

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**ASSESSMENT OF INFLUENCE OF MICROBIAL FERTILIZER
ON PRODUCTION OF TOMATO**

ZEYNEP ÖZGE TEPE

A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF MOLECULAR BIOLOGY AND GENETICS

ADVISOR: PROF. DR. YELDA ÖZDEN ÇİFTÇİ

JULY 2025

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL

**ASSESSMENT OF INFLUENCE OF MICROBIAL
FERTILIZER ON PRODUCTION OF TOMATO**

ZEYNEP ÖZGE TEPE

A THESIS OF MASTER OF SCIENCE
DEPARTMENT OF MOLECULAR BIOLOGY AND
GENETICS

ADVISOR: PROF. DR. YELDA ÖZDEN ÇİFTÇİ

JULY 2025

**T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ**

**MİKROBİYAL GÜBRENİN DOMATES ÜRETİMİ
ÜZERİNDEKİ ETKİSİNİN DEĞERLENDİRİLMESİ**

ZEYNEP ÖZGE TEPE

**YÜKSEK LİSANS TEZİ
MOLEKÜLER BİYOLOJİ VE GENETİK ANABİLİM
DALI**

DANIŞMAN: PROF.DR. YELDA ÖZDEN ÇİFTÇİ

TEMMUZ 2025



MASTER of SCIENCE JURY APPROVAL FORM

A thesis submitted by Zeynep Özge Tepe, defended on 04/07/2025 before the jury formed with the 30/06/2025 date and 2025/34 numbered decision of the GTU Graduate Administration Board, has been accepted as a MASTER of SCIENCE thesis in the Department of Molecular Biology and Genetics.

JURY

MEMBER

(THESIS ADVISOR) :PROF. DR. YELDA ÖZDEN ÇİFTÇİ

MEMBER

:DOÇ. DR. MİNE GÜL ŞEKER

MEMBER

:PROF. DR. YILDIZ AYDIN

APPROVAL

Gebze Technical University Graduate Administration Board

...../...../..... date and/..... numbered decision.

SIGNATURE/SEAL

ABSTRACT

The high demand for tomatoes can be attributed to two primary factors: their nutritional value and their extensive utilization within various industries, particularly the food industry, where they are employed in products such as sauces, ketchup, and tomato paste. The increasing global population has the potential to create a significant challenge in satisfying the world's food demands. To overcome this challenge and to achieve high yields, chemical fertilizers have been used extensively for many years. However, the excessive use of chemical fertilizers has been shown to lead to a number of environmental concerns, including the degradation of soil structure, the pollution of water resources, the loss of biodiversity, and the overall threat to environmental sustainability. Sustainable agriculture is based on conserving natural resources while maintaining production without harming the environment. In this context, integrating environmentally friendly practices into agricultural systems is crucial. Practices that minimize environmental impact while maintaining productivity are crucial in agriculture. Therefore, this study aims to reduce the use of chemical fertilizers in sustainable agriculture and investigate microbial fertilizers as a biological alternative.

In this context, a microbial consortium was established with bacteria (*Pseudomonas* sp., *Acinetobacter* sp., and *Enterobacter* sp.) isolated within the framework of a previous TUBITAK project (121O649). This consortium possesses the capacity to fix nitrogen, solubilize phosphate, form biofilms, and produce siderophores that support plant growth. The consortium was then applied to tomato plants by method of foliar spraying. The present study was conducted on three distinct substrates frequently utilized in soilless agriculture: cocopeat, perlite, and slag in Darica District Governorship Soilless Agriculture R&D Greenhouse. The spraying process was executed on two separate occasions during the flowering stage of tomato cultivation, and the impact of the microbial consortium was subjected to comparative analysis. The tomato plant was selected as a model organism for its economic value and its extensive use in experimental studies. The research is predicated on the hypothesis that microbial fertilizers will have a positive effect on tomato growth; however, the degree of this effect may vary depending on the characteristics of the growing medium. In this study, the contributions of the foliar application of microbial fertilizer to plant height, pH, chlorophyll content, and tomato growth were observed.

This study is expected to provide novel insights into the interaction of a unique microbial fertilizer consortium with diverse soilless agriculture substrates, particularly in the context of tomato cultivation. The findings are anticipated to contribute to the existing body of knowledge and promote sustainable agricultural practices.

Keywords: Tomato, Microbial Fertilizer, Soilless Agriculture, PGPR, Sustainable Agriculture.

ÖZET

Domates hem içeriğinin zenginliği hem de gıda endüstrisinde pek çok alanda (sos, ketçap, salça vb.) kullanıldığı için çok fazla talep görmektedir. Dünya nüfusundaki artış, bu gıda talebinin karşılanması açısından bir zorluk oluşturmaktadır. Bu zorluğun üstesinden gelmek ve yüksek verim elde etmek için kimyasal gübreler uzun yıllardır yoğun bir şekilde kullanılmaktadır. Ancak kimyasal gübrelerin aşırı kullanımı toprak yapısının bozulmasına, su kaynaklarının kirlenmesine ve biyolojik çeşitliliğin kaybolmasına neden olmakta, aynı zamanda çevresel sürdürülebilirliği tehdit etmektedir. Sürdürülebilir tarım, doğal kaynakların korunmasını ve çevreye zarar vermeden üretimin devamlılığını esas alır. Bu bağlamda, çevre dostu uygulamaların tarım sistemlerine entegre edilmesi önemlidir. Çevresel etkileri en aza indiren ve verimliliği koruyan uygulamalar tarımda büyük önem taşımaktadır. Bu nedenle bu çalışma, sürdürülebilir tarım için kimyasal gübre kullanımının azaltılması ve bunun yerine biyolojik bir alternatif olarak mikrobiyal gübrelerin kullanılmasını araştırmayı amaçlamaktadır. Bu bağlamda, ilk olarak TÜBİTAK projesi (121O649) çerçevesinde izole edilen, bitki gelişimini destekleyen azotu fiksedeleyen, fosfatı çözebilen, biyofilm ve siderofor oluşturan bakterilerle (*Pseudomonas* sp., *Acinetobacter* sp., *Enterobacter* sp.) kurulan bir mikrobiyal konsorsiyum domates bitkilerine püskürtme yoluyla uygulanmıştır. Bu uygulama, topraksız tarımda yaygın olarak kullanılan kokopit, perlit ve cüruf olarak üç farklı substrat üzerinde yapılmıştır (Darıca Kaymakamlığı Topraksız Tarım AR-GE Serası). Püskürtme işlemi, domatesin çiçeklenme aşamasında iki kez yapılmış ve mikrobiyal konsorsiyumun etkileri karşılaştırmalı olarak değerlendirilmiştir. Domates bitkisi, ekonomik değeri ve deneysel çalışmalarda yaygın kullanımı nedeniyle model organizma olarak seçilmiştir. Araştırma, mikrobiyal gübrelerin domates büyümesi üzerinde olumlu bir etkiye sahip olduğunu, ancak bu etkinin derecesinin yetiştirme ortamının özelliklerine bağlı olarak değişebileceğini göstermektedir.

Yapılan çalışmada yapraktan uygulanan mikrobiyal gübrenin bitki boy uzunluğu pH değeri klorofil miktarı ve domates gelişimine sağladığı katkılar gözlemlenmiştir. Çalışmaların tamamlanmasıyla, özgün bir mikrobiyal gübre konsorsiyumunun farklı topraksız tarım substratları ile domates üzerindeki etkileşiminin sonuçlarının literatürdeki boşluğun doldurulması ve sürdürülebilir tarım uygulamalarına katkı sağlanması beklenmektedir.

Anahtar Kelimeler: Domates, Mikrobiyal Gübre, Topraksız Tarım, Sürdürülebilir Tarım, PGPR.

ACKNOWLEDGEMENTS

I would like to thank with my sincerest respect and gratefulness to my very valuable advisor Prof. Dr. Yelda ÖZDEN ÇİFTÇİ, who has always been with me throughout my master's degree education, who has always enlightened my path with her knowledge and experience, and who has guided me with her patience and understanding. I would like to thank DOÇ. DR. Mine GÜL ŞEKER and Doç. Dr. Özlem AKKAYA for her contribution and experience in my thesis study. I would like to sincerely thank Darica District Governorship for their contributions to the realization of my thesis study; Mr. Turan ŞAHİN and the greenhouse personnels for their support during the studies carried out in the greenhouse. I would like to sincerely thank my esteemed teacher Dr. Nil TÜRKÖLMEZ for guiding me with her knowledge and experience during my research process, and my dear lab mate Aycan KAYRAV who contributed with her knowledge and experience by being with me at every stage of my experiments. I would like to sincerely thank my dear colleagues Gül Çiçek KILIÇ and Nida ARSLAN for their support throughout my graduate journey. I would like to sincerely thank my dear boyfriend Muhammed Furkan ÇAPANOĞLU, who has been with me under all circumstances since my undergraduate education and who has never lacked his support and motivation. In this process, I am grateful to my dear Sinan SARITOPRAK and Birsen SARITOPRAK, whose presence has always made me feel the closeness of a family. Finally, I would like to thank my family; my dear mother and father Tülay TEPE and Osman TEPE, my dear siblings Suna Ezgi TEPE, Eda Nur TEPE and Muhammed Anıl TEPE, who believed in me at every moment of my life, surrounded me with their love, and whose presence gave me strength; with gratitude and endless love that I cannot describe in words.

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	v
ÖZET	vi
ACKNOWLEDGEMENTS	vii
TABLE OF CONTENTS	viii
LIST OF SYMBOLS AND ABBREVIATIONS	x
LIST OF FIGURES	xi
LIST OF TABLES	xiii
1. INTRODUCTION	1
1.1 Aim, Contribution and Content	
2. LITERATURE REVIEW	4
2.1. General Information of Tomato	4
2.1.1. Global and Local Production of Tomato	5
2.2. Usage of Fertilizers and Agricultural Sustainability	7
2.3. Soilless Culture	8
2.3.1. Cocopeat	9
2.3.2. Perlite	10
2.3.3 Volcanic Slag	12
2.4. Microbial Fertilizers	13
2.4.1 Foliar Spraying Method	14
2.5. Plant Growth Promoting Rhizobacteria (PGPR) and Agricultural Importance	14
2.5.1. Nitrogen Fixation	16
2.5.2. Phosphate and Potassium Solubilization	17
2.5.3. Regulation of Phytohormone Production	18
2.5.4. Iron Carrier Production	19
3. EXPERIMENT	20
3.1. Materials	20
3.1.1. Microorganism Strains	20
3.1.2. Plant Material	20
3.1.3. Chemicals and Devices	20
3.2. METHODOLOGY	22
3.2.1. Growing Tomato in Greenhouse Conditions	22
3.2.2. Preparation of Bacterial Cultures	23
3.2.3. Gram Staining	23
3.2.4. Preparation of Bacterial Suspensions and Formation of Microbial Consortium	24
3.2.5. Application of Microbial Consortium to Tomato Plants	25
3.2.6. Measurement of Plant Stem Length	25

3.2.7. Chlorophyll Analysis	26
3.2.8. Total Tomato Yield by Treatment (kg/decare)	27
3.2.9. Tomato Fresh Weight Measurement	27
3.2.10. Tomato Dry Weight Measurement	28
3.2.11. pH Measurement	29
3.2.12. A study of the Titrimetric Quantification of Citric Acid in Tomato Fruits	29
3.2.13. Lycopene Analysis	30
3.2.14. Organoleptic Analysis	31
3.2.15. Statistical Analysis	32
4. RESULTS	33
4.1. Determination of Morphological and Cellular Characteristics of Bacterial Isolates Used in the Consortium	33
4.1.1. Morphological Examination of Isolates	33
4.1.2. Gram Staining Results of Isolates	34
4.2. Evaluation of the Effects of Microbial Consortium on Vegetative Growth of Tomato Plant	36
4.2.1. Measurement of Plant Stem Length	41
4.2.2. Determination of Chlorophyll Content in Plant Leaves	44
4.3. Investigation of the Effect of Microbial Consortium on Tomato Fruit Yield Parameters	45
4.3.1. Measurement of Total Yield of Tomato Plant	46
4.3.2. Fresh weight measurements of tomato fruits	46
4.3.3. Dry Weight Measurements of Tomato Fruits	47
4.3.4. Determination of pH Value of Tomato Fruits	48
4.3.5. Determination of Lycopene Content in Tomato Fruits by Spectrophotometric Method	49
4.3.6. Determination of Citric Acid Content in Tomato Fruits by Titrimetric Method	50
4.3.7. Organoleptic Evaluation Result	51
5. DISCUSSIONS	52
6. CONCLUSION	58
REFERENCES	59
BIOGRAPHY	62
PUBLICATIONS AND PRESENTATIONS FROM THE THESIS	63

LIST OF SYMBOLS AND ABBREVIATIONS

%	: Percentage
°C	: Centigrade Degrees
mL	: Milliliter
mg	: Milligram
nm	: Nanometer
g	: Gram
kg	: Kilogram
da	: Decare
cm	: Centimeters
A	: Absorbance
dH ₂ O	: Distilled Water
EC	: Electrical Conductivity
IAA	: Indole 3- Acetic Acid
LB	: Lurient Broth Medium
LSD	: Least Significant Difference
NaOH	: Sodium Hydroxide
PGPR	: Plant Growth Promoting Rhizobacteria
pH	: Power of Hydrogen
SE	: Standard Error
Sp	: Species

LIST OF FIGURES

	<u>Page</u>
Figure 2.1: Distribution of world tomato production by Countries.	6
Figure 2.2: Turkiye tomato cultivation area, production and yield.	6
Figure 2.3: Distribution of tomato cultivation area by provinces In Turkiye.	7
Figure 2.4: Images of cocopeat.	9
Figure 2.5: Process of Perlite Production.	11
Figure 2.6: Images of Volcanic Slag.	12
Figure 2.7: Plant Growth Promoting Bacteria (PGPR) direct and indirect mechanisms.	15
Figure 3.1: Image of tomatoes in the first week of microbial fertiliser application in the greenhouse.	22
Figure 3.2.: Preparation of Microbial Consortium.	25
Figure 3.3: Pre-harvest image of tomato plants in the greenhouse in the final week.	26
Figure 3.4: Chlorophyll analysis of leaf section.	27
Figure 3.5: Cross-Sections of Tomatoes from the Various Experimental Groups.	28
Figure 3.6: Drying procedure of tomato samples for dry weight analysis: Three fruits from each group were cut and oven-dried at 70 °C.	28
Figure 3.7: Titration acidity analyses in tomatoes.	30
Figure 3.8: Image of tomato samples after phase separation.	31
Figure 3.9: Measurement of supernatants in a UV spectrophotometer.	31
Figure 4.1: Colony morphology images of the isolates on LB agar plate and stereo microscope.	33
Figure 4.2: The results of the gram staining of the isolates were identified according to taxonomic classification.	35
Figure 4.3: Weakly growth of tomato in cocopeat with chemical fertilizer.	36
Figure 4.4: Weakly growth of tomato in cocopeat with chemical fertilizer + microbial fertilizer.	37
Figure 4.5: Weakly growth of tomato in perlite with chemical fertilizer.	38
Figure 4.6: Weakly growth of tomato in perlite with chemical fertilizer + microbial fertilizer.	39
Figure 4.7: Weakly growth of tomato in volcanic slag with chemical fertilizer.	40
Figure 4.8: Weakly growth of tomato in volcanic slag with chemical fertilizer + microbial fertilizer.	41
Figure 4.9: Weekly height growth comparison of tomatoes grown in perlite medium between control and microbial fertilizer treated groups.	42
Figure 4.10: Weekly height growth comparison of tomatoes grown in cocopeat medium between control and microbial fertilizer treated groups.	43

