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Effects of PGPR on Yield and Quality in Different Melon (*Cucumis melo* L.) Cultivars

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ABSTRACT

This study aimed to assess the impact of PGPR (Plant Growth-Promoting Rhizobacteria) on the yield and quality of various melon (*Cucumis melo* L.) cultivars under Van ecological conditions during the 2016/2017 season. The experiment utilized PGPR applications including FZB42 (*Bacillus amyloliquefaciens*), CC378/2 (*Pantoea agglomerans*), and CC44 (*Pseudomonas fluorescens*), with six melon cultivars: Kırkağaç 637, BT Akhisar, Napolyon F1, Lokma F1, Lokum F1, and Ananas. The study was conducted using a randomized block design with three replications. Results indicated that PGPR applications enhanced several growth and yield parameters: stem thickness increased by up to 9.2%, leaf length by up to 12.9%, petiole length by up to 8.3%, fresh leaf weight by up to 12.8%, dry leaf weight by up to 12.9%, average fruit yield per plant by up to 39.1%, average fruit weight by up to 21.9%, fruit flesh thickness by up to 17.6%, fruit width by up to 7.4%, fruit length by up to 9.2%, average number of branches by up to 21.1%, and total branch length by up to 13.2%.

Farklı Kavun (*Cucumis melo* L.) Çeşitlerinde PGPR Kullanımının Verim ve Kalite Üzerine Etkileri

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ÖZET

Bu araştırma, 2016/2017 sezonunda Van ekolojik şartlarında farklı kavun (*Cucumis melo* L.) çeşitlerinde PGPR (Bitki Gelişimini Destekleyen Rizobakteri) kullanımının verim ve kalite üzerindeki etkilerini belirlemek amacıyla yapılmıştır. Denemede, FZB42 (*Bacillus amyloliquefaciens*), CC378/2 (*Pantoea agglomerans*) ve CC44 (*Pseudomonas fluorescens*) izolatlarından oluşan PGPR uygulamaları kullanılmıştır. Denemede Kırkağaç 637, BT Akhisar, Napolyon F1, Lokma F1, Lokum F1 ve Ananas kavun çeşitleri kullanılmıştır. Araştırma, tesadüf blokları deneme desenine göre ve üç tekrar ile yürütülmüştür. Sonuçlar, PGPR uygulamalarının kavun bitkisinde; ana gövde kalınlığını %9.2, yaprak uzunluğunu %12.9, yaprak sapı uzunluğunu %8.3, yaş yaprak ağırlığını %12.8, kuru yaprak ağırlığını %12.9, bitki başına ortalama meyve verimini %39.1, ortalama meyve ağırlığını %21.9, meyve eti kalınlığını %17.6, meyve genişliğini %7.4, meyve boyunu %9.2, ortalama dal sayısını %21.1 ve toplam dal uzunluğunu %13.2 oranlarında artırdığını göstermiştir.

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INTRODUCTION

Melons (*Cucumis melo* L.) are a significant crop globally, valued for their sweet flavor, nutritional benefits, and economic importance. Melon is one of the most important vegetables species produced and consumed in almost every corner of Türkiye; as well as around the World (Erdinc *et al*., 2013, 2021). In the diverse ecological conditions of Van, the cultivation of melons presents unique challenges and opportunities. To enhance melon production, researchers and farmers are increasingly exploring sustainable agricultural practices, including the use of Plant Growth-Promoting Rhizobacteria (PGPR). PGPR are beneficial microorganisms that can improve plant growth, yield, and resilience by enhancing nutrient uptake, stimulating plant growth hormones, and suppressing plant pathogens.

In recent years, sustainable agricultural practices have become essential due to increasing environmental challenges, such as soil degradation, water scarcity, and climate change impacts on crop yields. PGPR has emerged as a promising solution to support plant resilience under such stresses, making it particularly valuable in areas with variable ecological conditions. PGPR not only enhances crop growth under optimal conditions but also improves plant tolerance to biotic or abiotic stresses by boosting antioxidant activities and aiding in osmotic balance (Bilge *et al*., 2019; Tunçtürk *et al*., 2019; Sadak *et al*., 2021). Given the susceptibility of melon crops to such stresses, particularly in regions like Van with diverse climates, understanding the role of PGPR can provide crucial insights for developing resilient and sustainable production systems. By integrating these beneficial bacteria into melon cultivation, growers may achieve consistent crop quality and yield even under suboptimal conditions

Previous research has highlighted the effectiveness of PGPR in various horticultural crops. PGPRs directly affect plant growth by producing growth hormones and altering the microbial balance in the rhizosphere. They also protect the plant against diseases by suppressing soil-borne pathogens (Siddiqui, 2006; Bilge *et al*., 2019; Tunçtürk *et al*., 2019). For example, Demir *et al*. (2023) demonstrated that biofertilizers, including PGPR like *Bacillus megaterium* and *Pseudomonas fluorescens*, significantly improved plant growth, yield, and nutrient concentration in lettuce and broccoli under greenhouse conditions. Similarly, studies by Zapata-Sifuentes *et al*. (2022) showed that PGPR can enhance growth parameters and fruit quality of cucumber under greenhouse conditions. These findings highlight the potential of PGPR to positively influence plant development and productivity.

Despite these promising results, research specifically targeting the effects of PGPR on melon cultivars, especially in the distinct ecological conditions of Van, is limited. This study aims to address this gap by evaluating the impact of four different PGPR isolates—Control, *Bacillus amyloliquefaciens* (FZB42), *Pantoea agglomerans* (CC378/2), and *Pseudomonas fluorescens* (CC44)—on six melon cultivars (Kırkağaç 637, BT Akhisar, Napoleon F1, Lokma F1, Lokum F1, and Ananas). By examining growth parameters such as stem thickness, leaf dimensions, fruit characteristics, and branch development, this research seeks to provide valuable insights into the benefits of PGPR application for optimizing melon production in Van's ecological conditions. The results are anticipated to contribute to more effective and sustainable melon cultivation practices, enhancing both yield and fruit quality in the region.

