillus*, which attract attention with their high growth rate, better transformation efficiency through electroporation, ability to synthesize indole-3-acetic acid and extracellular protease production, act as biocontrol agents with their ability to suppress different phytopathogenic species and are used as a source of various enzymes in biocontrol studies (Edwards & Seddon, 2001; Gupta et al., 2000). *Brevibacillus* species also play an important role in bioremediation to combat pollution caused by toxic metals and to reduce environmental pollution in agricultural soils, water and atmosphere. In different studies, *Brevibacillus* applications as PGPR were found to have a remarkable effect on root biomass (Burd et al., 2000; Grichko et al., 2000). Karlidag et al. (2009) found that bacterial applications together with fertilizer were the most effective application in increasing the growth and yield of strawberry plants. The yield and plant growth enhancing effects of bacteria on strawberry were explained by the nitrogen fixing and phosphorus solubilizing capacity of bacteria. Nehra et al. (2016) found that another *Brevibacillus* species, *B. brevis*

SVC(II)14, accelerated the growth and development of cotton plants and increased root development. The mobility of Strainin and its ability to survive at high temperatures (52 °C) showed that it is a suitable inoculant to improve cotton growth. Shi et al. (2022) found that *B. velezensis* YH20 significantly increased plant height and dry weight of *Carya illinoinensis* (Pecan) compared to the control group and had the most significant effect on growth promotion. *B. reuszeri* MPT17 strains were found to have the most significant effect in promoting plant root growth. Furthermore, compared to the control, the levels of available phosphorus and potassium in rhizosphere soils and the total potassium content in plant roots were improved as a result of *B. reuszeri* MPT17 treatment. *B. reuszeri* strain MPT17 was also found to promote the growth of *Pinus massoniana* in another study (Li et al., 2015).

It has been stated that nitrogen, phosphorus and potassium are the main essential nutrients of plants and their amounts in soil directly affect plant growth and development (Emmanuel & Babalola, 2020; Saxena et al., 2020). A significant positive correlation was found between soil nutrient content and biomass with PGPR applications (Song et al., 2021). Shi et al. (2022) found that there is a correlation between soil nutrient content and seedling biomass, phosphorus content in soil affects plant biomass accumulation, and the significant increase in biomass after inoculation with PGPR may be related to changes in soil nutrient levels. Many studies have shown that PGPRs, especially *Bacillus* species, become the dominant member of the microbial community in the inoculated medium, secrete bacteriostatic substances, aid plant nutrient uptake and promote plant growth by regulating endogenous hormones (Poveda & Gonzalez-Andres, 2021). The effects of PGPR applications on plants are the result of synergistic/antagonistic interactions between inoculated strains, i.e., induction or suppression of native microbiota and indigenous microbial populations (Trabelsi & Mhamdi, 2013).

4. Conclusion

As a result of both agricultural practices involving the intensive use of chemical fertilisers and the growing population and industrialisation, the world's atmospheric, terrestrial and aquatic systems are no longer sufficient to absorb and break down the increasing amount of waste produced. As a result, the environment is becoming increasingly contaminated with various toxic metals and compounds. Remediation of contaminated soils and waters is therefore essential. One way to address this problem is the use of plant growth-promoting bacteria as part of agricultural practices in protocols to improve plant and soil health. In both managed and natural ecosystems, the beneficial bacteria-plant relationship plays a key role in supporting plant health and growth and increasing yields. Plant growth-promoting bacteria are bacteria that can enhance plant growth and protect plants from diseases and abiotic stresses through a wide variety of mechanisms. Some important properties such as biological nitrogen fixation, phosphate and potassium solubilisation, ACC deaminase activity can be considered as the characteristics of plant growth promoting bacteria. The bacterial strains in this study were previously determined to fix nitrogen, solubilise phosphorus and possess ACC deaminase enzyme. The use of these bacterial strains in maintaining soil fertility and promoting plant growth is promising for the conservation of agricultural resources.