Figure 4.11: Weekly height growth comparison of tomatoes grown in volcanic slag medium between control and microbial fertiliser treated groups	43
Figure 4.12: Total yield of tomato plants of per kg/da.	46
Figure 4.13: The lycopene amount at different medium and fertilizer groups.	51
Figure 4.14: Average scores of the experimental Groups on the basis of sensory parameters	52

LIST OF TABLES

	<u>Page</u>
Table 2.1: World tomato cultivation area, production and yield.	5
Table 3.1.: Devices used in thesis.	21
Table 3.2.: Chemicals used in thesis.	21
Table 4.1: Assessment of the colony morphology of the isolates.	34
Table 4.2: Identification information of the isolates that were used	35
Table 4.3: Weekly Growth Differences in Tomato Plants.	45
Table 4.4: Chlorophyll a, chlorophyll b and carotenoid amount obtained from leaf samples of experimental groups.	46
Table 4.5: Fresh weight of tomato in each experimental group.	48
Table 4.6: Dry weights of tomatoes of experimental groups.	49
Table 4.7: pH values measured for each group.	50
Table 4.8: Three replicate averages and statistical analysis results (in %) of citric acid contents determined by titration with NaOH in tomato samples according to different growing media and fertilizer applications.	52

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most produced and consumed vegetables worldwide and has an important place in agricultural production due to its economic value and nutritional content. Tomato draws attention with its rich nutritional content, especially vitamin C, potassium and dietary fibre, and it is reported in scientific studies that it shows protective effects against cancer thanks to antioxidants such as lycopene it contains. Türkiye has an important share in world tomato production and is intensively grown especially in the Mediterranean and Aegean Regions. This situation causes tomato to be a strategic product for our country's agriculture and economy. However, the increase in the world population and the inadequacy of resources such as soil and water cause difficulties in terms of tomato and other vegetable and fruit production. Chemical fertilisers are used extensively to increase crop yields due to problems such as increase in world population, climate change, decrease in agricultural land, decrease or pollution of water resources. [Tilman et al., 2011]. The widespread use of chemical fertilisers in traditional agricultural systems negatively affects the environment. Especially soil pollution, pollution of water resources and the decrease in biodiversity have made it inevitable to turn to sustainable alternatives. The need for sustainable agricultural practices increases day by day. [Canton, 2021].

Soilless agriculture, which can be considered an alternative to sustainable agriculture, is a method that enables efficient production with different substrates. Soilless agriculture systems have been demonstrated to contribute to sustainable agriculture, particularly in urban areas, due to their efficiency in water and nutrient utilisation [Jones, 2021]. The advantages of this system are significant, including the ability to control environmental conditions, thereby reducing the risk of disease, and the capacity to produce consistently throughout the year. These factors contribute to the widespread adoption of this system. The growing media (substrates) utilised in soilless agriculture have been demonstrated to have a significant impact on various factors, including plant root development, water holding capacity, and nutrient uptake [Pardossi et al., 2020]. While cocopite is known for its high water-holding capacity, perlite is generally preferred due to its structural stability and air permeability.

Volcanic slag is being investigated as an environmentally sustainable substrate, offering adequate drainage due to its physical porosity. [Khan et al., 2019; El Sayed et al., 2022].

Another example of sustainable agriculture is the use of microbial fertilisers, which is one of the most environmentally sensitive fertilisation approaches. Plant Growth Promoting Rhizobacteria (PGPRs) support plant growth through various mechanisms, such as the production of indole-3-acetic acid (IAA), the solubilisation of phosphates, the synthesis of siderophores and the enhancement of stress tolerance [Radhakrishnan et al., 2017; Etesami & Adl, 2020]. PGPRs also establish symbiotic relationships with plants, enhancing growth and potentially reducing the need for chemical fertilisers (Shivay et al., 2019). PGPRs proliferate in the rhizosphere, colonising plant roots and becoming well established there. During this process, they produce phytohormones such as indole-3-acetic acid (IAA), gibberellic acid, auxins and abscisic acid (ABA). They also promote plant growth by releasing volatile organic compounds (VOCs) and various metabolites. By reducing increased ethylene levels, these bacteria help the plant maintain growth even under stress [Fusco et al., 2022].

1.1. Aim, Contribution and Content

The aim of this thesis was to determine the effects of microbial fertilizer applied during the cultivation of tomato (*Solanum lycopersicum* L.) plants in three different soilless substrates (cocopeat, perlite and volcanic slag) on plant growth, yield and quality parameters. The study evaluated the foliar microbial fertilisation method, which is an alternative application to reduce the use of traditional chemical fertilisers.

The scientific contribution of the thesis is to demonstrate the applicability of microbial fertiliser, one of the environmentally friendly fertilisation methods, in soilless farming systems and to reveal the agricultural potential of low-cost materials such as volcanic slag that can be used as an alternative to traditional substrates. With the application of microbial fertiliser to tomato plant, it was aimed to examine the potential effects of microbial consortium on leaf growth and fruit yield of tomato, - to develop environmentally friendly agricultural practices by reducing the use of chemical fertilisers and pesticides.

In addition, the foliar application method used in the study shows that microbial fertilisers can effectively support plant metabolism and provides a scientific basis for sustainable agricultural practices. In this study, agricultural and quality parameters such as plant height, fresh and dry weight, leaf chlorophyll content, fruit pH value, titration acidity and lycopene content were measured, and the data obtained were evaluated by statistical analyses.

2. LITERATURE REVIEW

2.1. General Information of Tomato

Tomato belongs to the Solanaceae family and is the third most widely grown and consumed vegetable worldwide. It has a wide range of uses in both fresh and processed products such as tomato paste, sauce and soup. It is an agricultural product with high nutritional value and great economic importance. It contains plenty of antioxidant compounds, vitamins A, C and E and carotenoids, especially lycopene. Due to these components, it displays many biological activities such as supporting the immune system, protecting against cardiovascular diseases and showing anti-carcinogenic effects. [Gen-Jiménez et al., 2023]. However, its production can be adversely affected from time to time due to diseases, pests and various environmental stress factors. It is of great importance to grow healthy seedlings resistant to these stresses. Although chemical pesticides traditionally used to solve these problems are effective in the short term, they can pose serious risks to human health and the environment in the long term [Liu et al., 2022].

At the same time, the intensive use of chemical fertilisers to increase yields has negative effects on the environment and human health. For these reasons, interest in organic and biological fertilisation methods is increasing. Organic fertilisers include compost, barnyard manure, green manures and biofertilizers of microbial origin. These fertilisers improve soil structure, increase biological activity, reduce nutrient losses by slow release and have a positive effect on yield. Indeed, studies show that organic and biological applications increase polyphenol and antioxidant content in tomato [Liu et al., 2022].

In addition to fertilisation methods that increase production potential and improve nutritional quality in tomatoes, the properties of the growing medium also play an important role in plant development. Cocopeat and perlite are the most widely known soilless cultivation media. Volcanic slag is one example of an organic growing medium, alongside perlite, and research into this medium is ongoing.

2.1.1. Global and Local Production of Tomato

The consumption of tomatoes is a global phenomenon. The substance is found in various forms, both cooked and uncooked. The tomato market has exhibited robust growth in recent years. However, the rapid increase in human population has created considerable challenges in achieving sustainability in agriculture, thereby resulting in a mismatch between demand and supply. In 2022, the global tomato cultivation area exhibited a contraction of 2.6% in comparison with the preceding year, amounting to approximately 49.2 million decares. A decline in global tomato production was observed, with a 1.7% decrease recorded compared to the previous year, resulting in an estimated total of approximately 186.1 million tonnes (Table 1.1, Figure 1.1)[TEPGE, September 2024].

Table 2.1: World tomato cultivation area, production and yield.

Years	Cultivated Area (thousand decares)	Production (thousand tons)	Yield (kg/decare)
2018	50.137	182.250	36,4
2019	49.183	181.829	37,0
2020	49.649	185.235	37,3
2021	50.466	189.281	37,5
2022	49.177	186.108	37,8

The distribution of global tomato production by country for the year 2022, expressed as a percentage. As demonstrated in Figure 2.1, China, California, Italy Turkiye, and other countries which are the leading countries in global tomato production of world tomato production in 2024.

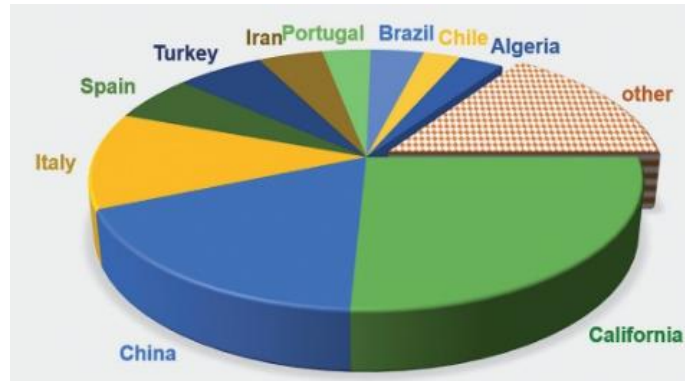


Figure 2.1: Distribution of world tomato production by countries 2024 %, [FAO,2024]

In Türkiye, tomato cultivation area expanded by 4.4% in 2023 compared to the previous year. Tomato production increased by 2.3% compared to the previous year and reached 13 million 300 thousand tonnes, while yield decreased by 2% compared to the previous year and reached 80.1 tonnes/ha (Figure 2.2,). [TEPGE, September 2024].

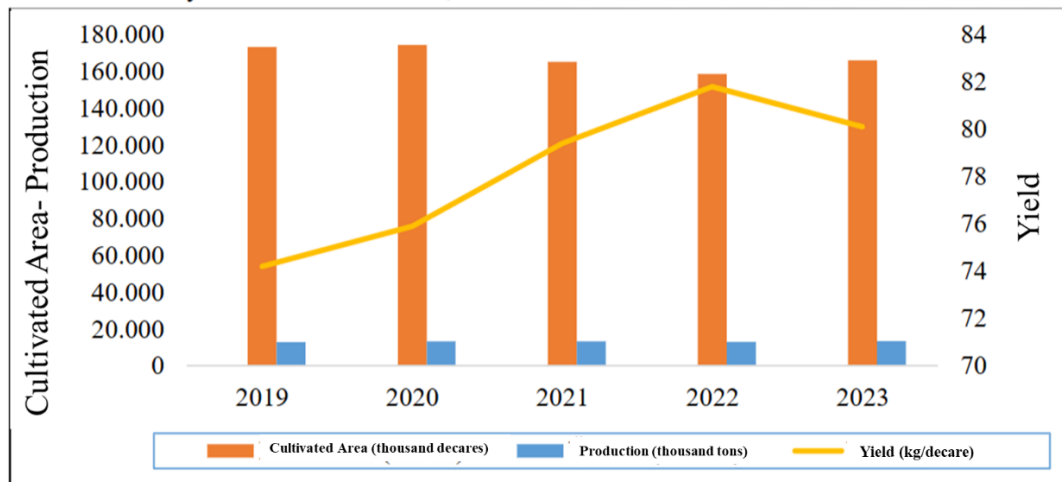


Figure 2.2: Türkiye tomato cultivation area, production and yield.

When tomato production by provinces in Türkiye in 2023 is analysed, Antalya ranks first with a share of 19.6%. Antalya is followed by Bursa with a share of 11.5% and Manisa with a share of 8.2% (Figure 2.3).

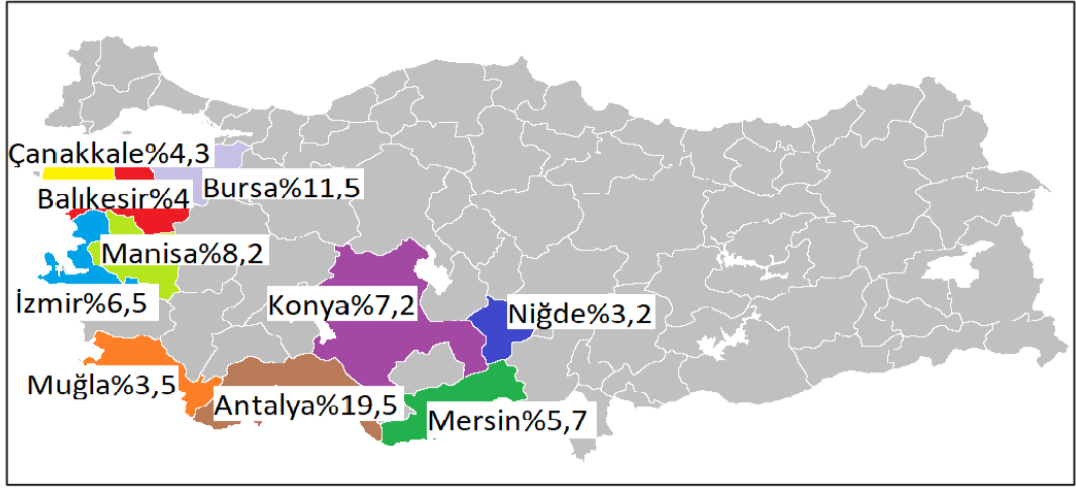


Figure 2.3: Distribution of tomato cultivation area by provinces in Turkey 2023%.
[TEPGE September 2024].

Tomato (*Solanum lycopersicum* L.) is one of the most widely grown vegetables worldwide, cultivated both in fields and greenhouses. According to data from the Food and Agriculture Organization (FAO), the global production of tomatoes in 2023 reached approximately 186 million tons [FAOSTAT, 2024]. It is estimated that approximately 20% of global production is realized in greenhouse systems [FAO, 2024]. In Turkey, accounted for 40.8% of the total vegetable production in 2023. The production of tomatoes in Turkey is conducted in both fields and greenhouses. The data indicates that tomato production greenhouse in Turkey accounts for 31.3% of the total tomato production, amounting to 4 million tons [TEPGE 2024].

2.2. Usage of Fertilizers and Agricultural Sustainability

The rapid increase in the world's population and the resulting increase in demand for food have led to the overuse of existing agricultural land and natural resources. In addition, although the intensive use of chemical fertilisers increases short-term yield, it causes long-term deterioration of soil health, loss of organic matter, decreased microbial diversity, salt and heavy metal accumulation, pH imbalance and ecosystem damage. [Musa et al., 2023]. Furthermore, these chemicals can pose a threat to human health via the food chain. [Wang et al., 2024]. The problems encountered in agriculture have increased the use of environmentally friendly and biological alternatives for sustainable production. Biofertilizers have become an important component of

sustainable agriculture thanks to their long-term effects on improving soil structure, supporting microbial life and maintaining ecological balance. [Desai et al., 2019]. In this context, the aim of sustainable agriculture is not only efficient production, but also the conservation of natural resources and the transfer of a healthy environment to future generations. [Carril et al., 2025].

2.3. Soilless Culture

Soil is the medium in which plants naturally grow. It supports plant growth by providing them with nutrients, air, and water. However, various biotic and abiotic factors can sometimes limit plant growth. These include soil-borne diseases, insect larvae, poor drainage, and high acidity or alkalinity. Additionally, increasing urbanization and unfavourable geographical conditions lead to a decrease in arable land. These developments have led to the creation of soilless farming techniques that reduce soil use and provide more controlled production. [Gautam et al., 2020].