MATERIALS AND METHODS

Plant Materials

The study used the following melon cultivars:

Kırkağaç 637: Early maturing, strong plants with round-oval fruits (2.5-3 kg). Dark yellow skin with green spots, thick white flesh, and high sweetness. Long shelf life.

BT Akhisar Topan: Developed from Akhisar-Kırkağaç melons, round fruits (2-3 kg) with yellow skin and green spots. Sweet, small seed cavity, high yield, matures in 90-100 days.

*Napolyon F1***:** High yielding with good disease resistance. Homogenous fruits with high sugar content, suitable for open fields.

Lokma F1: Early maturing, high-yielding, and suitable for stringing. Round Galia-type fruits (2-2.5 kg) with good shelf life.

Lokum F1: Strong plant with pineapple-type fruits (2-3 kg). Excellent aroma and taste, suitable for greenhouses, tunnels, and open fields.

Ananas F1: Hybrid with high aroma and sugar content. Oval fruits weigh 2-2.5 kg.

Identification of appropriate bacterial isolates

The PGPR isolates [FZB42 (*Bacillus amyloliquefaciens*), CC378/2 (*Pantoea agglomerans*), and CC44 (*Pseudomonas fluorescens*),] used in the experiment were available in the stocks of Van Yuzuncu Yil University, Faculty of Agriculture, Department of Plant Protection and whose efficacy was determined in previous studies were used.

Growing medium characteristics

In the experiment, peat-perlite mixture was used at a ratio of 3:1 and 72-vials were used as seedling growing medium. [Peat content: EC: 35 mS/m, pH: 5.5-6.5, Fertilizer content: 1.0 kg/m^3; Perlite content: SiO_2 (72.0 - 76.0 %), Al_2O_3 (11.0 - 17.0 %), K_2O (4.0 - 5.0 %), Na_2O (2.9 - 4.0 %), CaO (0.5 - 2.0 %), MgO (0. 1 - 0.5 %), Fe_2O_3 (0.5 - 1.5 %), TiO_2 (0.03 - 0.2 %), MnO_2 (0.03 - 0.1 %), SO_3 (0 - 0.2 %), H_2O (2 - 7 %).]

Location of the Research Site

The research was conducted in the experimental field of Van Yuzuncu Yil University Research and Application Farm in 2016. The field trial was conducted between April 14 and August 12, and the greenhouse trial was conducted between October 2 and December 15. Van province is located in a basin surrounded by mountains to the west of Lake Van in the Eastern Anatolia Region, 1720 m above sea level and 38-25' north latitude and 43-21' east longitude. The trial area is located northeast of Lake Van, approximately 2 km from the lakeshore.

Climate Characteristics of the Research Site

Van has a continental climate with cold and snow-covered winters and cool and dry summers. Being located on the shores of Lake Van makes the climate of the province relatively mild. Monthly climate data for the periods of the study are presented in Table 1.

Table 1

Some Climate Data for Van Province and the 2016/2017 Season (Anonymous, 2018)

Month	Precipitation (mm)	Temperature (°C)	Relative Humidity (%)
	2016-2017	Long Term Means	2016-2017
September	26.5	13.6	17.5
October	88.8	46.8	11.7
November	27.3	47.0	4.2
December	77.0	36.0	-1.85
January	18.5	34.6	-3.2
February	15.3	33.6	-3.5
March	34.7	46.7	3.2
April	60.5	55.9	8.5
May	90.6	45.8	13.9
June	-	18.1	19.5
July	3.3	5.4	23.9
August	3.1	3.7	24.3
Total	442.3	387.2	-
Average	-	-	9.9

Soil characteristics of the research site

Some physical and chemical analyses of the soil samples taken from 0-30 cm from the experimental area where the research was conducted were carried out in Van Commodity Exchange Laboratory and the results of the analysis are shown in Table 2.

Table 2

Field and Greenhouse Parcels' Soil Analysis Results

Field soil Analyses	Results	Status
Potassium (K_2O)	131.7918	High
Phosphorus (P_2O_5)	6.6983	Medium
Lime (%)	7.3429	Moderately calcareous
Organic Matter (%)	0.5039	Very low
Total Salt (%)	0.0060	Salt-free
pH	7.16	Slightly alkaline
Saturation (%)	27	Sandy

METHODS

Plant cultivation

For the field trial, six melon varieties, three different PGPR isolates, and a control were sown in 72-well trays on April 25, 2016. Twelve seedlings per plot were planted at 120 cm by 60 cm spacing, resulting in 24 treatments with three replications on May 28, 2016. As base fertilizer only, 25 kg da^{-1} Diammonium phosphate was applied.

PGPR Applications

Each root bacterial isolate was grown in KB medium for 48 hours at 24°C. Bacterial cultures were suspended with 1.5% CMC. PGPR treatments were performed one week apart, starting at seedling emergence. At seedling emergence, a concentration of 10^9 cfu/ml was applied to the roots by inoculation.