Bacterial strains isolated from plants resistant to extreme conditions in Iğdır province were used for the first time in this study in eggplant cultivation, which is important for the province. It was determined that single or mixed bacterial applications increased the yield and quality parameters of eggplant compared to fertiliser application. However, it was observed that *K. cyrocrescens* strain IT 160 was the most effective stimulant bacterium in increasing eggplant yield and increased the yield by 41%. The application of *K. cyrocrescens* strain IT 160 as a bioinoculant in eggplant cultivation will reduce the use of chemical fertilisers, reduce production costs and environmental pollution and contribute to the increase of agronomic efficiency.

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

Allan, R. N., Lebbe, L., Heyrman, J., De Vos, P., Buchanan, C. J., & Logan, N. A. (2005). *Brevibacillus levickii* sp. nov. and *Aneurinibacillus terranovensis* sp. nov., two novel thermoacidophiles isolated from geothermal soils of northern Victoria Land, Antarctica. *International Journal of Systematic and Evolutionary Microbiology*, *55*(3), 1039-1050. https://doi.org/10.1099/ijs.0.63397-0

Bartel, L. C., Abrahamovich, E., Mori, C., López, A. C., & Alippi, A. M. (2019). *Bacillus* and *Brevibacillus* strains as potential antagonists of *Paenibacillus larvae* and *Ascosphaera apis*. *Journal of Apicultural Research*, *58*(1), 117-132. https://doi.org/10.1080/00218839.2018.1495439

Başer, M. (2015). *Farklı lokasyonlarda dikim sıklığı ve budama uygulamalarının patlıcanda verim, kalite ve bitki gelişimine etkisi* (Master's thesis, Tokat Gaziosmanpaşa University). (In Turkish)

Bintas, P. A., Çığ, A., & Türkoğlu, N. (2020). Investigation of the effects of some bacterial isolates and fertilizer applications on nutrient contents of hyacinth. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *48*(2), 978-988. https://doi.org/10.15835/nbha48211911

Bintaş, P. A., Çığ, A., & Türkoğlu, N. (2021). Some phenological and morphological properties of *Hyacinthus orıentalis* cv. "delft blue" with treated bacterial inoculations. *Polish Journal of Environmental Studies*, *30*(2), 1549-1556. https://doi.org/10.15244/pjoes/126484

Bisht, H., & Kumar, N. (2023). Characterization and evaluation of the nickel-removal capacity of *Kluyvera cryocrescens* M7 isolated from industrial wastes. *Pollution*, *9*(3), 1059-1073. https://doi.org/10.22059/poll.2023.347580.1586

Burd, I. G., Dixon, D. G., & Glick, B. R. (2000). Plant growth promoting bacteria that decrease heavy metal toxicity in plants. *Canadian Journal of Microbiology*, *46*(3), 237-245. https://doi.org/10.1139/w99-143

Castro, C. M. D., Almeida, D. L. D., Ribeiro, R. D. L. D., & Carvalho, J. F. D. (2005). Plantio direto, adubação verde e suplementação com esterco de aves na produção orgânica de berinjela. *Pesquisa Agropecuária Brasileira*, *40*, 495-502. https://doi.org/10.1590/S0100-204X2005000500011 (In Portuguese)

Compant, S., Clément, C., & Sessitsch, A. (2010). Plant growth-promoting bacteria in the rhizo-and endosphere of plants: Their role, colonization, mechanisms involved and prospects for utilization. *Soil Biology and Biochemistry*, *42*(5), 669-678. https://doi.org/10.1016/j.soilbio.2009.11.024

Consentino, B. B., Aprile, S., Rouphael, Y., Ntatsi, G., De Pasquale, C., Iapichino, G., Alibrandi, P., & Sabatino, L. (2022). Application of PGPB combined with variable n doses affects growth, yield-related traits, n-fertilizer efficiency and nutritional status of lettuce grown under controlled condition. *Agronomy*, *12*(2), 236. https://doi.org/10.3390/agronomy12020236