Soilless agriculture is a production system in which essential nutrients are received directly from nutrient solutions by plants. Eliminating the need for soil reduces the need for processes such as weed control. In this system, there is no nutrient competition, so nutrient management becomes easier. This process has been demonstrated to reduce nutrient toxicity and promote healthier plant growth. [Subramani et al., 2020].

Soilless farming also allows for year-round production independent of climate. Soilless culture offers significant advantages, particularly in terms of quality crop production. For yield-critical species, such as medicinal plants, soilless culture facilitates more precise management of physical, chemical, and microbiological factors (i.e., physical, chemical, and microbial properties). The properties of the growing media used are instrumental in providing these advantages. Consequently, a comprehensive assessment of the substrates' physical, chemical, and biological properties is imperative.

In soilless systems, substrates (growing media) function as an alternative to soil, providing physical support for plant growth. These substrates also facilitate water and nutrient retention, thereby enabling healthy root development by maintaining root contact with the atmosphere. The substrates utilized in these processes may be

classified as inorganic or organic. Inorganic substrates include perlite, rock wool, expanded clay, and pebbles, whereas organic substrates encompass cocopeat, rice husks, and composted plant material. Cocopeat has been identified as one of the most widely used organic substrates in tomato cultivation, as evidenced by numerous studies. [Boyaci et al., 2022].

2.3.1. Cocopeat

Cocopeat is a growing medium of organic origin that is obtained by processing coconut shells through a series of mechanical actions, such as grating and grinding (Figure 2.4). Prior to its utilization in agricultural production, sterilization via steam is applied to eradicate pests and pathogens. [Gautam et al., 2020]. The natural structure of this substance provides a healthy environment for root growth and creates a protective barrier against root diseases.



Figure 2.4: Images of cocopeat.

The material's defining characteristics include its high-water holding capacity, good porosity, and strong air circulation. The physical properties of this material have been demonstrated to facilitate the maintenance of optimal moisture and oxygen balance within the root zone, even under conditions of drought or impaired drainage. [Raju et al., 2023]. The spongy structure of cocopeat affords it the capacity to function as an ideal growing medium, a quality that is especially beneficial in regions experiencing water limitations. In addition, it is utilized as a soil improver in agricultural regions.

From a chemical perspective, the pH of cocopeat ranges from slightly acidic to neutral, and the electrical conductivity (EC) level is conducive to plant growth. It is notable for its high potassium content, though it exhibits comparatively low levels of nitrogen and

phosphorus. [Subramani et al., 2020]. The organic structure of the substance under investigation has been shown to be conducive to a high degree of microbial diversity. This process not only facilitates the uptake of nutrients by the plant but also establishes a natural defence system that enhances resistance against plant diseases. [Ok, 2025].

One of the study indicates that the yield and success of tomato production are significantly influenced by the type of growing medium employed. The utilization of an optimal growing medium has been demonstrated to result in enhanced yields and improved product quality. Coconut husk has been demonstrated to offer several advantages as a growing medium. The short fibers of this material can be composted into a successful growing substrate. This medium has been demonstrated to exhibit high moisture-holding capacity and facilitate air circulation, both of which are critical for sustaining plant health and promoting the development of robust root systems. In a recent study, two tomato varieties, Bella and Sinatra, were examined under greenhouse conditions. The results demonstrated that both varieties exhibited successful growth on coconut husk media. Furthermore, the coconut fiber media was found to decompose more slowly than other substrates. This finding suggests that extended and repeated crop cycles may be achievable. The findings indicate that coconut coir is a suitable and effective growing medium for tomato production under greenhouse conditions, offering both economic and agronomic advantages. [Vinkovic et al., 2007].

2.3.2. Perlite

Perlite is a prevalent ingredient in soilless agriculture, being one of the most widely used inorganic growing media. Perlite, a silicon mineral that occurs naturally because of volcanic eruptions, undergoes an expansion process when exposed to temperatures of approximately 180°C, resulting in a porous and light-weight structure. [Gautam et al., 2020]. This expanded aluminium silicate rock, which is obtained by subjecting the rock to heat treatment, physically provides good aeration and effective drainage for plant roots (Figure 2.5).

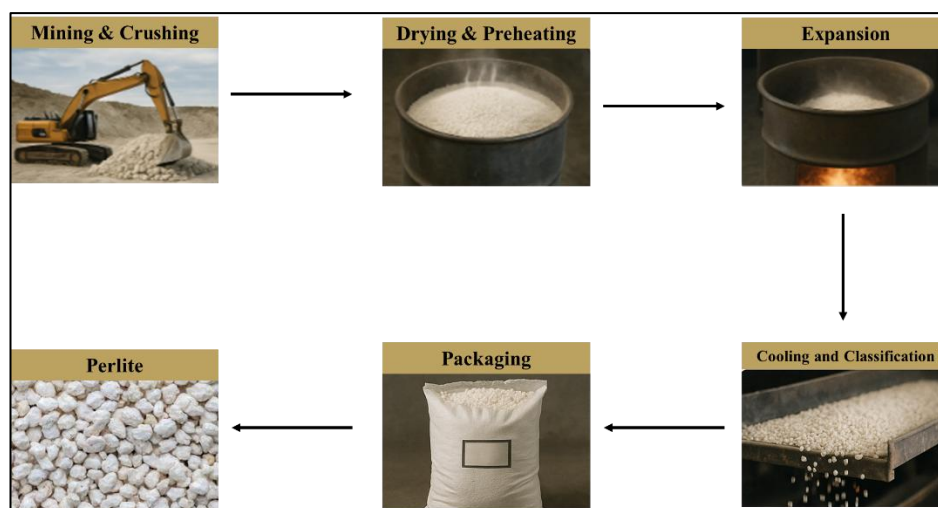


Figure 2.5: Process of Perlite Production.

Chemically, the solution does not undergo reactions the medium has a neutral pH value and does not provide nutrients for the cells. Consequently, the provision of nutrients must be externally supplied in the form of a nutrient solution. The material exhibits a low water-holding capacity, a property that prevents the accumulation of excess moisture in the root zone and facilitates oxygen uptake. However, this property also indicates that perlite necessitates frequent irrigation due to its limited water-holding capacity. [Ok, 2025]. Furthermore, the microbial activity is constrained by the presence of minimal organic matter. Consequently, perlite can be utilized as an effective carrier medium for microbial fertilizers or microbial inoculants, thereby enhancing its biological functionality.

In this study, pure perlite was found to yield the highest total fruit yield and average fruit weight. This finding demonstrated the effectiveness and superiority of perlite as a growing medium. The obtained results emphasize the critical importance of proper substrate selection in hydroponic tomato cultivation and provide valuable information for producers aiming to increase both yield and fruit quality. [Lee et al., 1999].

A recent study demonstrated that a significant quantity of nutrients is retained in perlite. It was observed that the difference in nutrient uptake between the two methods gradually decreased as the crop cycle progressed. A similar reduction in nutrient retention was observed in perlite media over time. This observation suggests that the nutrient retention capacity of new perlite substrates is optimal and declines with time. [Cedeno et al., 2024].

2.3.3. Volcanic Slag

Volcanic slag is a mineral-rich natural substrate that is formed by volcanic eruptions (Figure 2.6). The subject of this study is characterized by an abundance of plant nutrients, with elevated concentrations of silica, aluminum, iron, calcium, magnesium, and potassium. [Parikh et al., 2020]. The utilization of this substance is predominantly in the agricultural sector, with applications including soil enhancement, improved drainage, pH regulation, and the facilitation of microorganism activities. [Smith & Jones, 2018]. The utilization of volcanic slag in soil has been demonstrated to exert a favorable impact on root development, as evidenced by an enhancement in water-holding capacity. [Kim et al., 2019]. It has also been demonstrated to facilitate the absorption of essential minerals, thereby satisfying the macro- and micronutrient requirements of plants. [Garcia et al., 2021].



Figure 2.6: Images of Volcanic Slag.

In the growing of tomatoes, volcanic slag can be utilized as a medium for growth in soilless or semisolid systems. The physical structure of the slag has been shown to support root development in terms of air permeability and water holding capacity, while its mineral content contributes to plant nutrition. [Lee et al., 2022]. Moreover, studies have indicated that volcanic slag can enhance plant vitality through its beneficial influence on microbial activity. [Zhang et al., 2020]. Volcanic slag is a sustainable alternative material in agricultural production. However, to achieve maximum yield, it is essential to process slag in a proper manner, in combination with

alternative fertilization methods, and to adjust the application dose with precision. [Hernandez et al., 2023].

The experimental results demonstrated that the addition of an appropriate amount of volcanic slag had a positive effect on cucumber plant growth, photosynthetic performance of the leaves, fruit yield, and quality. The yield exhibited a 24.28% increase. Concurrently, the levels of sugar, vitamin C, and soluble solids exhibited an increase, while the levels of potentially toxic nitrate decreased. The presence of volcanic slag has been shown to enhance the quality of organic matter, increase the availability of potassium and nitrogen, and adjust the pH level to more favorable conditions. [Chen et al., 2025].

2.4. Microbial Fertilizers

Biofertilizers contain beneficial microorganisms, which help to improve soil quality and increase crop yield. The application can be made to the seed, soil or leaf surface. They colonise the plant rhizosphere or internal tissues, converting nutrients into forms that plants can absorb, thereby improving nutrient availability. They also provide biocontrol by suppressing soilborne pathogens. [Nair & Brahmaprakash., 2017]. The presence of microorganisms in microbial fertilizers whether these are single or multiple is key to supporting plant growth directly or indirectly.

Microbial fertilisers accelerate the decomposition of soil organic matter, enrich microbial diversity, and contribute to a more favourable microbial environment in the soil. [Denaya et al., 2021]. Microorganisms such as arbuscular mycorrhizal fungi, *Trichoderma* species and plant growth-promoting rhizobacteria are microbial fertilisers that have been successfully used to increase stress tolerance and improve crop quality. [Fusco et al., 2022]. It is evident that biofertilizers and biostimulants exhibit several properties that serve to reduce dependence on chemical fertilisers. Furthermore, they have been shown to optimise plant-nutrient interactions, thereby increasing yield and quality. Indeed, they are a key component in the transition to a sustainable, environmentally friendly agricultural model. [Pérez-Piqueres et al., 2025].

The utilization of microbial fertilizers can be performed through diverse methodologies, including seed coating, root application, drip irrigation, and foliar spraying. The utilization of foliar application is of particular significance in soilless

farming systems, where it has been observed to enhance the effectiveness and facilitate microbial colonization in plants exhibiting a high degree of surface absorption. This method is also advantageous in terms of increasing plant resistance to stress conditions and providing growth-promoting effects. [Bhattacharyya et al., 2012].

2.4.1. Foliar Spraying Method

Foliar microbial fertilizer application is a method of biological fertilization in which beneficial microorganisms are directly sprayed onto the leaf surface of plants. The objective of this application is to enhance nutrient uptake and plant health by supporting the symbiotic relationship between plants and microorganisms. [Kumar et al., 2021]. Microbial fertilizers consist of various beneficial species, including nitrogen-fixing bacteria, phosphate solubilizing microorganisms, siderophore-producing bacteria, and plant growth-promoting microorganisms. [Vessey., 2003]. These microorganisms, when applied to the foliage, attach directly to the leaf epidermis, thereby exerting a positive influence on plant performance. This occurs through mechanisms such as phytohormone production, which increases photosynthetic efficiency, modulation of leaf stomata, and adaptation of the plant immune system. [Elsharkawy et al., 2020]. A notable advantage of foliar microbial fertilizer application is its rapid action. The microorganisms that colonize the leaf surface facilitate the rapid absorption of nutrients through the leaf tissue. Consequently, the absorption of macronutrients, particularly nitrogen and phosphorus, is enhanced, leading to a favourable impact on the rate of plant growth. [Paul et al., 2019]. Furthermore, an increased microorganism population on the leaf surface provides a natural protection mechanism against plant diseases by suppressing pathogens through competition. [Khan et al., 2017].

2.5. Plant Growth Promoting Rhizobacteria (PGPR) and Agricultural Importance

Plant Growth-Promoting Rhizobacteria (PGPR) are beneficial microorganisms that directly or indirectly affect plant growth in a beneficial way. These bacteria are found in the rhizosphere and colonise the plant root system, promoting plant growth through various mechanisms. These mechanisms include phytohormone production (auxin, gibberellin, and indole-3-acetic acid), nitrogen fixation, solubilisation of insoluble

minerals such as phosphate and potassium, siderophore production, secretion of pathogen suppressive antibiotics, induced systemic resistance (ISR), and enhancement of biotic-abiotic stress tolerance. [Denaya et al., 2021].

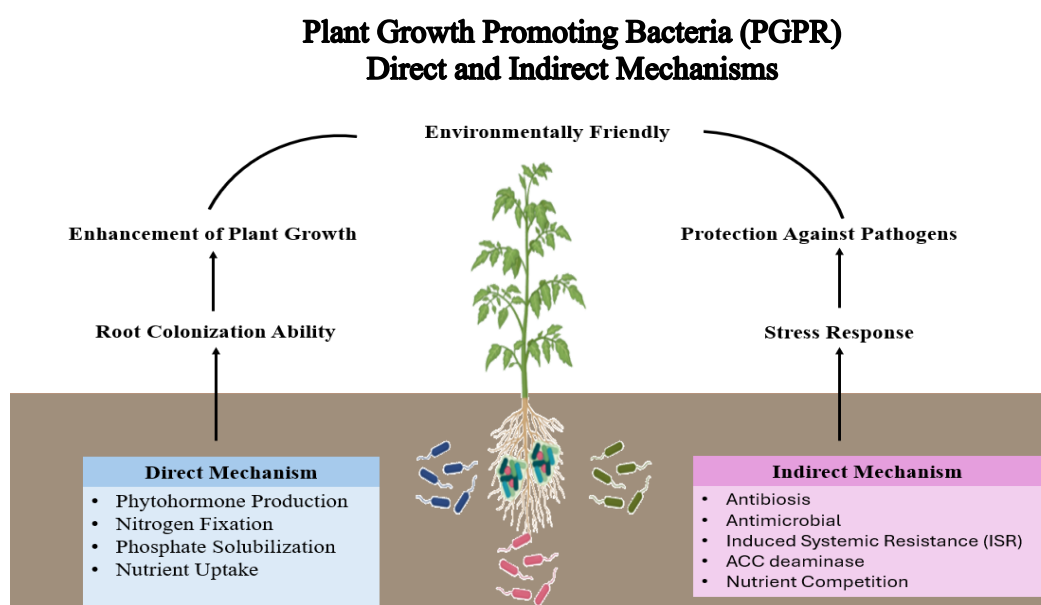


Figure 2.7: Plant Growth Promoting Bacteria (PGPR) direct and indirect mechanisms. [created with BioRender.com].

The direct effects of PGPRs are the production of compounds that stimulate plant growth directly. These include indole-3-acetic acid (IAA), gibberellic acid, auxins and volatile organic compounds. Phytohormones promote plant growth and cell differentiation, as well as facilitating nutrient uptake from the soil (Figure 2.7). Furthermore, some PGPR strains, particularly *Bacillus* species, can significantly increase shoot and root length, as well as total plant biomass, thereby improving yields. These strains have been successfully applied to important vegetable crops, such as tomatoes. [Liu et al., 2024].

In indirect mechanisms, PGPR competes with pathogenic microorganisms and prevents them from settling in the root system. PGPR also protects plants against diseases by producing antibiotics, antimicrobial compounds and siderophores. (Figure 2.) Furthermore, certain PGPR strains have been observed to produce ACC deaminase enzymes, which serve to mitigate the adverse effects of elevated ethylene hormone levels on plant growth under stress conditions. This enzyme has been shown to degrade

1-aminocyclopropane-1-carboxylic acid (ACC), the precursor compound of ethylene, thereby enhancing a plant's resistance to stress. [Pérez-Piqueres et al., 2025].