Determination of Plant Growth and Fruit Parameters

Plant growth and fruit parameters were evaluated in mid-August on the middle six plants from each plot. Leaf length was measured on the leaf blade at the 4th node using a ruler. Fresh leaf weight was recorded with a precision balance (±0.1g), while leaf dry weight was obtained after drying the leaves to constant weight and measured using a precision balance (±0.01g). Leaf petiole length was assessed with a ruler, and petiole width was determined with a digital caliper. The average number of branches was determined by counting, and the total branch length was measured with a ruler. Main stem thickness at the 4th node was recorded using a digital caliper. Average fruit weight was measured with a precision balance (±1g), and the average number of fruits was determined by counting. Fruit stalk length, fruit diameter, and length were measured with a digital caliper and a ruler, respectively. Fruit flesh and rind thickness were also measured using a digital caliper. Soluble solid content (°Brix) in the fruit juice were measured using a hand refractometer, and the fruit juice pH was determined with a pH meter.

Statistical analysis

The data obtained from Randomized Blocks experimental design were analyzed using analysis of variance (one-way ANOVA) within the SPSS software package (IBM SPSS Statistics 21.0) according to the randomized block experimental design. The means were separated by "Duncan Multiple Comparison Test".

RESULTS AND DISCUSSION

Effects of PGPR Applications on Leaf Petiole Length of Different Melon Cultivars

Significant differences ($P \leq 0.001$) were found between PGPR applications and melon varieties for average leaf petiole length, as shown in Table 3. All PGPR isolates significantly affected the average leaf petiole length compared to the control. The control group's average leaf petiole length was 78.34 cm, whereas the highest average length (88.47 cm) was observed with the FZB42 PGPR isolate. The FZB42 was followed by CC44 with an average length of 86.57 cm and CC37/2 with 84.75 cm.

Statistical differences ($P \leq 0.001$) were also found among the melon varieties. The lowest average leaf petiole length (82.14 cm) was recorded in the Lokum F1 variety, while the highest (86.83 cm) was observed in the Ananas variety. Other varieties such as BT Akhisar, Kırkağaç 637, Napolyon F1, and Lokma F1 followed in decreasing order.

The interaction between melon varieties and PGPR was also significant ($P \leq 0.01$). The highest values (91.29 cm and 91.11 cm) were observed in the Ananas variety with CC44 and FZB42 applications, respectively. The lowest value (77.22 cm) was found in the Kırkağaç 637 variety under control conditions.

The study demonstrated that PGPR applications increased leaf petiole length between 8.1% to 12.9% compared to control treatments. The studies frequently report the use of PGPR strains as microbial fertilizers and biological control agents. For instance, Ji *et al*. (2006) found that some PGPR strains improved disease resistance in tomato plants against P. s. pv. *tomat*o and X. a. pv. *vesicatoria*, suggesting that combining rhizosphere and leaf applications of PGPR strains yielded better results in field conditions.

Table 3

Effects of PGPR Applications on Leaf Length of Different Melon Cultivars (cm)

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	77.22 k**	78.52 ı-k	79.29 ı-k	78.11 jk	78.49 ı-k	78.45 ı-k	78.34 D***
CC37/2	87.67 a-e	84.85 d-h	83.90 e-h	83.42 f-h	82.23 g-ı	86.49 b-f	84.75 C
CC44	88.85 a-d	89.48 a-c	83.17 f-h	84.85 e-h	81.73 h-j	91.29 a	86.57 B
FZB42	87.75 a-e	89.24 a-c	90.28 ab	86.30 b-f	86.10 c-g	91.11 a	88.47 A
MEAN	85.37AB***	85.52 AB	84.16 BC	83.17 CD	82.14 D	86.83 A	

***: Significant at P≤0.001 level; **: Significant at P≤0.01 level;

Effects of PGPR Applications on Leaf Fresh Weight of Different Melon Cultivars

The effects of PGPR applications on average leaf fresh weight are shown in Table 4. Significant differences (P≤0.001) were observed among the PGPR applications. All PGPR isolates significantly affected the average leaf fresh weight compared to the control. The average leaf fresh weight in the control group was 9.53 g, while the highest average (10.75 g) was observed with the CC44 PGPR isolate. This was followed by FZB42 with 10.72 g and CC37/2 with 10.29 g.

No significant differences were found among melon varieties regarding leaf fresh weight. However, the lowest average leaf fresh weight (9.98 g) was found in the Kırkağaç 637 variety, while the highest (10.61 g) was observed in the Napolyon F1 variety. No significant differences were observed in the interaction between melon varieties and PGPR applications.

Overall, PGPR applications increased leaf fresh weight by 7.9% to 12.8% compared to the control treatments. In line with these findings, the study by Kokalis-Burelle *et al*. (2003) reported that PGPR applications increased leaf fresh weight and improved plant growth and quality in melon and watermelon plants.

Table 4

Effects of PGPR Applications on Leaf Fresh Weight of Different Melon Cultivars (g)

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	9.01 ns	9.42	10.34	9.47	9.38	9.58	9.53 C***
CC37/2	9.60	10.35	10.60	10.63	9.93	10.57	10.29 B
CC44	10.62	10.65	10.60	11.05	10.90	10.70	10.75 A
FZB42	10.68	10.48	10.91	10.42	10.94	10.92	10.72 A
MEAN	9.98 ns	10.22	10.61	10.40	10.29	10.44	

***: Significant at P≤0.001 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Leaf Dry Weight of Different Melon Cultivars

The effects of PGPR applications on average leaf dry weight in different melon cultivars are presented in Table 5. Significant differences (P≤0.05) were found among PGPR applications. All PGPR isolates significantly increased the average leaf dry weight compared to the control, which had an average of 3.08 g. The highest leaf dry weight (3.48 g) was observed with the CC37/2 isolate, followed by CC44 (3.35 g) and FZB42 (3.30 g). No significant differences were found among melon varieties. The lowest average leaf dry weight (3.14 g) was observed in the Napolyon F1 variety, while the highest (3.41 g) was in the Lokum F1 variety. PGPR applications increased leaf dry weight by 7.1% to 12.9%. Previous studies have shown that PGPR applications can enhance plant growth and quality, including

increasing fresh and dry weights in melon and watermelon seedlings (Kokalis-Burelle *et al*., 2003).