Demir, Z. (2020). Effects of microbial bio-fertilizers on soil physicochemical properties under different soil water regimes in greenhouse grown eggplant (*Solanum melongena* L.). *Communications in Soil Science and Plant Analysis*, *51*(14), 1888-1903. https://doi.org/10.1080/00103624.2020.1798983

Edwards, S. G., & Seddon, B. (2001). Mode of antagonism of *Brevibacillus brevis* against *Botrytis cinerea in vitro*. *Journal of Applied Microbiology*, *91*(4), 652-659. https://doi.org/10.1046/j.1365-2672.2001.01430.x

Emmanuel, O. C., & Babalola, O. O. (2020). Productivity and quality of horticultural crops through co-inoculation of arbuscular mycorrhizal fungi and plant growth promoting bacteria. *Microbiological Research*, *239*, 126569. https://doi.org/10.1016/j.micres.2020.126569

Fategbe, M. A., Ibukun, E. O., Kade, I. J., & Rocha, J. B. T. (2013). A comparative study on ripe and unripe eggplant (*Solanum melongena* L.) as dietary antioxidant sources. *Journal of Medicinal Plants Research*, *7*(6), 209-218.

Fathalla, A., & Sabry, S. (2020). Effect of 1-aminocyclopropane-1-carboxylic acid deaminase producing fluorescent *Pseudomonas* on the growth of eggplant under drought stress. *Plant Archives*, *20*(1), 3389-3394.

Fu, Q., Liu, C., Ding, N., Lin, Y., & Guo, B. (2010). Ameliorative effects of inoculation with the plant growth-promoting rhizobacterium *Pseudomonas* sp. DW1 on growth of eggplant (*Solanum melongena* L.) seedlings under salt stress. *Agricultural Water Management*, *97*(12), 1994-2000. https://doi.org/10.1016/j.agwat.2010.02.003

Grichko, V. P., Filby, B., & Glick, B. R. (2000). Increased ability of transgenic plants expressing the bacterial enzyme ACC deaminase to accumulate Cd, Co, Cu, Ni, Pb, and Zn. *Journal of Biotechnology*, *81*(1), 45-53. https://doi.org/10.1016/S0168-1656(00)00270-4

Guedes, V. H. F., Oliveira, D. M. A. O., Santos, R. L., Oliveira, G. A. A. O., & Oliveira, F. L. N. O. (2018). The effects of a biofertilizer containing growth promoting bacteria on the eggplant (*Solanum melongena* L.). *Journal of Experimental Agriculture International*, *26*(6), 1-8. https://doi.org/10.9734/JEAI/2018/44045

Gupta, A., Kaushik, C. P., & Kaushik, A. (2000). Degradation of hexachlorocyclohexane (HCH; α, β, γ and δ) by *Bacillus circulans* and *Bacillus brevis* isolated from soil contaminated with HCH. *Soil Biology and Biochemistry*, *32*(11-12), 1803-1805. https://doi.org/10.1016/S0038-0717(00)00072-9

Gürkök, S., & Görmez, A. (2016). *Isolation and characterization of novel chitinolytic bacteria*. International Conference on Advances in Natural and Applied Sciences: Icanas 2016. Antalya.

Innerebner, G., Knief, C., & Vorholt, J. A. (2011). Protection of *Arabidopsis thaliana* against leaf-pathogenic *Pseudomonas syringae* by *Sphingomonas* strains in a controlled model system. *Applied and Environmental Microbiology*, *77*(10), 3202-3210. https://doi.org/10.1128/AEM.00133-11

Kanber, R. (1997). *Sulama*. Çukurova Üniversitesi Ziraat Fakültesi Yayını. (In Turkish)

Karlidag, H., Yildirim, E., Turan, M., & Donmez, M. F. (2009). *Effect of plant growth-promoting bacteria on mineral-organic fertilizer use efficiency, plant growth and mineral contents of strawberry (Fragaria x ananassa L. Duch.)*. 14th International Conference on Organic Fruit-Growing. Hoffenheim.