It is evident that bacteria such as *Bacillus*, *Pseudomonas* and *Rhizobium* are ideal biofortifying agents for sustainable agriculture, due to their non-toxic and environmentally friendly properties. This environmental sensitivity of PGPRs renders them a viable alternative to chemical fertilisers. Furthermore, their capacity to function as pesticides, fungicides and detoxification agents for heavy metals renders them suitable for utilisation in soil improvement. [Wang et al., 2024].

PGPRs have been demonstrated to exhibit great potential for both plant growth and environmental sustainability. The utilisation of these microorganisms in the formulation of biological fertilisers has been demonstrated to enhance agricultural productivity while concomitantly contributing to the preservation of ecosystem health by virtue of the reduction in the use of chemical fertilisers. Consequently, PGPR applications are among the most environmentally friendly and innovative solutions in contemporary agriculture. [Kong et al., 2025].

2.5.1. Nitrogen Fixation

Nitrogen is an essential processment for the growth and development of plants. Although the atmosphere contains around 78% nitrogen gas (N_2), most of this is unavailable to plants. Converting nitrogen into a form that can be taken up by plants is therefore important for agricultural production. This conversion is carried out by nitrogen-fixing microorganisms. These microorganisms reduce atmospheric nitrogen to ammonia (NH_3), which becomes available to plant roots. [Denaya et al., 2021].

Nitrogen fixing bacteria are categorised into two primary classifications: symbiotic bacteria and free-living bacteria (asymbiotic). Among the free-living nitrogen-fixing bacteria, *Azotobacter* species are particularly significant. These bacteria have been demonstrated to indirectly support plant growth by increasing soil nitrogen content. Conversely, symbiotic nitrogen fixers exhibit a mutually beneficial relationship, particularly with legume plants. One of the most prominent genera within this group is *Rhizobium*, which has been identified as a key player in the process of nitrogen fixation through the formation of nodules on the roots of legumes. In symbiotic interaction, plants secrete flavonoid compounds from their root zones, thereby

attracting microorganisms to the rhizosphere. In communication with the root microbiota, flavonoids function as signalling molecules. It is evident that *Rhizobium* bacteria can detect these signals and, in response, produce Nod factors. This interaction is known to initiate nodule formation. The process of nitrogen fixation occurs within the nodule. In addition, there are some free-living or rhizosphere-located bacteria that are capable of fixing nitrogen in non-legume plants. This group includes species such as *Arthrobacter*, *Alcaligenes*, *Mycobacterium*, *Pseudomonas*, *Bacillus* and *Azospirillum*. These microorganisms have been shown to play an active role in the nitrogen cycle within the rhizosphere, thereby promoting plant growth. [Pe' rez-Piqueres et al., 2025].

2.5.2. Phosphate and Potassium Solubilisation

Phosphorus is the second most crucial macronutrient for plant growth and development, after nitrogen. It plays a critical role in basic physiological and biochemical processes in plants, including energy transfer, cell division, root development, flowering and fruit formation. However, the long-term utilisation of chemical phosphorus fertilisers in agricultural contexts has been demonstrated to result in the conversion of over 70% of the phosphorus present in soil into inorganic forms, thereby impeding its absorption by plant life. The presence of this inorganic phosphorus in the soil has been observed to result in reactions with Fe^{3+} (iron), Al^{3+} (aluminium) and Ca^{2+} (calcium) ions, leading to the formation of insoluble phosphate compounds. These compounds are not directly absorbable by plants; consequently, despite the abundance of phosphorus in the soil, it is not made available to plants in sufficient quantities. There are various mechanisms through which the use of beneficial microorganisms capable of phosphate solubilisation can convert insoluble phosphate compounds into forms available to plants. These microorganisms include some soil bacteria (e.g. *Pseudomonas* and *Bacillus*) and fungi (e.g. *Aspergillus* and *Penicillium*). These microorganisms secrete organic acids. Examples of these acids include citric, oxalic and gluconic acid. These acids lower the soil pH. They also release insoluble phosphates. Consequently, the utilisation of phosphate solubilising microorganisms in agriculture not only augments phosphorus uptake by plants but also promotes sustainable agricultural practices by diminishing the reliance on chemical fertilizers. [Wang et al., 2024].

Potassium (K) is the third most significant macronutrient in plant nutrition, following nitrogen (N) and phosphorus (P). It is involved in vital processes such as enzyme activation, osmotic balance, photosynthesis, protein synthesis and sugar transport in plant metabolism. The effects of elevated atmospheric carbon levels on plant growth and yield have been extensively researched, and it is well documented that elevated carbon levels have a direct effect on plant growth, root development, yield and product quality. [Smith et al., 2019]. Despite the fact that potassium is present in abundance in soil, predominantly in silicate minerals, these forms are not directly utilizable by plants due to their insoluble nature. It is evident that the majority of potassium present within soil is comprised of insoluble mineral complexes, thereby resulting in its bioavailability being considerably low. The utilization of potassium solubilizing microorganisms is becoming increasingly significant. Some bacterial species, such as *Bacillus* and *Pseudomonas*, and fungal species, including *Aspergillus* and *Penicillium*, have been found to possess the capacity to convert insoluble potassium compounds into a form that is subsequently usable by plants. This conversion is achieved through the secretion of organic acids or the production of chelating agents, processes that has the potential to enhance plant nutrition and promote sustainable agriculture by decreasing the reliance on chemical fertilizers. [Wang et al., 2024].

2.5.3. Regulation of Phytohormone Production

Phytohormones are chemical messengers that regulate various physiological processes, including growth and development, in plants. These hormones regulate a variety of physiological processes, including cell division and differentiation, flowering, fruit formation, ripening, and stress responses. Plant Growth-Promoting Rhizosphere bacteria (PGPR—Plant Growth-Promoting Rhizobacteria) synthesize these hormones, develop symbiotic interactions with plants, and directly promote growth. The phytohormones produced by PGPRs play a significant role in regulating plant-microbiota interactions. The utilization of phytohormone-producing PGPR strains as biofertilizers in agriculture has been demonstrated to enhance plant growth and increase tolerance to environmental stressors. This approach offers an environmentally friendly alternative for sustainable agricultural practices. Phytohormones are primarily classified into five groups: auxin (indole-3-acetic acid, IAA), cytokines, gibberellin, ethylene, and abscisic acid. [Jiménez et al., 2023].

Auxin (IAA) is one of the most prevalent plant growth regulators and is synthesized by PGPRs, typically via tryptophan. IAA has been shown to stimulate fibrous root formation, promote root elongation, and regulate cell division and differentiation. Cytokinin, a class of phytohormones, are known to promote cellular division and have been identified as essential for the proper development of root systems and stems in plant subjects. PGPR-derived cytokines regulate processes such as fibrous rooting, stem elongation, light perception, opening of stomata, and delaying leaf senescence. Gibberellin has been shown to play a critical role in various plant processes, including the termination of seed dormancy, the initiation of germination, the promotion of stem elongation, flowering, and fruit development. It has also been observed to enhance plant resistance to environmental stresses. Ethylene has been demonstrated to be particularly effective in the process of fruit ripening. PGPRs have been demonstrated to regulate this process, albeit indirectly. Ethylene plays a multifaceted role in various physiological processes, including root development, defoliation, phosphorus utilization efficiency, and stress responses. [Wang et al., 2024].

2.5.4. Iron Carrier Production

Iron (Fe) is a vital microelement for plant growth and development. [Smith et al., 2021]. Specifically, it plays a pivotal role in fundamental metabolic processes, including respiration, photosynthesis, and nitrogen fixation. However, the predominant form of iron in soil is Fe^{3+} (ferric), and under conditions of alkaline pH, it undergoes conversion into insoluble iron oxide compounds, which are not absorbed by plants. This phenomenon has been demonstrated to exert a deleterious effect on the growth of plants. A solution to this problem is the production of low-molecular-weight iron-chelating compounds, called siderophores, by plant growth-promoting rhizosphere bacteria (PGPR—plant growth-promoting rhizobacteria). Siderophores have been shown to enhance the solubility of Fe^{3+} ions by mobilizing insoluble iron compounds present within the soil, thereby facilitating the uptake of iron by plant roots. Siderophores synthesized. [Zhao et al., 2025].

PGPRs have been shown to promote iron uptake in plants and to positively affect plant health by maintaining soil microbial balance. Consequently, by enhancing iron bioavailability, these microorganisms optimize the nutrient balance of plants and provide a sustainable boost to agricultural productivity.

3. EXPERIMENT

3.1. Materials

3.1.1. Microorganism Strains

Six of the bacteria (*Pseudomonas* sp., *Acinetobacter* sp., *Enterobacter* sp.) that support plant growth, fix nitrogen, solubilise phosphate, form biofilms and siderophores (*Pseudomonas* sp., *Acinetobacter* sp., *Enterobacter* sp.) were isolated from wheat growing cultivation areas (Konya, Ankara Tekirdağ, Ankara, Konya, Sivas and Diyarbakir) within the framework of the TÜBİTAK project (121O649) and obtained from the stocks of the Microbiota Laboratory of the Department of Molecular Biology and Genetics, Gebze Technical University.

3.1.2. Plant Material

The experimental treatment was applied to tomatoes cultivated in a soilless environment within the project greenhouse operated by the Darica District Governorship.

3.1.3. Chemicals and Devices

The devices used in the thesis study are shown in Table 3.1, and the chemicals used in Table 3.2.

Table 3.1.: Devices used in thesis.

Devices	Brand
Laminar Cabin	Heraeus
Spectrophotometer	Shimadzu
Centrifugal	MPW MED.INSTRUMENTS
Incubator	Nüve
Precision Balance	EW 220-3NM
Magnetic Mixer	Daihan Scientific
Autoclave	Nüve 90
pH Meter	Hanna Instruments,
Biosafety Cabinet	Tezsan
+4 °C Refrigerator	Vestel
-20 °C Deep Freezer	Bosch
-80 °C Deep Freezer	Thermo Scientific

Table 3.2: Chemicals used in the thesis.

Chemicals	Brands
Gram Staining Kit	Sigma Aldrich
Ethyl Alcohol	Merck
Glycerol	Sigma Aldrich
Sodium Chloride (NaCl)	Sigma Aldrich
Immersion Oil	Merck
Phenylphthalein	Merck
Acetone	Merck
Hexane	Riedel-de Haen
Ethanol	Merck
Sodium Hydroxide	Sigma Aldrich

3.2. METHODOLOGY

3.2.1. Growing Tomato in Greenhouse Conditions

In this study, tomato (*Solanum lycopersicum L.*) plants were cultivated in a soilless agriculture greenhouse under the administration of Darıca District Governorate (Figure 3.2.) The experiment involved the use of three distinct growing media: cocopeat, perlite and volcanic slag. The experimental design involved the establishment of control and microbial fertiliser treatment groups for each substrate medium, with each group comprising nine replications. In total, 54 pots were utilised in the experiment ($3 \text{ substrates} \times 2 \text{ treatments} \times 9 \text{ replicates} = 54 \text{ pots}$). The plants were cultivated under controlled greenhouse conditions. The greenhouse environment was maintained at a daytime temperature of 28°C and a nighttime temperature of 18°C , and the photoperiod was set at 16 hours of light and 8 hours of darkness. The humidity level was maintained within the range of 50% to 60%.



Figure 3.1: Image of tomatoes in the first week of microbial fertiliser application in the greenhouse.

3.2.2. Preparation of Bacterial Cultures

Bacterial isolates obtained from stocks were inoculated into Luria-Bertani (LB) liquid medium, prepared under sterile conditions, and incubated overnight (approximately 16-18 hours) in a shaker incubator at 37°C . Samples were obtained from the growing

cultures and inoculated by spreading method into Petri dishes containing LB solid medium. The petri dishes were then placed into an incubation incubator, which was set to maintain a temperature of 37 °C. The samples were left to incubate for a period of 24 hours.

3.2.3. Gram Staining

Gram staining is a fundamental and prevalent laboratory technique employed for the differentiation of bacteria according to structural variations in their cell walls. Gram-positive bacteria: The peptidoglycan layer is characterised by its thickness and multilayered structure. This configuration is instrumental in facilitating the retention of the dye, thereby yielding a purple colouration. Gram-negative bacteria: The peptidoglycan layer of these organisms is known to be thin, and they are also characterised by an outer membrane that is rich in lipids. The outer membrane of the stain is known to be difficult to retain; therefore, the counterstain applied in the final step gives them a pink-red colour. The following are the primary steps:

The application of primary dye (crystal violet) results in the staining of cells with a purple colouration. The addition of mordant (lugol/iodine) is integral to the preservation of the dye within the cell. The process of decolourisation can be achieved through the utilisation of either ethanol or a mixture of ethanol and acetone. The presence of a thick peptidoglycan layer in Gram-positive bacteria results in the absorption of the dye, thereby maintaining the purple colouration. The outer membrane of Gram-negative bacteria is known to dissolve, resulting in the release of the dye and consequent loss of colour.

A single bacterial colony was selected from each Petri dish containing LB agar and transferred onto a slide. A quantity of distilled water (dH₂O) was spread in a uniform layer and the preparations were left to dry in the air. The dried slides were then subjected to a process of fixation, whereby they were passed rapidly through the flame on multiple occasions. The Gram-stained preparations were subjected to the following steps, respectively:

The slides were subjected to staining with crystal violet for a period of one minute, after which they were thoroughly washed with distilled water. The subjects were then administered a solution of iodine (Lugol's solution) for a period of one minute, after

which they were rinsed again with distilled water. In the decolourisation step, 96% ethyl alcohol was applied to the preparations, left for 10-15 seconds and then washed again with distilled water. In order to achieve the desired counterstaining effect, the preparations were subjected to a staining process using safranin for a duration of 10-30 seconds. This was followed by a thorough rinsing step with distilled water to ensure the removal of any residual staining. The stained preparations were then desiccated on blotting paper prior to being examined under a light microscope at 100× magnification using immersion oil.

3.2.4. Preparation of Bacterial Suspensions and Formation of Microbial Consortium

Bacterial isolates were inoculated into 50 mL sterile Falcon tubes containing Luria-Bertani (LB) liquid medium. The tubes were then incubated overnight at 37 °C in a shaker incubator. Following this, the tubes were subjected to a process of centrifugation, resulting in the removal of the supernatant fluid. The formation of a homogeneous suspension was achieved by the addition of a sterile 0.9% saline solution to the pelleted bacteria. The suspensions were thoroughly mixed by means of vortexing. For each bacterial isolate, 250 mL of suspension was prepared, and the bacterial density was adjusted to MacFarland 0.5 standard. These procedures were performed identically for all bacterial isolates, and subsequently, all suspensions were amalgamated to constitute a microbial consortium (Figure 3.2)

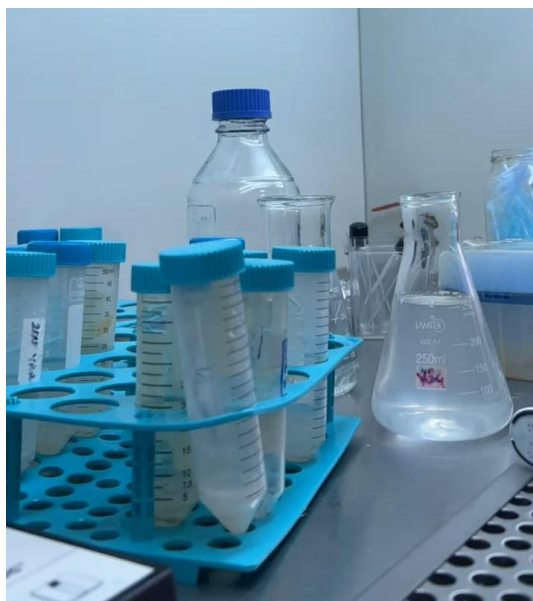


Figure 3.2.: Preparation of Microbial Consortium.