Table 5

Effects of PGPR Applications on Leaf Dry Weight of Different Melon Cultivars (g)

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	2.89 ns	3.10	2.95	3.31	3.19	3.04	3.08 B*
CC37/2	3.73	3.52	3.08	3.38	3.84	3.37	3.48 A
CC44	3.19	3.64	3.35	3.20	3.29	3.43	3.35 A
FZB42	3.41	3.27	3.19	3.30	3.35	3.32	3.30 AB
MEAN	3.30 ns	3.38	3.14	3.29	3.41	3.29	

*: Significant at P≤0.05 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Leaf Petiole Length of Different Melon Cultivars

The impact of PGPR applications on average leaf petiole length is presented in Table 6. No significant differences were found among the melon cultivars regarding leaf petiole length. The lowest mean petiole length was observed in the Ananas cultivar (102.33 mm), while the highest was found in the Napolyon F1 cultivar (105.25 mm). PGPR applications increased (P≤0.001) petiole lengths by 7.6% to 8.3%, suggesting the benefits of PGPR in enhancing growth parameters in vegetables. Previous studies have reported similar positive effects of PGPR on plant height, stem diameter, root length, and seedling growth in Cucurbits and Solanaceous crops (Kokalis-Burelle *et al*., 2002; Garcia *et al*., 2003).

Table 6

Effects of PGPR Applications on Leaf Petiole Length of Different Melon Cultivars (cm)

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	95.33 ns	98.33	99.00	99.00	97.33	96.33	97.55 B***
CC37/2	105.66	105.00	112.00	102.33	105.33	100.00	105.05 A
CC44	104.33	104.00	106.00	108.00	105.66	106.00	105.66 A
FZB42	105.33	101.33	104.00	109.00	106.00	107.00	105.44 A
MEAN	102.66 ns	102.16	105.25	104.58	103.58	102.33	

***: Significant at P≤0.001 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Leaf Petiole Thickness of Different Melon Cultivars

The effects of PGPR applications on leaf petiole thickness in different melon cultivars as presented in Table 7. No significant differences were found among PGPR treatments; however, all PGPR isolates notably affected petiole thickness compared to the control. The control had an average thickness of 3.33 mm, while the highest thickness was observed with the CC37/2 and FZB42 isolates (3.66 mm), followed by the CC44 isolate (3.44 mm). Among cultivars, no s significant differences were detected. The Kırkağaç 637 cultivar had the lowest average petiole thickness (3.41 mm), while BT Akhisar, Lokma F1, and Ananas had the highest thickness (3.58 mm). The cultivar x PGPR interaction was also insignificant.

Table 7

Effects of PGPR Applications on Leaf Petiole Thickness of Different Melon Cultivars (mm)

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	3.00 ns	3.66	3.33	3.33	3.00	3.66	3.33 ns
CC37/2	3.66	3.66	3.66	3.66	4.00	3.33	3.66
CC44	3.66	3.33	3.33	3.66	3.00	3.66	3.44
FZB42	3.33	3.66	3.66	3.66	4.00	3.66	3.66
MEAN	3.41 ns	3.58	3.50	3.58	3.50	3.58	

ns: not significant, there is no statistical difference between means

Effects of PGPR Applications on Average Number of Branches of Different Melon Cultivars

The effects of PGPR applications on the average branch number of different melon cultivars are shown in Table 8. Significant differences (P≤0.001) were found among PGPR treatments, with all isolates significantly increasing branch numbers compared to the control. The control had an average of 4.17 branches, while the highest number (5.05) was observed with the FZB42 isolate, followed by CC44 (4.83) and CC37/2 (4.17). No significant differences were found among cultivars. The BT Akhisar cultivar had the lowest average branch number (4.50), while Lokum F1 had the highest (4.83). The cultivar x PGPR interaction was not statistically significant.

Table 8

Effects of PGPR Applications on Average Number of Branches of Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	4.00 ns	3.67	5.00	3.67	4.67	4.00	4.17 B***
CC37/2	4.67	4.67	5.33	4.33	4.67	5.00	4.78 A
CC44	5.33	4.67	4.67	5.00	4.67	4.67	4.83 A
FZB42	4.67	5.00	5.33	5.33	5.33	4.67	5.05 A
MEAN	4.67 ns	4.50	4.59	4.59	4.83	4.59	

***: Significant at P≤0.001 level; ns: not significant, there is no statistical difference

PGPR applications increased branch numbers by 14.6% to 21.1%. Similar studies, such as Köse (2003), found that bacterial applications significantly increased runner numbers in Selva strawberry cultivars. Another study by Gholami *et al*. (2012) reported that PGPR such as Azospirillum and Azotobacter significantly enhance plant growth parameters, with observed increases in dry weights of leaf, stem, and grain, as well as total biomass, demonstrating the potential of PGPR in improving plant health and productivity under field conditions. The supportive effects of bacterial inoculation on plant growth and development were notable.

Effects of PGPR Applications on Total Branch Length of Different Melon Cultivars

The effects of PGPR applications on the average total branch length of different melon cultivars are shown in Table 9. Significant differences (P≤0.001) were found among PGPR treatments, with all isolates significantly increasing total branch length compared to the control. The control had an average total branch length of 78.61 cm, while the highest was 89.00 cm with the FZB42 isolate, followed by CC44 at 87.11 cm and CC37/2 at 86.28 cm.