Kassi, A. K., Javed, H., & Mukhtar, T. (2019). Screening of different aubergine cultivars against infestation of brinjal fruit and shoot borer (*Leucinodes orbonalis* Guenee). *Pakistan Journal of Zoology*, *51*(2), 603-609. https://doi.org/10.17582/journal.pjz/2019.51.2.603.609

Kocayiğit, F. (2010). *Bazı sebzelerin kurutma karakteristiklerinin incelenmesi* (Master's thesis, Yıldız Technical University). (In Turkish)

Külahlıoğlu, İ. (2016). *Patlıcanda türler arası melezleme (Solanum melongena L. X Solanum torvum Sw.) engelinin aşılması üzerine araştırmalar* (Master's thesis, Mustafa Kemal University). (In Turkish)

Li, Q., Wu, X. Q., & Ye, J. R. (2015). Isolation and identification of a mycorrhiza helper bacteria (MHB) *Brevibacillus reuszeri* on *Pinus massoniana* roots. *Scientia Silvae Sinicae*, *51*, 159-164.

López, S. M. Y., Pastorino, G. N., Malbran, I., & Balatti, P. A. (2019). Enterobacteria isolated from an agricultural soil of Argentina promote plant growth and biocontrol activity of plant pathogens. *Revista de la Facultad de Agronomía,* *118*(2), 022. https://doi.org/10.24215/16699513e022

Lucy, M., Reed, E., & Glick, B. R. (2004). Applications of free living plant growth-promoting rhizobacteria. *Antonie van Leeuwenhoek*, *86*, 1-25. https://doi.org/10.1023/B:ANTO.0000024903.10757.6e

Nehra, V., Saharan, B. S., & Choudhary, M. (2016). Evaluation of *Brevibacillus brevis* as a potential plant growth promoting rhizobacteria for cotton (*Gossypium hirsutum*) crop. *Springerplus*, *5*, 1-10. https://doi.org/10.1186/s40064-016-2584-8

Özgen, T. (2019). *Patlıcan (Solanum melongena L.) genotiplerinin Fusarium oxysporum f. sp. melongenae'ya dayanıklılık düzeylerinin ve kök yapılarının incelenmesi* (Master's thesis, Ondokuz Mayıs University). (In Turkish)

Parlakova Karagöz, F., Dursun, A., & Kotan, R. (2019). Effects of rhizobacteria on plant development, quality of flowering and bulb mineral contents in *Hyacinthus orientalis* L. *Alinteri Journal of Agriculture Science*, *34*(1), 88-95. https://doi.org/10.28955/alinterizbd.585219

Parlakova Karagöz, F. (2020). Evaluation of the bacteria formulation different inoculum densities on growth and development of *Euphorbia pulcherrima*. *Folia Horticulturae*, *32*(2), 179-188. https://doi.org/10.2478/fhort-2020-0017

Poveda, J., & Gonzalez-Andres, F. (2021). *Bacillus* as a source of phytohormones for use in agriculture. *Applied Microbiology and Biotechnology*, *105*, 8629-8645. https://doi.org/10.1007/s00253-021-11492-8

Sano, K. I., & Anraku, A. (2018). Draft genome sequence of *Brevibacillus reuszeri* strain NIT02, isolated from a laundered rental cloth hot towel. *Genome Announcements*, *6*(2), e01353-17. https://doi.org/10.1128/genomea.01353-17

Saputri, I. A., Hera, H. & Irfan, M. (2023). The effect of nutritan liquid fertilizer with different concentrations on growth and production of shallots (*Allium ascalonicum* L.). *Seminar Nasional Integrasi Pertanian dan Peternakan*, *1*(1), 223-235.