3.2.5. Application of Microbial Consortium to Tomato Plants

The prepared microbial consortium was applied to the microbial fertiliser-treated groups of three different growing media (cocopeat, perlite and volcanic slag), each consisting of nine replicates. The application was initiated during the flowering period of the plants and was carried out by spraying the leaf surface (foliar application) method, with a volume of 50 mL per sample. Microbial fertiliser was applied on two occasions during the experimental period, at weeks 12 and 14.

3.2.6. Measurement of Plant Stem Length

The stem length of the cultivated tomato plants was measured at regular weekly periods starting from the 12th week, with the final measurements taken at the 18th week.



Figure 3.3: Pre-harvest image of tomato plants in the greenhouse in the final week.

3.2.7. Chlorophyll Analysis

After measuring the fresh weights of leaf sections taken from each experimental group, the samples were placed in Eppendorf tubes. Two microlitres of acetone were added to each tube, which was then covered with aluminium foil and protected from light. The samples were kept in the refrigerator overnight at 4 °C for extraction (Figure 3.2.5). After this time, 1 μ L of each sample was taken and measured at wavelengths of 661.6 nm, 644.8 nm and 470 nm in a spectrophotometer. The formula used for the calculation of chlorophyll and carotenoid amounts is given below (3.1). [Lichtenthaler, 1987].

$$\begin{aligned}
 \text{Chlorophyll a (Ca)} &= (11.24 \times A_{661.6}) - (2.04 \times A_{644.8}) \\
 \text{Chlorophyll b (Cb)} &= (20.13 \times A_{644.8}) - (4.19 \times A_{661.6}) \\
 \text{Carotenoid (Cx+c)} &= [(1000 \times A_{470}) - (1.9 \times \text{Ca}) - (63.14 \times \text{Cb})] / 214
 \end{aligned}
 \tag{3.1}$$

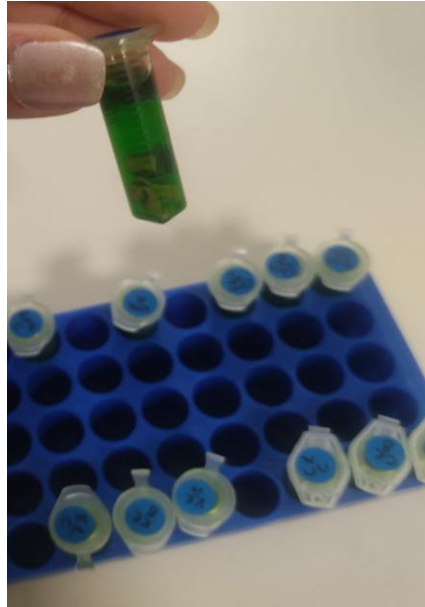


Figure 3.4: Chlorophyll analysis of leaf section.

3.2.8. Total Tomato Yield by Treatment (kg/decare)

Fresh weights of 9 different tomato bunches randomly selected from each experimental group were measured using a precision balance. The means and standard errors of the obtained data were statistically calculated using SPSS program. Considering that a total of approximately 2000 plants were grown in greenhouse conditions and at least 10 harvests were realized, the average panicle weight was multiplied by these numerical data; then the result obtained was converted to kg/ha to express the amount of yield per decare (da) and total yield was calculated.

3.2.9. Tomato Fresh Weight Measurement

The fresh weights of tomatoes in each experimental group were measured in 3 replicates using a precision balance (Figure 3.5).

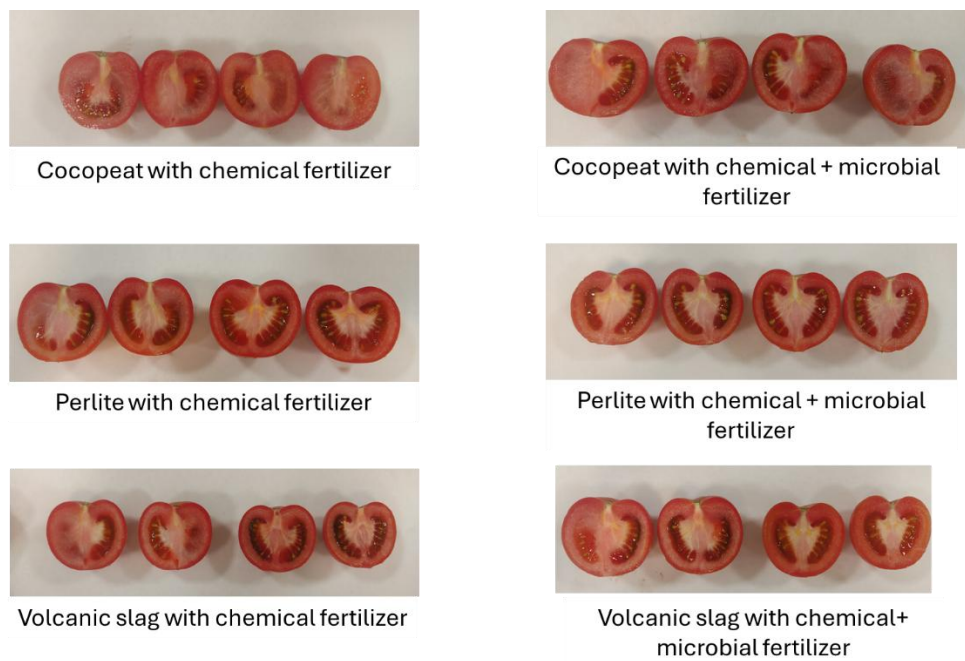


Figure 3.5: Cross-sections of tomatoes from the experimental groups.

3.2.10. Tomato Dry Weight Measurement

The dry weights of the samples were determined through a process of cutting and drying. Three tomato samples from each group were cut in half and dried in an oven at 70 °C for five days (Figure 3.6). After this, the dry weight of each sample was measured using a precision balance and recorded.



Figure 3.6: Drying procedure of tomato samples for dry weight analysis.

Three fruits from each group were cut and oven-dried at 70 °C.

3.2.11. pH Measurement

In measuring the pH of the samples, the pH meter probe was inserted into the halved samples, and the pH was measured and recorded.

3.2.12. A study of the Titrimetric Quantification of Citric Acid in Tomato Fruits

Two fruits were harvested from each experimental group, yielding a total of 12 samples. One of these samples was meticulously cut and weighed and subsequently utilized in a titration analysis to determine its acidity. Following the homogenization of the weighed fruit samples, they were dissolved in 100 mL of distilled water and filtered through filter paper to obtain a clear and colorless juice. A volume of 20 mL of juice from each sample was transferred into a beaker, followed by the addition of approximately two drops of 1% phenolphthalein indicator. The prepared mixtures were placed in a magnetic stirrer and 0.1 N NaOH solution was added dropwise. The titration process was terminated when the mixture turned pink, and the volume of NaOH consumed was recorded. The citric acid content of the fruit samples was determined by calculating the mean of the three measurements using the following formula (3.2): [Anonim, 2002].

$$\% \text{Titrateable Acidity} = \frac{N \times V \times F \times mEq \times 100}{G} \quad (3.2)$$

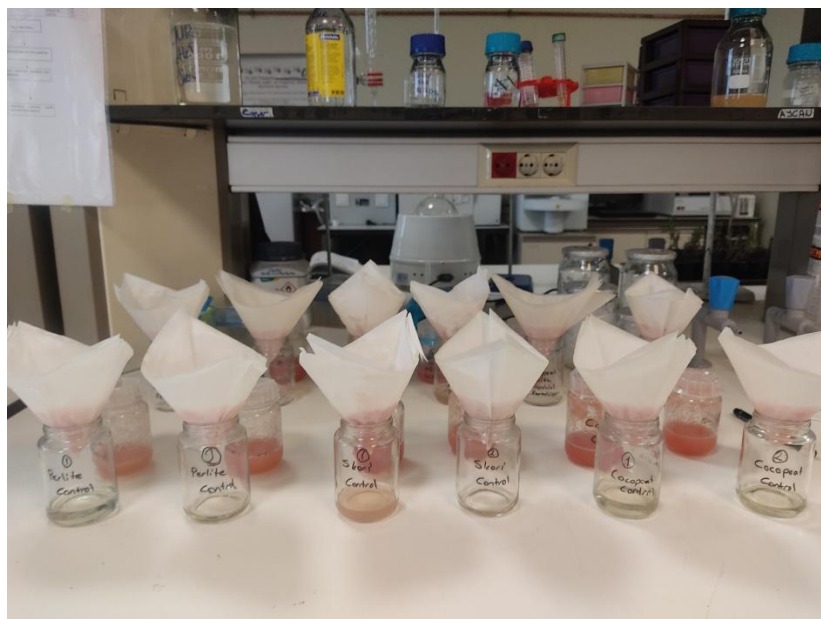


Figure 1.7: Titration acidity analyses in tomatoes.

3.2.13. Lycopene Analysis

The tomato was then blended to achieve homogeneity. A solution was prepared containing 25 mL of hexane, ethanol, and acetone in a volumetric ratio of 2:1:1:1. A total of 25 mL of solvent was added to 1 gram of the tomato sample, which was then stored in the dark for a period of 30 minutes. Following a 30-minute incubation period, 10 mL of dH₂O were added, and the mixture was placed in the ultrasonicator for a further 10 minutes. After phase separation (figure 3.8), the measurement of the solution's upper layer (supernatant) was obtained using a UV spectrophotometer at 472 nm and 502 nm, respectively (figure 3,9). [Alda et.al., 2009].



Figure 3.8: Image of tomato samples after phase separation.

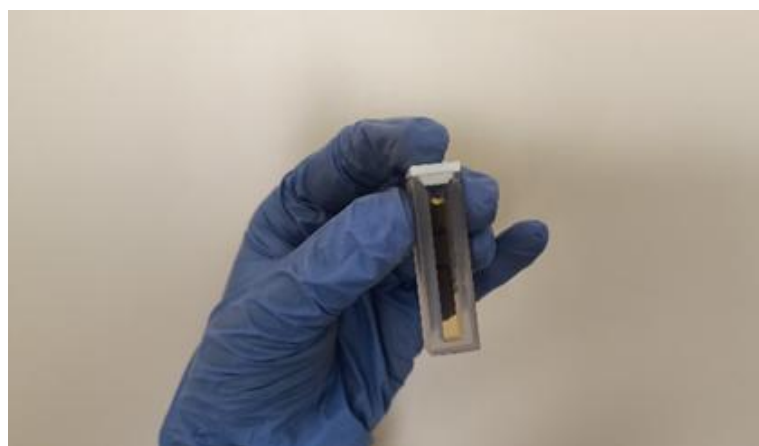


Figure 3.9: Measurement of supernatants in a UV spectrophotometer.

3.2.14. Organoleptic Analysis

The organoleptic properties of the fruits, including taste, aroma, textural characteristics, mouthfeel, peel thickness, color, and general taste, were evaluated through sensory analysis sessions. These sessions were conducted with the participation of a total of 20 volunteer tasters aged 20-50 years. Participants were instructed to rinse their mouths with water before the tasting procedure. Tomato samples from each group of the experiment were sliced and arranged on plates numbered from 1 to 6. Participants were instructed to sample the tomatoes and subsequently rate their preferences on a scale ranging from 1 (lowest) to 5 (highest) for each parameter.

The following parameters were evaluated:

- Taste: The taste sensation of the fruit on the tongue, for example sweetness or sourness.
- Aroma: Sensory characteristics perceived by the smell of the fruit.
- Texture: The physical structure of the fruit, such as roughness or softness, which is felt during chewing.
- Mouthfeel: The general sensory sensation of the fruit in the mouth, such as freshness, softness or stickiness.
- Peel Thickness: The thickness of the peel and the mouthfeel of the fruit.
- Color: The intensity and brightness of color in the appearance of the fruit.
- Overall Acceptability: The extent to which the fruit is generally liked by the consumer.

After the tasting test was completed, the experimental group to which the numbered samples belonged was shared with the participants. The data obtained as a result of these evaluations allowed an objective sensory comparison of fruit quality.

3.2.15. Statistical Analysis

From week 12 to week 18, the experimenters measured plant height on a weekly basis in each experimental group. A comprehensive analysis was conducted to assess the freshness and dryness of the fruit, as well as to determine the pH values, chlorophyll content obtained from leaves, and acidity values. The pH values were determined using the titration method, a technique that involves the use of a pH meter to accurately measure the pH of a solution. The chlorophyll content was determined by measuring the total chlorophyll content in the leaves using a spectrophotometer, a tool that utilizes light absorption to determine the concentration of chlorophyll. The acidity values were determined by titration, a method that involves the addition of a small amount of a strong acid to a solution until the desired pH is reached. The statistical analysis of the obtained data was conducted using the ANOVA with least significant difference (LSD) test to ascertain the significant differences ($P \leq 0.05$) between the groups. The results of this analysis were interpreted in accordance with the findings obtained.

4. RESULTS

4.1. Determination of Morphological and Cellular Characteristics of Bacterial Isolates Used in the Consortium

Six isolates were selected from those obtained from the TÜBİTAK project (121O649) to form a microbial consortium. A comparison was made between the previously identified bacteria and those obtained from the isolates to determine the risk of contamination in the samples. This comparison was made using morphological and cellular tests.

4.1.1. Morphological Examination of Isolates

The colony morphology of the isolates was analysed. The results were presented within Table 4.1 and Figure 4.1.

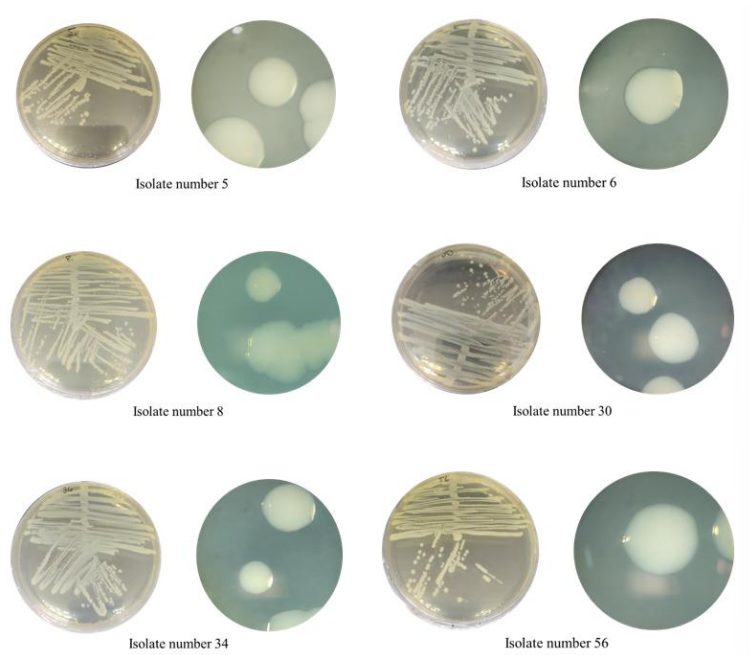


Figure 4.1: Colony morphology images of the isolates on LB agar plate and stereo microscope.