No significant differences were found among cultivars. The BT Akhisar cultivar had the lowest

average total branch length (82.08 cm), while Napolyon F1 had the highest (86.67 cm). This was followed by Lokma F1, Lokum F1, Ananas, and Kırkağaç in terms of lower total branch length. The cultivar x PGPR interaction was also insignificant. PGPR applications increased average total branch length by 9.7% to 13.2%. Similar studies have shown that PGPR applications improve various growth parameters and plant development. For instance, Ibiene *et al*. (2012) reported enhanced plant growth in tomato seedlings, while Garcia *et al*. (2003) found increased seedling growth in tomatoes and peppers.

Table 9

Effects of PGPR Applications on Total Branch Length (cm) of Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	74.66 ns	79.00	80.00	77.00	80.00	81.00	78.61B***
CC37/2	84.33	86.67	88.33	86.00	85.67	86.67	86.28A
CC44	83.00	87.67	90.00	90.33	86.00	85.67	87.11A
FZB42	86.33	85.33	88.33	92.00	91.33	90.67	89.00A
MEAN	82.08 ns	84.67	86.67	86.33	85.75	86.00	

***: Significant at P≤0.001 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Main Stem Thickness of Different Melon Cultivars

The effects of PGPR applications on the average main stem thickness of different melon cultivars are presented in Table 10. Statistically significant differences (P≤0.001) were found among PGPR treatments, with all isolates significantly increasing the main stem thickness compared to the control. The control had an average main stem thickness of 10.28 mm, while the highest thickness was 11.23 mm with the FZB42 isolate, followed by CC44 at 11.09 mm and CC37/2 at 11.06 mm.

Among cultivars, no significant differences were observed. However, the Kırkağaç 637 cultivar had the lowest average main stem thickness (10.80 mm), and Napolyon F1 had the highest (11.05 mm).

The cultivar x PGPR interaction was statistically significant (P≤0.001). The highest value was obtained with the Lokma F1 x FZB42 PGPR combination (11.69 mm), while the lowest values were observed with Napolyon F1 and Lokma F1 in the control group (10.14 mm and 10.17 mm, respectively).

PGPR applications increased the average main stem thickness by 7.5% to 9.2%. Similar studies have shown positive effects of PGPR on plant growth. For example, Walia *et al*. (2014) reported that *Bacillus subtilis* improved seed germination, stem length, root length, and dry weights in tomatoes. PGPRs enhance plant development by improving nutrient uptake, hormone content, chlorophyll levels, and organic acids. Literature shows that PGPRs can increase yield, root and stem thickness, delay leaf aging, and improve disease resistance (Çakmakçı *et al*., 2005; 2007).

Table 10

Effects of PGPR Applications on Main Stem Thickness (mm) of Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	10.35e-f***	10.14 f	10.17 f	10.31 e-f	10.38 ef	10.35 ef	10.28 B***
CC37/2	11.00 b-d	10.62 d-f	11.23 a-c	11.47 ab	10.95 b-d	11.10 b-d	11.06 A
CC44	11.01 b-d	11.24 a-c	11.35 a-c	10.61 b	11.31 a-c	11.04 b-d	11.09 A
FZB42	10.83 c-e	11.44 ab	11.49 ab	11.69 a	10.61 d-f	11.34 a-c	11.23 A
MEAN	10.80 ns	10.86	11.05	11.01	10.81	10.96	

***: Significant at P≤0.001 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Average Fruit Weight of Different Melon Cultivars

The effects of PGPR applications on the average fruit weight of different melon cultivars are presented in Table 11. Significant differences (P≤0.001) were observed among PGPR treatments, with all isolates significantly increasing fruit weight compared to the control. The control had an average fruit weight of 1490 g, while the highest average fruit weight was 1817 g with the FZB42 isolate, followed by CC44 at 1794 g and CC37/2 at 1781 g.

Table 11

Effects of PGPR Applications on Average Fruit Weight (g) of Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	1340.3 ns	1547.7	1521	1388	1606	1557	1490 B***
CC37/2	1794.0	1953.3	1788	1690	1759	1703	1781 A
CC44	1717.3	1996.0	1873	1601	1827	1751	1794 A
FZB42	1840.7	2193.7	1744	1679	1667	1780	1817 A
MEAN	1773 B**	1922 A	1731 AB	1589 B	1715 AB	1698 B	

***: Significant at P≤0.001 level; **: Significant at P≤0.01 level; ns: not significant, there is no statistical difference

Significant differences (P≤0.01) were also found among melon cultivars. The lowest average fruit weight was observed in the Lokma F1 cultivar (1589 g), while the highest was in the BT Akhisar cultivar (1922 g). Napolyon F1 and Lokum F1 were intermediate, and Ananas and Lokma F1 had the lowest average fruit weight. The cultivar x PGPR interaction was not statistically significant.

PGPR applications increased average fruit weight by 19.5% to 21.9%.. The positive effects of PGPR on plant growth and yield are well-documented, with studies showing benefits across various crops including wheat (de Freitas, 2000), sugar beet and barley (Şahin *et al*., 2004), wheat and spinach (Çakmakçı *et al*., 2007), broccoli (Aydın *et al*., 2012), radish (Güllüce *et al*., 2012), and lettuce (Gül *et al*., 2008).

Effects of PGPR Applications on Average Number of Fruits per Plant for Different Melon Cultivars

Table 12 presents the impact of PGPR applications on the average number of fruits per plant for various melon cultivars. Significant differences (P≤0.001) were observed among PGPR treatments. All PGPR isolates significantly increased the average number of fruits per plant compared to the control. The control treatment resulted in an average of 2.21 fruits per plant, whereas the highest average (3.32 fruits per plant) was achieved with the CC37/2 PGPR isolate. This was followed by FZB42 with an average of 3.09 fruits per plant and CC44 with 3.08 fruits per plant.