Saxena, A. K., Kumar, M., Chakdar, H., Anuroopa, N., & Bagyaraj, D. J. (2020). *Bacillus* species in soil as a natural resource for plant health and nutrition. *Journal of Applied Microbiology*, *128*(6), 1583-1594. https://doi.org/10.1111/jam.14506

Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., & Gobi, T. A. (2013). Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus*, *2*, 1-14. https://doi.org/10.1186/2193-1801-2-587

Shi, J. W., Lu, L. X., Shi, H. M., & Ye, J. R. (2022). Effects of plant growth-promoting rhizobacteria on the growth and soil microbial community of *Carya illinoinensis*. *Current Microbiology*, *79*, 352. https://doi.org/10.1007/s00284-022-03027-9

Shipoh, P. M. (2021). *Isolation, identification and characterization of Cleome gynandra L. bacterial seed endophytes from Northern Namibia* (Master thesis, Namibia University).

Söğüt, S., & Çığ, F. (2019). Determination of the effect of plant growth promoting bacteria on wheat (*Triticum aestivum* L.) development under salinity stress conditions. *Applied Ecology & Environmental Research*, *17*(1), 1129-1141. https://doi.org/10.15666/aeer/1701_11291141

Song, Q., Song, X., Deng, X., Luo, J., Wang, J., Min, K., & Song, R. (2021). Effects of plant growth promoting Rhizobacteria microbial on the growth, rhizosphere soil properties, and bacterial community of *Pinus sylvestris* var. *mongolica* seedlings. *Scandinavian Journal of Forest Research*, *36*(4), 249-262. https://doi.org/10.1080/02827581.2021.1917649

Souza, R. D., Ambrosini, A., & Passaglia, L. M. (2015). Plant growth-promoting bacteria as inoculants in agricultural soils. *Genetics and Molecular Biology*, *38*(4), 401-419. https://doi.org/10.1590/s1415-475738420150053

Temel, I. (2023). *Farklı kaynaklardan izole edilen bakteri strainlerinin Acidovorax citrulli'nin biyokontrolündeki rolü ile kavun (Cucumis melo L.) bitkisinde verim ve kaliteye etkileri* (Doctoral dissertation, Iğdır University). (In Turkish)

Trabelsi, D., & Mhamdi, R. (2013). Microbial inoculants and their impact on soil microbial communities: A review. *BioMed Research International*, *2013*(1), 863240. https://doi.org/10.1155/2013/863240

TÜİK. (2019). *Bitkisel üretim istatistikleri*. Retrieved Jan 12, 2019, from https://tuikweb.tuik.gov.tr/UstMenu (In Turkish)

Vazquez, P., Holguin, G., Puente, M. E., Lopez-Cortes, A., & Bashan, Y. (2000). Phosphate-solubilizing microorganisms associated with the rhizosphere of mangroves in a semiarid coastal lagoon. *Biology and Fertility of Soils*, *30*, 460-468. https://doi.org/10.1007/s003740050024

Vinent, S., Diaz, M., Delgedo, E., Barbosa, H., & Raton, T. (2014). Efectos de *Brevibacillus bortelensis* B65 sobre la germinacion y el desarrollo de posturas de hortalizas en fase semillero. *Cultivos Tropicales*, *35*(3), 17-23. (In Spanish)

Whipps, J. M. (2001). Microbial interactions and biocontrol in the rhizosphere. *Journal of Experimental Botany*, *52*(1), 487-511. https://doi.org/10.1093/jexbot/52.suppl_1.487

Yücel, Y. C. (2020). *Farklı patlıcan (Solanum melongena L.) genotiplerin azot etkinlik bakımından agronomik, fizyolojik ve morfolojik karakterizasyonu ve anaçlık potansiyellerinin belirlenmesi* (Master's thesis, Erciyes University). (In Turkish)