Table 4.1: Assessment of the colony morphology of the isolates.

Isolate Number	Color	Shape	Margin	Height	Surface	Size	Appearance	Optical properties
5	White	Circular	Entire	Flat	Smooth	Medium	Shiny	Translucent
6	White	Circular	Entire	Flat	Smooth	Medium	Dull	Opaque
8	White	Circular	Entire	Flat– raised	Smooth	Small	Dull	Opaque
30	White	Circular	Entire	Flat	Smooth	Medium	Shiny	Translucent
34	White	Circular	Entire	Flat	Smooth	Medium- large	Dull	Opaque
56	White	Circular	Entire	Flat – raised	Undulate	Small	Shiny	Translucent

The bacterial isolates utilised in the study were cultivated on LB agar medium, and their colony morphology was meticulously evaluated. As demonstrated in Table 5, the evaluation results indicated that all isolates were white in colour, circular in shape and had entire (straight) margins.

With regard to colony height, isolates 8 and 56 exhibited a distinct height compared to the other isolates. With surface characteristics considered, it was evident that the vast majority of isolates exhibited comparable surface morphologies, with the exception of isolate 56.

In terms of colony size, isolates 5, 6 and 30 exhibited comparable characteristics, while isolates 8 and 56 demonstrated equivalent dimensions. However, isolate 34 exhibited a distinct size from all other isolates.

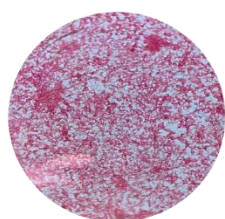
With consideration for colony appearance, isolates 5, 30 and 56 exhibited similar characteristics, while isolates 6, 8 and 34 showed similar characteristics. A similar situation was also observed for optical properties (translucency/matte); isolates 5, 30 and 56 were in the same group, while isolates 6, 8 and 34 were in a different group.

4.1.2. Gram Staining Results of Isolates

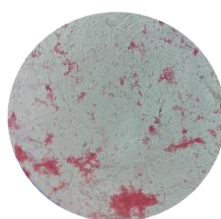
The identification of the isolates utilised in this study was performed by 16s rDNA sequence analysis, as detailed in Senanur Acet's thesis (2023). As demonstrated in Table 4.2, the BLAST results indicated the successful identification of the taxonomic classification of each bacterium. Gram staining was performed to determine whether the identified bacteria were at risk of contamination prior to use (Figure 4.2). The results were confirmed with the identified bacterial samples.

Table 4.2: Identification information of the isolates that were used.

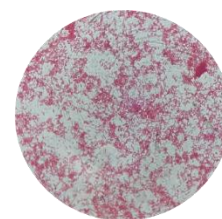
Isolate Number	Gram staining	Bacterial Shape	Taxonomic identification
5	Gram(-)	Coccobacillus	<i>Pseudomonas</i> sp.
6	Gram(-)	Bacillus	<i>Pseudomonas</i> sp.
8	Gram(-)	Coccus	<i>Acinetobacter</i> sp.
30	Gram(-)	Bacillus	<i>Enterobacter</i> sp.
34	Gram(-)	Coccobacillus	<i>Enterobacter</i> sp.
56	Gram(-)	Coccobacillus	<i>Enterobacter</i> sp.



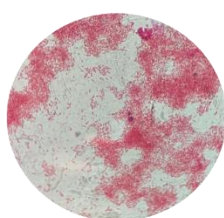
Pseudomonas sp.



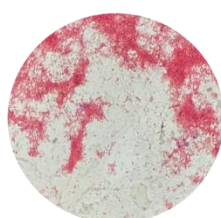
Pseudomonas sp.



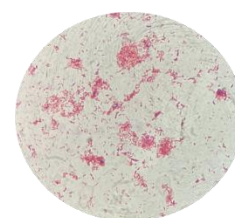
Acinetobacter sp.



Enterobacter sp.



Enterobacter sp.



Enterobacter sp.

Figure 2.2: The results of the gram staining of the isolates were identified according to taxonomic classification. The following samples were identified as *Pseudomonas* sp. (5, 6), *Acinetobacter* sp. (8), and *Enterobacter* sp. (30,34, and 56).

Gram staining results of the bacteria used, and previously isolated bacterial samples were compared. According to the results obtained, all isolates used in the study showed Gram-negative characteristics. According to morphological evaluations, isolate 6 was bacillus and isolate 8 was coccus; the other isolates had coccobacillus morphology. According to taxonomic estimations, it was determined that they belonged to *Pseudomonas* sp., *Acinetobacter* sp., and *Enterobacter* sp. species, respectively.

4.2. Evaluation of the Effects of Microbial Consortium on Vegetative Growth of Tomato Plant

The initial measurements of plant height were obtained during the 12th week of the experiment, when the plants were in the flowering stage. These measurements were continued until the 18th week. In addition, the number of flowers and fruits in the plant was recorded on a weekly basis for the purpose of comparison. In order to examine the effect of fertilisation on the leaves, leaf chlorophyll was determined.



Figure 4.3: Weakly growth of tomato in cocopeat with chemical fertilizer.



Figure 4.4: Weakly growth of tomato in cocopeat with chemical fertilizer + microbial fertilizer.

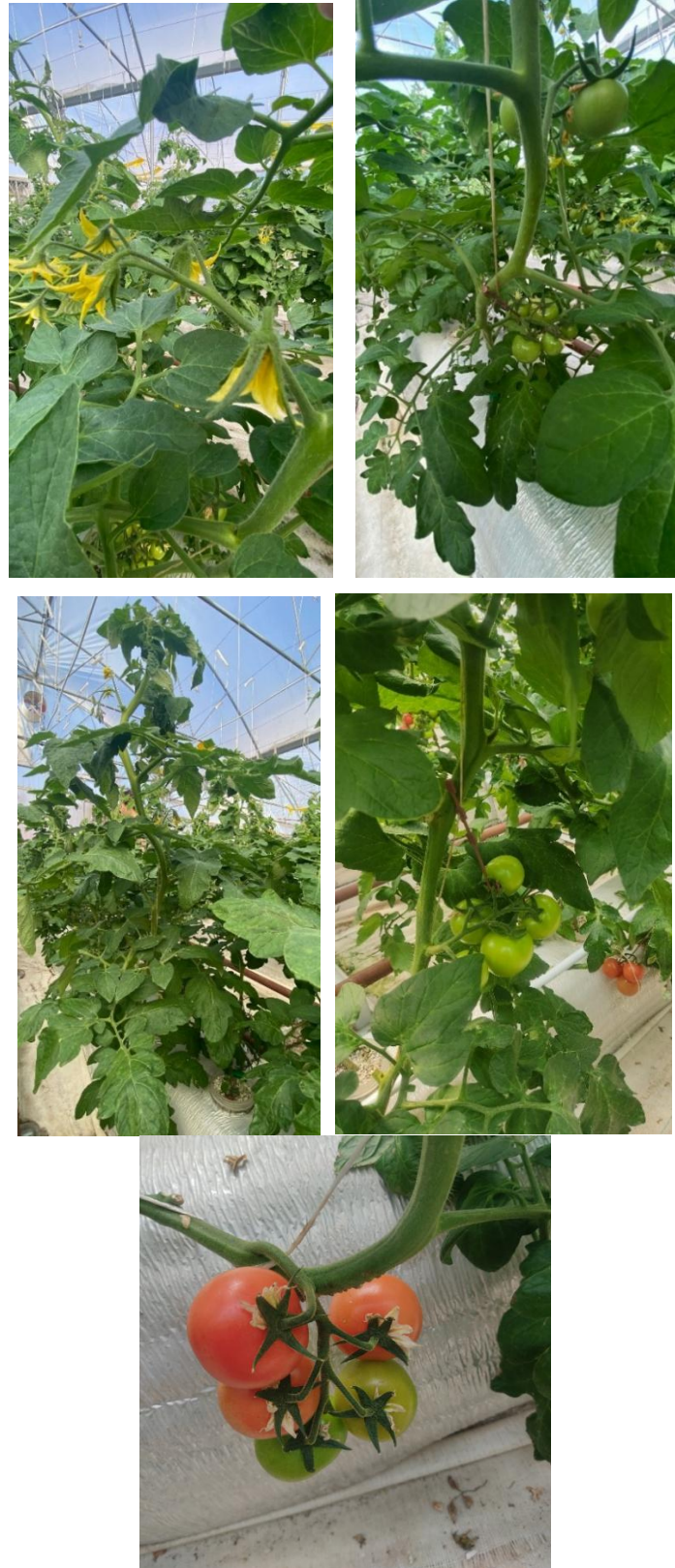


Figure 4.5: Weakly growth of tomato in perlite with chemical fertilizer.



Figure 4.6: Weakly growth of tomato in perlite with chemical fertilizer + microbial fertilizer.



Figure 4.7: Weakly growth of tomato in volcanic slag with chemical fertilizer.



Figure 4.8: Weakly growth of tomato in volcanic slag with chemical fertilizer + microbial fertilizer.

4.2.1. Measurement of Plant Stem Length

The experimental period began in the 12th week of plant growth, and plant height measurements were terminated at the time of harvest in the 18th week. Comparative graphs were created to illustrate the effect of microbial fertilisers applied to three

different substrate environments on the length of tomatoes. These comparative graphs are presented in Figures 4.9, 4.10 and 4.11.

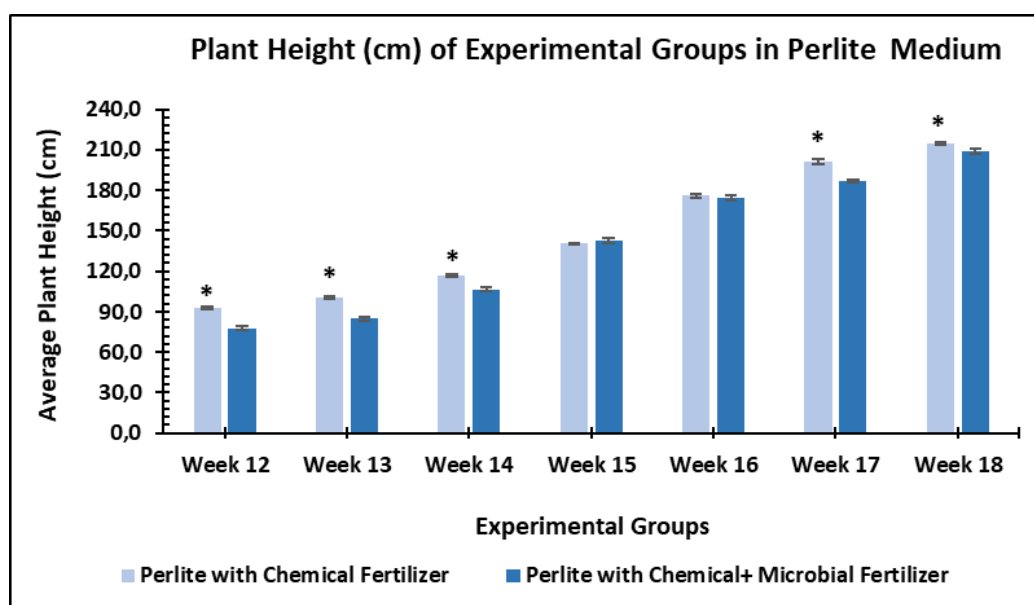


Figure 4.9: Weekly height growth comparison of tomatoes grown in perlite medium between control and microbial fertiliser treated groups. According to LSD test, shows that there is a statistical difference ($p \leq 0.05$) between the trials.

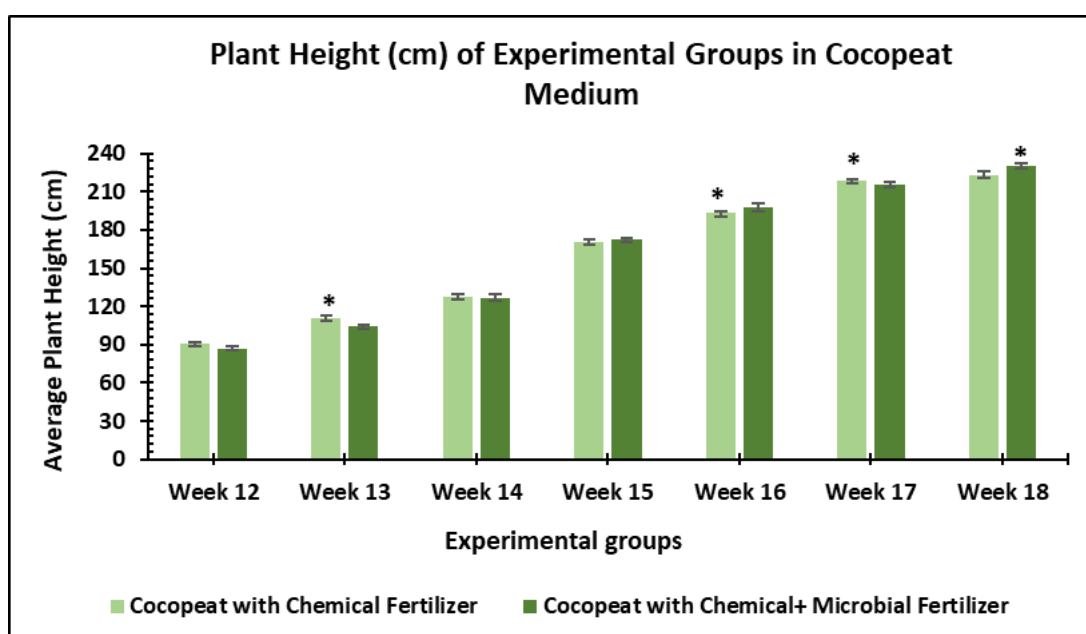


Figure 4.10: Weekly height growth comparison of tomatoes grown in cocopeat medium between control and microbial fertiliser treated groups. *Shows statistical difference $p \leq 0.05$.

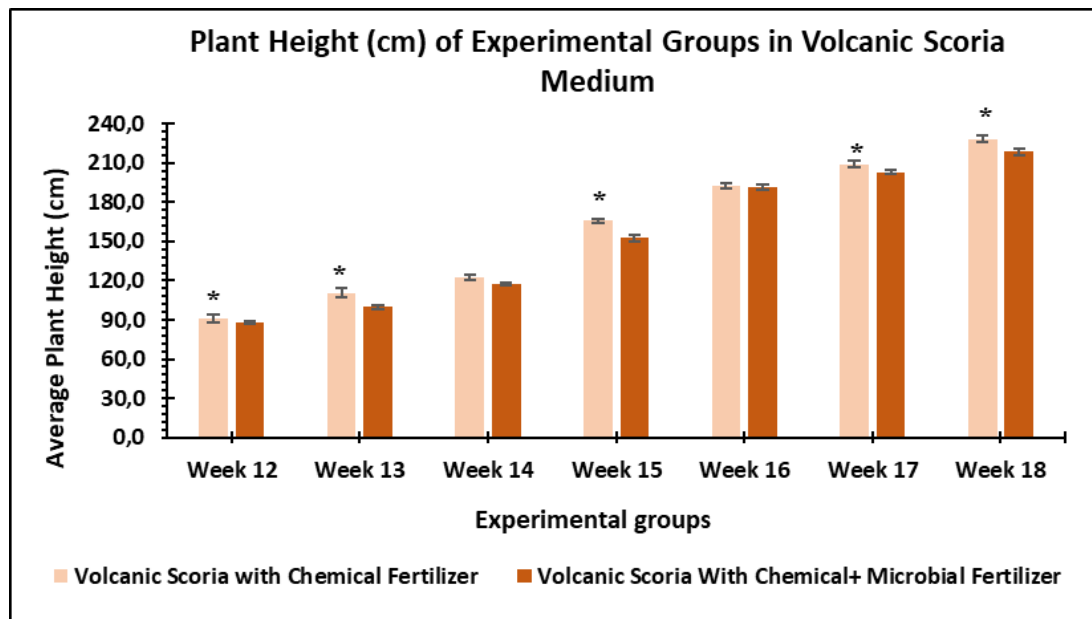


Figure 4.11: Weekly height growth comparison of tomatoes grown in volcanic slag medium between control and microbial fertiliser treated groups. *Shows statistical difference $p \leq 0.05$.