Significant differences (P≤0.01) were also found among melon cultivars. The Kırkağaç 637 cultivar had the lowest average number of fruits per plant (2.70), while the Ananas cultivar had the highest (3.11). The remaining cultivars were ranked as follows: Lokum F1, Lokma F1, Napolyon F1, and BT Akhisar. The cultivar x PGPR interaction did not show significant statistical differences.

PGPR applications increased the average number of fruits per plant by 39.3% to 50.2%. Similar results have been reported for other crops. For instance, bacterial inoculants such as Enterobacter have been shown to enhance plant growth and yield in wheat, rice, and sugarcane (Saikia *et al*., 2012; Tahir *et al*., 2013; Karpagam and Nagalakshmi, 2014). Additionally, PGPR application has been noted to support fruit growth and maturation (Ohwaki and Hirata, 1992; Marschner, 1995). While traditional fertilizers containing hormones, amino acids, and minerals can enhance plant development, they can

also lead to high chemical usage and increased costs. In contrast, PGPR applications can achieve similar effects with minimal quantities, offering a more cost-effective alternative.

Table 12

Effects of PGPR Applications on Average Number of Fruits per Plant for Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	2.13 ns	2.29	2.13	2.12	2.30	2.30	2.21 C***
CC37/2	2.96	3.39	3.24	3.30	3.37	3.65	3.32 A
CC44	2.65	2.93	3.06	3.17	3.39	3.32	3.08 B
FZB42	3.08	2.86	3.15	2.99	3.27	3.17	3.09 B
MEAN	2.70 C**	2.87 C	2.88 BC	2.89 BC	3.08 AB	3.11 A	

***: Significant at P≤0.001 level; **: Significant at P≤0.01 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Fruit Stalk Length for Different Melon Cultivars

Table 13 details the impact of PGPR applications on the average fruit stem length across various melon cultivars. Significant differences (P≤0.001) were observed among PGPR treatments. All PGPR isolates significantly increased the average fruit stem length compared to the control. The control treatment resulted in an average fruit stem length of 22.83 mm, whereas the highest average (24.94 mm) was achieved with the CC44 PGPR isolate. This was followed by CC37/2 with an average of 24.77 mm and FZB42 with 24.61 mm.

No significant differences were found among the melon cultivars in terms of fruit stem length. However, the Kırkağaç 637 cultivar had the lowest average fruit stem length (23.91 mm), while the Lokma F1 cultivar had the highest average (24.75 mm). The remaining cultivars were ranked as follows: Napolyon F1, Lokum F1, Ananas, and BT Akhisar. However, the cultivar x PGPR interaction did not show significant statistical differences.

PGPR applications increased the average fruit stem length by 7.7% to 9.2%. These results suggest that PGPR treatments can positively influence fruit stem length, aligning with findings from similar studies where PGPR applications have enhanced various plant growth parameters.

Table 13

Effects of PGPR Applications on Fruit Stalk Length (mm) for Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	21.00 ns	22.67	22.67	24.67	23.33	22.67	22.83 B***
CC37/2	24.67	24.33	25.33	25.00	24.67	24.67	24.77 A
CC44	23.00	24.67	25.00	25.00	25.33	24.67	24.94 A
FZB42	25.00	24.67	24.67	24.33	24.00	25.00	24.61 A
MEAN	23.91 ns	24.08	24.41	24.75	24.33	24.25	

***: Significant at P≤0.001 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Fruit Diameter (cm) for Different Melon Cultivars

Table 14 presents the impact of PGPR applications on the average fruit diameter across various melon cultivars. Statistically significant differences (P≤0.05) were observed among PGPR treatments. All PGPR isolates significantly increased the average fruit diameter compared to the control. The control

treatment had an average fruit diameter of 14.28 cm, while the highest average diameter (15.34 cm) was achieved with the CC44 PGPR isolate. This was followed by CC37/2 with an average of 15.20 cm and FZB42 with 15.16 cm.

No significant differences were observed among the melon cultivars regarding fruit diameter. However, the Ananas cultivar had the smallest average fruit diameter (14.65 cm), while the Napolyon F1 cultivar had the largest average (15.27 cm). The remaining cultivars were ranked as follows: Kırkağaç 637, BT Akhisar, Lokma F1, and Lokum F1. The cultivar x PGPR interaction did not show significant statistical differences.

PGPR applications increased the average fruit diameter by 6.1% to 7.4%. These results are consistent with similar studies where PGPR applications have enhanced fruit size and growth parameters in various crops, including tomatoes (Ibiene *et al*., 2012) and peppers (Garcia *et al*., 2003).

Table 14

Effects of PGPR Applications on Fruit Diameter (cm) for Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	13.86 ns	14.28	15.02	14.39	14.28	13.36	14.28 B*
CC37/2	15.97	15.34	15.55	14.92	14.70	14.70	15.20 A
CC44	15.66	15.44	15.66	15.23	14.81	15.23	15.34 A
FZB42	15.55	15.55	15.23	14.70	14.81	15.13	15.16 A
MEAN	15.26 ns	15.15	15.36	14.81	14.65	14.73	

*: Significant at P≤0.05 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Fruit Length for Different Melon Cultivars

Table 15 illustrates the impact of PGPR applications on the average fruit length across various melon cultivars. No significant differences were found among the PGPR treatments in terms of fruit length. The control application resulted in an average fruit length of 15.88 cm. The highest average fruit length was recorded with the CC44 PGPR isolate at 17.11 cm. This was followed by CC37/2 with an average of 16.80 cm and FZB42 with 16.77 cm.