The comparison of weekly data on plant height differences collected during the experiment is shown in Table 4.3. The results indicate that the application of microbial fertilizer did not exert a deleterious effect on plant height development. Furthermore, the increases in plant height observed in certain weeks were concomitant with the application of microbial fertilizer. It was also observed that plant height was lower in the substrate media treated with microbial fertilizer from the beginning of the measurements. In the 15th and 16th weeks, the plant height exhibited an increase in the perlite and cocopeat microbial fertilizer groups in comparison to the control group. At week 16, a significant increase in plant height was observed in the cocopeat microbial fertilizer group compared to the control groups, indicating a statistically significant difference ($p \leq 0.05$). A subsequent comparison of the data obtained from all groups revealed a statistically significant increase in the experimental group cultivated in cocopeat medium and treated with microbial fertilizer during the final week. A subsequent comparison of the data obtained from all groups revealed a statistically significant increase in the experimental group cultivated in cocopeat medium and treated with microbial fertilizer during the final week.

Table 4.3: Weekly Growth Differences in Tomato Plants.

Weekly Growth Differences of Tomato Plants According to Substrate Types and Microbial Fertilizer Application						
(cm)						
	Differen ce (Week 13 – Week 12)*	Differen ce (Week 14 – Week 13)*	Differen ce (Week 15 – Week 14)	Differen ce (Week 16 – Week 15)	Differen ce (Week 17 – Week 16)	Differen ce (Week 18 – Week 17)
Perlite with Chemical Fertilizer	7,3	6	24,1	35,4	25,2	13,7
Perlite with Chemical + Microbia l Fertilizer	7	21,9	35,9	31,7	12,4	22,3
Cocopeat with Chemical Fertilizer	20,5	17	42,8	22,7	24,9	4,7
Cocopeat with Chemical + Microbia l Fertilizer	17,1	22,9	45,3	25,9	17,4	14,4
Volcanic Slag with Chemical Fertilizer	19,3	11,6	43,7	26,6	16,6	19,5
Volcanic Slag with Chemical + Microbia l Fertilizer	12,1	17,9	35	38,7	11,9	15,4

*In the 12th and 14th weeks, microbial fertilizer was treated.

4.2.2. Determination of Chlorophyll Content in Plant Leaves

The effect of the foliar application of microbial fertiliser on chlorophyll content in leaves was evaluated by determining the levels of chlorophyll a, chlorophyll b, and carotenoid in freshly collected leaf samples obtained from each of the experimental groups Table 4.4.).

Table 4.4: Chlorophyll a, chlorophyll b and carotenoid amounts obtained from leaf samples of experimental groups.

	Chlorophyll a (Mean±SE)	Chlorophyll b (Mean±SE)	Carotenoid (Mean±SE)
Perlite with Chemical Fertilizer	25.41±1.09 ^{ab}	31.74±0.66 ^c	8.15±0.76 ^{ab}
Perlite with Chemical+ Microbial Fertilizer	21.66±0.33 ^c	43.80±0.92^a	5.11±0.20 ^c
Cocopeat with Chemical Fertilizer	23.45±0.56 ^{bc}	37.69±3.91 ^b	7.36±1.15 ^b
Cocopeat with Chemical+ Microbial Fertilizer	28.28±1.89^a	36.33±4.06 ^b	5.84±0.58 ^{bc}
Volcanic Slag with Chemical Fertilizer	26.15±0.43 ^{ab}	23.82±1.20 ^d	9.55±0.38^a
Volcanic Slag with Chemical+ Microbial Fertilizer	24.98±0.50 ^b	30.69±5.62 ^c	6.74±0.21 ^{bc}

A comparison of the data in Table 4.4 indicated that the highest levels of chlorophyll a were observed in the cocopeat environment where microbial fertiliser had been applied. The maximum chlorophyll b concentration was observed in the perlite group that received microbial fertiliser. Following analysis of carotenoid content, the control group that had been cultivated in a volcanic slag medium was found to demonstrate the highest levels. However, cocopeat with Chemical +microbial fertilizer group was the lowest level of the carotenoid amount.

4.3. Investigation of the Effect of Microbial Consortium on Tomato Fruit Yield Parameters

After harvesting, various physico-chemical analyses were carried out on randomly selected tomato bunches from each group. Initially, the total weights of the bunches in each sample group were determined. Then, the fresh and dry weights of individual

tomato fruits were measured, and their water content was indirectly evaluated. In the scope of the internal quality parameters of tomatoes, pH values were determined, lycopene and citric acid contents were measured by quantitative analysis. These are among the important phytochemicals reflecting nutritional and functional properties. The present study utilized a set of measurements to comparatively assess the effects of varying growing environments and microbial fertilizer applications on the physical properties and biochemical composition of tomatoes.

4.3.1. Measurement of Total Yield of Tomato Plant

The total yield obtained from nine separate bunch samples from each experimental group was calculated. Following a comprehensive examination of the data, it was determined that the highest total yield value was achieved by the group that utilized volcanic slag chemical + microbial fertilizer. The lowest total yield value was observed in the group receiving cocopeat chemical fertilizer.

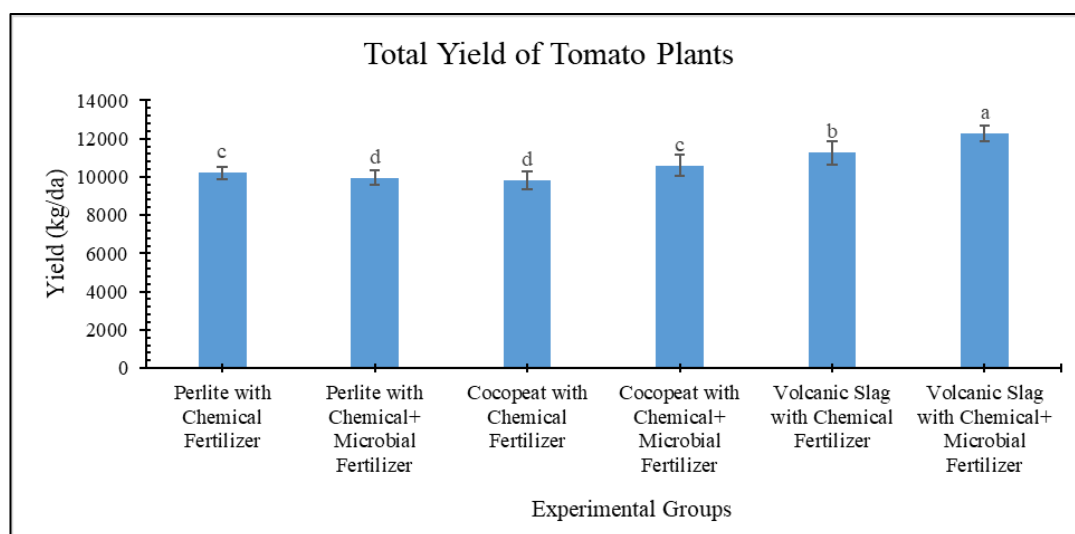


Figure 4.12: Total yield of tomato plants of per kg/da. According to LSD test, a,b,c and d show that there is a statistical difference ($p \leq 0.05$) between the trials.

4.3.2. Fresh Weight Measurements of Tomato Fruits

The fresh weights of tomato samples from each experimental group were measured in three replicates, and the results are presented in Table 4.5. The findings revealed that

the application of chemical and microbial fertilizers in perlite resulted in the highest fresh fruit weight among the study groups. However, the lowest fresh weight was observed in the group treated with both chemical and microbial fertilizers in volcanic slag medium. A statistical analysis of the experimental groups indicated significant differences ($p \leq 0.05$) among them in each substrate medium.

Table 4.5: Fresh weight of tomato in each experimental group.

Experimental Group	Tomato Fruits Fresh Weight (g) (Means $\pm$ SE)
Perlite with Chemical Fertilizer	107.00 $\pm$ 1.69 ^b
Perlite with Chemical+ Microbial Fertilizer	113.28 $\pm$ 5.43 ^a
Cocopeat with Chemical Fertilizer	103.78 $\pm$ 3.72 ^c
Cocopeat with Chemical+ Microbial Fertilizer	105.26 $\pm$ 3.04 ^b
Volcanic Slag with Chemical Fertilizer	107.36 $\pm$ 4.30 ^a
Volcanic Slag with Chemical+ Microbial Fertilizer	102.67 $\pm$ 3.93 ^c

4.3.3. Dry Weight Measurements of Tomato Fruits

The dry weights of the tomato samples were determined, and the resulting data were then compared among the various experimental groups (Table 4.6). The analysis of the measurements revealed that the group grown in volcanic slag medium with chemical and microbial fertilizers exhibited the highest dry matter content. The second group was grown in perlite medium. The lowest dry weight was observed in the group treated with both chemical and microbial fertilizers in cocopeat medium. These results suggest that the application of different growing media and types of fertilizers may have a significant impact on the dry matter accumulation of tomatoes.

Table 4.6: Dry weights of tomatoes of experimental groups.

Experimental Groups	Tomato Fruits Dry Weight (g) (Means±SE)
Perlite with Chemical Fertilizer	7.71±0.14 ^a
Perlite with Chemical+ Microbial Fertilizer	7.72±0.55 ^a
Cocopeat with Chemical Fertilizer	7.46±0.49 ^b
Cocopeat with Chemical+ Microbial Fertilizer	6.65±0.12 ^c
Volcanic Slag with Chemical Fertilizer	7.38±0.22 ^b
Volcanic Slag with Chemical+ Microbial Fertilizer	8.00±0.49 ^a

4.3.4. Determination of pH Value of Tomato Fruits

The pH values of tomato fruits were measured, and the resulting data were subjected to statistical analysis. The pH measurements were made for three replicate samples taken from each experimental group, and the results are presented in Table 4.7 together with the standard error averages. The statistical analysis of these data enabled the investigation of the pH disparities between the groups. Consequently, the potential effects of increasing applications of growing media and fertilizer on fruit pH were examined.

Table 4.7: pH values measured for each group.

Experimental Group	pH Values (Mean±SE)
Perlite with Chemical Fertilizer	4.22±0.03 ^{bc}
Perlite with Chemical+ Microbial Fertilizer	4.37±0.04 ^b
Cocopeat with Chemical Fertilizer	4.70±0.05 ^a
Cocopeat with Chemical+ Microbial Fertilizer	4.18±0.06 ^c
Volcanic Slag with Chemical Fertilizer	4.23±0.01 ^{bc}
Volcanic Slag with Chemical+ Microbial Fertilizer	4.66±0.08 ^a

When the pH values of tomatoes are examined, the highest pH value is seen in the group that was treated with cocopeat chemical fertilizer. The group with volcanic slag chemical fertilizer + microbial fertilizer has the second highest pH value. The experimental group with the lowest pH value is the group with cocopeat chemical + microbial fertilizer.

4.3.5. Determination of Lycopene Content in Tomato Fruits by Spectrophotometric Method

The content of lycopene in the samples of tomatoes was determined by spectrophotometric analysis at 472 nm and 502 nm wavelengths (Figure 4.13). This analysis was performed using a spectrophotometer. The results obtained were presented in a comparative manner. The findings of the analysis indicated that the group treated with chemical and microbial fertilizers in a cocopeat medium exhibited the highest lycopene content. Conversely, the group that received chemical and microbial fertilizer in perlite medium exhibited the lowest lycopene content. These findings suggest that different growing media and fertilization strategies may have significant effects on the phytochemical composition of tomato fruit.

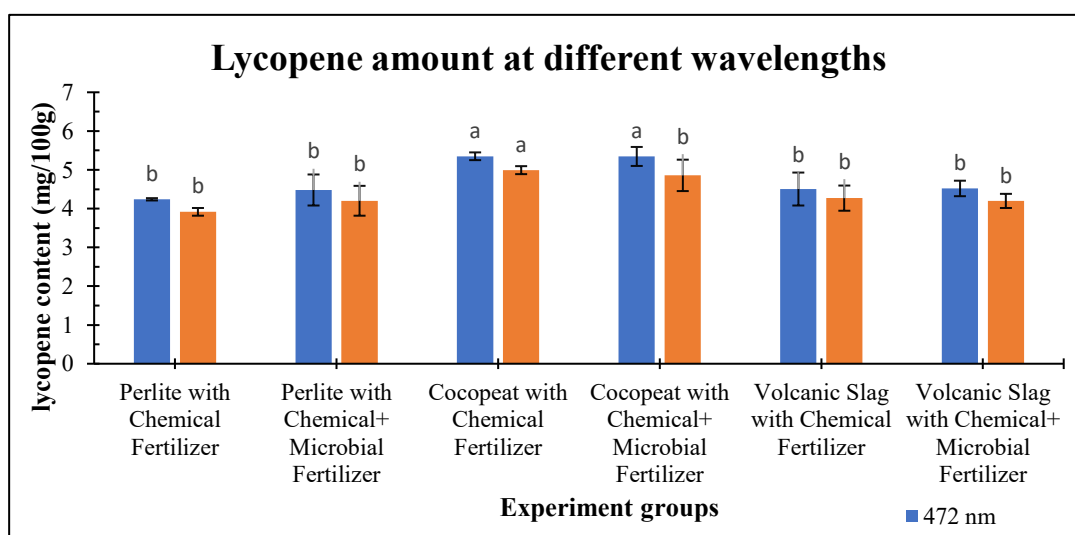


Figure 4.13: The lycopene amount at different medium and fertilizer groups. In cocopeat with chemical + microbial group have significantly differences ($p \leq 0.05$) between chemical fertilizer and adding microbial fertilizer.

4.3.6. Determination of Citric Acid Content in Tomato Fruits by Titrimetric Method

To determine the amount of citric acid in tomato fruits, the samples were titrated with sodium hydroxide (NaOH). Three replicate analyses were performed for each experimental group, and the resulting data were statistically evaluated (Table 4.8). A comparison of the groups revealed that the highest citric acid percentage was found in the group where only chemical fertilizer was applied on cocopeat medium. Conversely, the group that received chemical and microbial fertilizers in the slag environment exhibited the lowest citric acid content. In perlite medium, the chemical and microbial fertilizer group exhibited higher citric acid content compared to the chemical fertilizer only group.

Table 4.8: Three replicate averages and statistical analysis results (in %) of citric acid contents determined by titration with NaOH in tomato samples according to different growing media and fertilizer applications.