Significant differences (P≤0.05) were observed among the melon cultivars. The Napolyon F1 cultivar had the smallest average fruit length at 14.95 cm, while the Lokma F1 cultivar had the largest average fruit length at 17.50 cm. The remaining cultivars were ranked as follows: Lokum F1, BT Akhisar, Ananas, and Kırkağaç 637. No significant differences were detected in the cultivar x PGPR interaction.

In the present study, PGPR applications did not show significant differences in their effects on fruit length. This result is consistent with another study by Naidu *et al*. (2013), where these researchers demonstrated that the foliar application of microbial-enriched compost tea significantly enhances fruit quality traits in muskmelon, including increased fruit size and mesocarp thickness.

Table 15
Effects of PGPR Applications on Fruit Length (cm) for Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	14.33 ns	16.00	15.00	17.00	16.00	17.00	15.88 ns
CC37/2	15.66	17.66	14.83	18.33	17.33	17.00	16.80
CC44	17.66	18.00	14.33	18.00	18.00	16.66	17.11
FZB42	18.00	17.00	15.66	16.66	17.66	15.66	16.77
MEAN	16.41 A*	17.16 A	14.95 B	17.50 A	17.25 A	16.58 A	

*: Significant at P≤0.05 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Fruit Flesh Thickness for Different Melon Cultivars

Table 16 shows the impact of PGPR applications on the average fruit flesh thickness across various melon cultivars. Significant differences (P≤0.01) were found among the PGPR treatments. All PGPR isolates significantly increased the average fruit flesh thickness compared to the control. The control application had an average fruit flesh thickness of 3.11 cm. The highest average fruit flesh thickness was recorded with the CC44 PGPR isolate at 3.66 cm. This was followed by FZB42 with 3.55 cm and CC37/2 with 3.50 cm.

Among the melon cultivars, no significant differences were observed in fruit flesh thickness. However, the lowest average fruit flesh thickness was found in the Kırkağaç 637 cultivar (3.41 cm), while the highest was in the Lokma F1 cultivar (3.58 cm). The remaining cultivars followed in the order: Napolyon F1, BT Akhisar, Lokum F1, and Ananas. No significant statistical differences were detected in the cultivar x PGPR interaction.

In this study, PGPR applications increased the average fruit flesh thickness by 12.5% to 17.6%. This result is consistent with another study by Naidu et al. (2013), which reported an 8.81% increase in fruit firmness and a 7.50% increment in mesocarp size, highlighting the positive impact of microbial treatments on fruit flesh characteristics.

Table 16
Effects of PGPR Applications on Fruit Length (cm) for Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	3.00 ns	3.00	3.00	3.00	3.33	3.33	3.11 B**
CC37/2	3.66	3.33	3.66	3.66	3.33	3.33	3.50 A
CC44	3.33	3.66	4.00	4.00	3.66	3.33	3.66 A
FZB42	3.66	4.00	3.33	3.66	3.00	3.66	3.55 A
MEAN	3.41 ns	3.50	3.50	3.58	3.33	3.41	

**: Significant at P≤0.01 level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Fruit Rind Thickness for Different Melon Cultivars

Table 17 presents the effects of PGPR applications on average fruit rind thickness across various melon cultivars. No significant differences were found among the PGPR treatments. The control application resulted in an average rind thickness of 4.24 mm. The highest average rind thickness was observed with the CC44 PGPR isolate at 4.30 mm, followed by CC37/2 with 4.28 mm and FZB42 with 4.25 mm.

Among the melon cultivars, no significant differences were found in rind thickness. However, the lowest average rind thickness was in the Kırkağaç 637 cultivar (4.21 mm), while the highest was in the Lokum F1 cultivar (4.30 mm). The other cultivars followed in order: Lokma F1, BT Akhisar, Napolyon F1, and Ananas. No significant differences were detected in the cultivar x PGPR interaction.

Table 17

Effects of PGPR Applications on Fruit rind width (mm) for Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	4.16 ns	4.19	4.19	4.22	4.42	4.24	4.24 ns
CC37/2	4.20	4.33	4.37	4.28	4.23	4.26	4.28
CC44	4.26	4.48	4.24	4.29	4.25	4.28	4.30
FZB42	4.24	4.15	4.22	4.36	4.33	4.20	4.25
MEAN	4.21 ns	4.29	4.25	4.29	4.30	4.24	

ns: not significant, there is no statistical difference

Effects of PGPR Applications on Soluble Solid Content for Different Melon Cultivars

Table 18 presents the effects of PGPR applications on the soluble solid content (SSC) of various melon cultivars. No significant differences were found among the PGPR treatments. The control application resulted in an average SSC of 10.06 Brix. The highest average SSC was observed with the CC37/2 PGPR isolate at 10.22 Brix, followed by CC44 with 10.18 Brix and FZB42 with 10.00 Brix.

Statistical analysis revealed significant differences among melon cultivars ($P \leq 0.01$). The lowest average SSC was found in the Lokma F1 cultivar (9.78 Brix), while the highest was in the BT Akhisar cultivar (10.33 Brix). The other cultivars followed in order: Napolyon F1, Lokum F1, Ananas, and Kırkağaç 637. However, no significant statistical differences were detected in the cultivar x PGPR interaction.

In this study, PGPR applications did not result in significant differences in SSC compared to the control. However, Naidu *et al*. (2013) demonstrated that the application of microbial-enriched compost tea resulted in a 16.21% increase in total soluble solids concentration (SSC), indicating improved fruit sweetness and quality.

Table 18

Effects of PGPR Applications on Soluble Solid Content (Brix) of Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	10.43 ns	10.16	10.17	9.50	10.14	9.94	10.06 ns
CC37/2	10.40	10.50	10.20	9.90	10.27	10.05	10.22
CC44	9.83	10.50	10.13	10.13	10.23	10.22	10.18
FZB42	9.76	10.17	10.32	9.60	9.90	10.24	10.00
MEAN	10.10 A**	10.33 A	10.20 A	9.78 B	10.13 A	10.11 A	

**: Significant at $P \leq 0.01$ level; ns: not significant, there is no statistical difference

Effects of PGPR Applications on Fruit pH of Different Melon Cultivars

Table 19 presents the effects of PGPR applications on the pH levels of various melon cultivars. No significant differences were observed among the PGPR treatments. The control group had an average pH of 6.70. The highest average pH was found with the control group (PGPR0) at 6.70, followed by

CC37/2 with 6.59 and CC44 with 6.58.

Table 19

Effects of PGPR Applications on Fruit pH of Different Melon Cultivars

PGPR	CULTIVARS						MEAN
	Kırkağaç 637	BT-Akhisar Topan	Napolyon F1	Lokma F1	Lokum F1	Ananas	
CONTROL	6.76 ns	6.46	6.66	6.91	6.67	6.74	6.70 ns
CC37/2	6.45	6.62	6.48	6.69	6.55	6.76	6.59
CC44	6.50	6.56	6.52	6.64	6.60	6.66	6.58
FZB42	6.35	6.35	6.58	6.53	6.78	6.74	6.55
MEAN	6.52 ns	6.50	6.56	6.69	6.65	6.73	

ns: not significant, there is no statistical difference

Statistical analysis showed significant differences among melon cultivars. The lowest average pH was recorded for the BT Akhisar cultivar at 6.50, while the highest was found in the Ananas cultivar at 6.73. The other cultivars followed in the order: Lokma F1, Lokum F1, Napolyon F1, and Kırkağaç 637. No significant statistical differences were detected in the cultivar x PGPR interaction.

In the study by Murgese *et al*. (2020), the application of a consortium of plant growth-promoting bacteria (PGPB) to Barattiere (*Cucumis melo* L.) plants showed significant improvements in fruit yield, early maturity, and physiological parameters, even when used with reduced doses of mineral fertilizers. This study highlights the potential of PGPR to enhance plant growth and nutrient uptake by upregulating genes involved in nitrogen, iron, and phosphorus transport. Similar to these findings, our study demonstrates that PGPR applications can positively impact yield and quality traits in melons, suggesting that integrating PGPR could reduce the need for full fertilizer doses while maintaining or improving crop performance. This approach aligns with sustainable agricultural practices by minimizing chemical inputs and supporting environmental and economic benefits.

In the study by Altuntaş and Kutsal (2022), the impact of various plant growth-promoting rhizobacteria (PGPR) on melon development and fruit quality was evaluated under both irrigated and non-irrigated conditions. Their findings demonstrated that while PGPR treatments did not significantly affect most fruit quality parameters, *Bacillus subtilis* notably improved total soluble solids (TSS) in Kırkağaç 637 melons grown under non-irrigated conditions. This highlights the potential of specific PGPR strains to enhance fruit quality, particularly in challenging growing environments. In our study, similar PGPR applications showed varying effects on melon yield and quality traits, suggesting that the choice of PGPR strain and application conditions can significantly influence crop performance. Integrating PGPR into melon cultivation could be a valuable strategy for optimizing fruit quality and yield, especially in regions with limited irrigation resources.

CONCLUSION

The present study evaluated the effects of different plant activators on various melon cultivars (Kırkağaç 637, BT Akhisar Topan, Napolyon F1, Lokma F1, Lokum F1, and Ananas) in Van conditions, focusing on plant growth, yield, and quality. The results revealed significant improvements in parameters such as stem diameter, stem length, leaf fresh and dry weight, average fruit weight, fruit width, fruit length, petiole length, average number of branches, average branch length, and average number of fruits per plant due to the application of CC37/2, CC44, and FZB42. However, no statistically significant effects were observed for soluble solid content (SCC), pH, rind thickness, and petiole thickness in relation to PGPR applications.

The application of CC37/2, CC44, and FZB42 bacteria improved plant growth and fruit quality

by affecting the mineral content, amino acids, organic acids, and hormone levels in the melons. This indicates that PGPRs may enhance these compounds, which in turn boosts plant development and fruit quality. These findings suggest that PGPRs could offer significant economic and environmental benefits in vegetable cultivation, with minimal impact on human health. Further research should explore the use of these bacteria as biofertilizers in commercial vegetable production and their effects on other vegetable species.

Additionally, the highest average branch number was observed in the Ananas cultivar, while BT Akhisar had the highest average fruit weight, and Ananas also showed the highest average fruit yield. It is recommended that specialized sales outlets or distributors be established to make these plant activators accessible to producers and provide agricultural extension services on their use. Successful isolates such as CC44/2, CC44, and FZB42 should be formulated and tested for practical application. Furthermore, producers should be encouraged to adopt integrated pest management practices and monitor soil health regularly to complement the benefits of PGPR applications. Developing and implementing educational programs on the benefits and techniques of using PGPRs can enhance their adoption and effectiveness. Collaborative efforts with agricultural extension services and research institutions can also facilitate the dissemination of best practices and innovations in PGPR use.

Ethical Statement

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Author Contributions

Research Design (CRediT 1) Author 1 (50%) - Author 2 (50%)

Data Collection (CRediT 2) Author 1 (70%) - Author 2 (30%)

Research - Data Analysis - Validation (CRediT 3-4-6-11) Author 1 (50%) - Author 2 (50%)

Writing the Article (CRediT 12-13) Author 1 (60%) - Author 2 (40%)

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12 Responsible Production and Consumption

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