Experimental Group	Titration Acidity (%) (Means±SE)
Perlite with Chemical Fertilizer	0.34±0.03 ^b
Perlite with Chemical+ Microbial Fertilizer	0.45±0.04 ^a
Cocopeat with Chemical Fertilizer	0.49±0.04 ^a
Cocopeat with Chemical+ Microbial Fertilizer	0.48±0.01 ^a
Volcanic Slag with Chemical Fertilizer	0.32±0.02 ^b
Volcanic Slag with Chemical+ Microbial Fertilizer	0.26±0.02 ^c

4.3.7. Organoleptic Evaluation Result

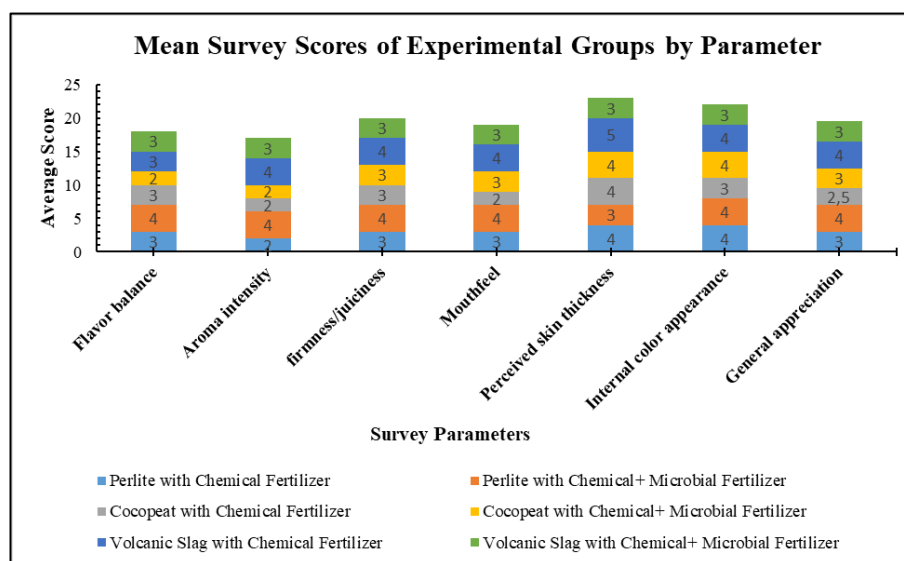


Figure 4.14: Average scores of the experimental groups (Perlite Chemical Fertilizer, Perlite Chemical Fertilizer + Microbial Fertilizer, Cocopeat Chemical Fertilizer, Cocopeat Chemical Fertilizer + Microbial Fertilizer, Volcanic Slag Chemical Fertilizer, Volcanic Slag Chemical Fertilizer + Microbial Fertilizer) on the basis of sensory parameters (taste, aroma, texture, mouthfeel, peel thickness and general liking) evaluated by 20 volunteer tasters. Scores range from 1 (lowest) to 5 (highest).

According to the survey results (figure 4.14), the highest appreciation in terms of taste parameter was observed in the group treated with microbial fertilizer in perlite environment. In the evaluation of peel thickness, the highest score was obtained by the group treated with volcanic slag chemical fertilizer. In aroma, texture and mouthfeel parameters, the perlite microbial fertilizer group and the slag control group obtained the highest scores compared to the other groups. In terms of general taste, the perlite microbial fertilizer group and the volcanic slag control group were the most preferred groups by the tasters.

5. DISCUSSIONS

Tomatoes are among the most widely consumed vegetables globally due to their varied uses in various food products, including sauces, tomato paste, and ketchup. These fruits are notable for their high content of organic acids, including calcium (Ca), potassium (K), and magnesium (Mg), as well as vitamins such as B, E, C, and K. They also contain carotenoids. Tomato (*Solanum lycopersicum*), a frequently preferred model plant, is distinguished by its high yield, industry suitability, and nutrient content. It has been demonstrated to possess a protective effect against cardiovascular diseases and certain types of cancer, particularly attributable to lycopene, a potent antioxidant presents in the fruit. A global analysis of tomato production between 2018 and 2022 reveals a concurrent increase in yield despite a decline in both area and quantity produced. [TEPGE, September 2024]. An analysis of the global tomato production distribution reveals Türkiye's position as a major producer, ranking among the top three countries (see Figure 2). This observation underscores the substantial demand for tomatoes in Türkiye, highlighting the country's significant role in the global tomato production landscape. Despite the evident increase in cultivated area and production between 2019 and 2023, a decline in yield is observed (see Table 2 and Figure 3). This phenomenon can be attributed to two main factors: chemical fertilization and the excessive use of pesticides, which are used to reduce crop loss. Nevertheless, the ingestion of lethal doses of pesticides can result in a multitude of deleterious consequences, including soil and water contamination, biodiversity loss, and the presence of pesticide and chemical residues in fruits and vegetables. [Megali et al., 2014]. This crisis has become permanent, and its effects will accumulate in the environment, exerting a negative impact on human health through the food chain. Recent progress in the field of microbial fertilizers has been observed. A growing number of solution-oriented approaches to this issue have begun to emerge on a global scale. Consequently, solutions have begun to emerge under the rubric of sustainable agriculture. The objective of sustainable agriculture is to establish a healthy environment conducive to the proliferation of various organisms and biodiversity, while also ensuring the production of crops that endure over an extended period. In order to curtail the utilization of chemical fertilizers in the near term and circumscribe their application in the long term, the employment of biological organic fertilizers and microbial bacteria, fungi, and microorganisms as an alternative has commenced.

[Desai et al., 2020]. Microbial fertilizers are composed of a microbial consortium of beneficial microorganisms. These fertilizers have been shown to enhance soil health, achieving a balance between the efficient production of crops and the principles of sustainable agriculture. The bacteria utilized in this study for the purpose of producing microbial fertilizer have been isolated from soil in a TUBITAK (121O649) project and have been identified as plant growth-promoting rhizobacteria (PGPR). Plant growth-promoting rhizobacteria (PGPR) have been shown to promote plant growth without causing damage to the soil environment. The utilization of this method has yielded notable advancements in several key areas, including enhanced productivity, augmented tolerance to abiotic stress, and the improvement of nutritional and functional quality in tomato fruit. The promotion of plant growth is achieved through both direct and indirect mechanisms, including the reduction of ethylene levels, facilitation of nutrient uptake by plants, stimulation of induced systemic resistance, and biocontrol against diseases through the production of antibiotics. The bacteria selected for the microbial consortium were *Pseudomonas* sp., *Acinetobacter* sp., and *Enterobacter* sp., These bacteria were selected based on their ability to perform nitrogen fixation, phosphate solubilization, biofilm production, indole acetic acid (IAA) production, and siderophore production. Nitrogen plays a pivotal role in plant growth and development. Plants are incapable of directly absorbing nitrogen due to its presence in the atmosphere. Consequently, nitrogen-fixing bacteria play a pivotal role in the fixation of free nitrogen and its conversion into a form that is utilizable by plants. *Pseudomonas* sp. and *Bacillus* sp., two types of bacteria, have been observed to facilitate the fixation of nitrogen in non-legume plants. Advancements in the field of microbial fertilizers have been made, with ongoing research focusing on the conversion of phosphorus in soil into an inorganic state as a result of prolonged use of chemical fertilizers. In this instance, the formation of phosphates occurs, which can subsequently be solubilized by beneficial microorganisms. IAA, or auxin hormone, is a phytohormone that plays a crucial role in regulating plant growth. This process enables the differentiation of plant cells. *Bacillus* sp. is the most prevalent of the PGPR species. The application of *Bacillus* strains to all three tomato cultivars resulted in a significant enhancement of shoot length, root length, and total biomass. [Liu et al., 2024].

Furthermore, the integration of microbial fertilizer in soilless environments has introduced a novel element to the existing literature. A confluence of factors, including increasing urbanization, unfavourable geographical conditions, the climate crisis, soil pollution, decline in soil fertility, and soil-borne diseases, has led to limitations in the utilization of soil. Consequently, the utilization of soilless agriculture practices has emerged as a contemporary approach.[Gautam et al., 2020]. Soilless agriculture involves the application of diverse substrates, encompassing both inorganic and organic materials. In such environments, the plants obtain the nutrients they require from the nutrient solution. The cultivation of these organisms in artificial environments is often more straightforward than in soil. The experiment utilized three distinct soilless farming media. The materials in question are cocopeat slag and perlite. Cocopeat is an inorganic substrate composed of coconut shell and fibers. Perlite and slag are organic substrates that are formed as a result of volcanic eruptions. Cocopeat is currently the most widely used soilless agriculture medium. Its water-holding capacity exceeds that of other media. [Ok, 2025]. Volcanic slag is an organic substrate that contains a higher mineral content compared to cocopeat and perlite. Additionally, volcanic slag is formed in Türkiye.

In three different environments, the physical and chemical properties of the plants were compared with the application of both chemical fertilizer alone and microbial fertilizer in addition to chemical fertilizer. The application of microbial fertilizer was executed in two instances, employing the foliar spraying method during the 12th and 14th weeks of tomato development. The experiment was terminated by harvesting the tomato at the 18th week of tomato development. Foliar fertilization is a method of fertilization by which plant nutrients are applied directly to the leaf surface. This method facilitates the absorption of micronutrients by the plant, with particular efficacy in nutrients that are typically challenging for roots to absorb. [Fernández & Eichert, 2009]. As demonstrated in the research, the application of fertilizers to the foliage of plants has been shown to stimulate metabolic processes and enhance photosynthetic efficiency, chlorophyll content, and overall growth performance.[Salisbury & Ross, 1992]. Additionally, foliar fertilization constitutes an alternative feeding method when soil conditions prove to be disadvantageous.[Kannan, 2010]. For instance, when plant uptake of elements such as iron, zinc, or manganese is limited in the soil, foliar application can be employed to ameliorate the deficiency. In this regard, foliar

fertilization is often the preferred method, particularly in controlled environment farming systems, including greenhouse farming, vertical farming, and soilless cultivation.

The graphs presented in Figures 4.9, 4.10, and 4.11 illustrate the diverse substrate environments, encompassing both chemical and chemical + microbial fertilizer substrates, for each substrate group. A close examination of the graphs reveals that the microbial fertilizer administered in cocopeat medium resulted in a significant increase in plant height compared to the group that received chemical fertilizer exclusively. This phenomenon may be attributed to the fact that the cocopeat provides a physical environment conducive to root development, and the foliar application of microbial fertilizer exerts a direct influence on plant metabolism through the leaf. These bacteria, located on the surface of the leaf, have the capacity to synthesize natural plant growth hormones, including indole-3-acetic acid (IAA), which has been demonstrated to stimulate cell division and elongation. [Glick, 2012]. In other environments, plant height was found to be higher in groups that received microbial fertilizer in addition to chemical fertilizer. Plants cultivated in perlite-based substrates may exhibit diminished metabolic activity, attributable to water/moisture imbalances and stunted root development. In such instances, foliar microbial stimuli may exhibit suboptimal responsiveness. [Nguyen et al., 2021].

The present study investigated the effect of foliar application of microbial fertilizer on chlorophyll a content in plant leaves. The findings indicated that the application of both chemical and microbial fertilizers in a cocopeat environment resulted in higher chlorophyll a content compared to the other experimental groups. A statistically significant difference was observed between the other groups ($p \leq 0.05$). This phenomenon can be attributed to the impact of microbial fertilizer on photosynthetic pigment synthesis, a process that is facilitated by the cocopeat environment, which contributes to the demonstration of this activity. The perlite microbial fertilizer group exhibited a higher chlorophyll b content compared to all other groups. The function of chlorophyll b in photosynthesis is to absorb sunlight. A comparison of the experimental groups in the perlite environment revealed that the application of microbial fertilizer in conditions of limited light promoted plant growth, particularly in instances where photosynthesis proved to be inadequate. A subsequent comparison of the carotenoid amounts revealed that the highest value was observed in the group

where volcanic slag chemical fertilizer had been applied. This phenomenon is indicative of the plant's defensive response to excessive light accumulation. [Yadav, S. et al., 2020].

In this study, the impact of microbial fertilizer on the quality of tomatoes was examined. To this end, panicle weights, fresh weights, and dry weights of tomatoes were analyzed. A subsequent comparison of the panicle weights revealed that the panicle weight of the slag chemical + microbial fertilizer group exceeded that of the other groups; however, this difference was not statistically significant. Consequently, it was observed that the microbial fertilizer applied did not exert any deleterious effect on tomato weight. A comparison of fresh and dry weights revealed that perlite chemical + microbial fertilizer exhibited the highest fresh weight, while cocopeat microbial fertilizer demonstrated the lowest dry weight. However, upon further analysis of the difference between fresh weight and dry weight, it was observed that the group with the highest water content was the one treated with perlite chemical + microbial fertilizer.

The pH values of tomatoes are examined to evaluate the plant's nutrient uptake and to assess its growth parameters. A comparison of the pH values in the experimental groups reveals that the Cocopeat with Chemical Fertilizer group has the highest pH value, while the Cocopeat with Chemical + Microbial Fertilizer group has the lowest pH value. This scenario was not replicated in other groups. The impact of microbial fertilizer was found to be increasingly pronounced in perlite and volcanic slag environments, while its effect was less pronounced in cocopite environments. An interaction was observed between the cocopeat medium, which is inorganic and contains organic matter, and the microbial fertilizer that was applied. Given that the pH value of ripe tomato fruit is typically between 4.0 and 4.6, it can be concluded that the substrate media and the microbial fertilizer applied did not exert a negative effect on the pH of the tomato.

Lycopene, a carotenoid, is found in abundance in ripe tomatoes. The substance is highly prized for its antioxidant properties. The values of lycopene in tomatoes were calculated at two distinct wavelengths and subsequently compared (Figure 4.13). The analysis revealed that the cocopeat experimental groups exhibited a higher concentration of lycopene. Given that lycopene is a type of carotenoid, the highest carotenoid value was observed in the volcanic slag chemical fertilizer group. In

volcanic slag, the high carotenoid content in the leaf but low lycopene content in the fruit may be explained by the fact that the plant may have directed its energy more towards photosynthesis and leaf health. In the experimental groups of the cocopeat, lycopene levels were found to be high in the fruit and low in the leaf. This suggests that the plant may have directed its energy toward fruit pigmentation and seed protection during the ripening period.

Citric acid is one of the primary organic acids that determine the quality of tomato taste and provide tomatoes with a balanced flavor profile. Citric acid has been demonstrated to suppress the growth of microorganisms by providing a low pH. This increases the resistance of tomatoes to spoilage and prolongs their shelf life [Tadesse et al., 2015]. The acidity value, as measured by titration, is reported as 0.30-0.50% citric acid equivalent.[AOAC, 1995]. According to the available data, the highest degree of acidity was observed in the cocopeat chemical fertilizer group, with a value of 0.49%, while the lowest was recorded in the Volcanic Slag with Chemical+ Microbial Fertilizer group, at 0.26%.

The present study investigated the effects of different growth media and fertilizer treatments on the organoleptic characteristics of tomatoes. The results obtained were then compared and interpreted with the existing literature. The organoleptic analyses demonstrated that the application of microbial fertilizer in a perlite environment produced a significant impact, exhibiting positive effects on taste and other organoleptic parameters. This observation was particularly evident when compared to the perlite chemical fertilizer application group. These findings are consistent with the plant quality-enhancing effects of microbial fertilizers reported in previous studies. The study's findings revealed significant differences in parameter determination of tomato quality. These results were discussed in comparison with similar studies in the literature.

6. CONCLUSION

A thorough analysis of these parameters demonstrated that microbial fertilizer or substrates utilized as an alternative to soil did not exert a deleterious effect on tomato fruit development. The continued study of this phenomenon may yield the possibility of applying microbial fertilizer as a chemical fertilizer through the root pathway. This will facilitate the observation of the disparities between plants cultivated in soil and those cultivated in soilless. Given that bacteria with PGPR properties were obtained from plants living in the roots of wheat plants, it is reasonable to hypothesize that the same study can be done with soil beneficial bacteria obtained from the roots of tomato plants. This fertilizer can be applied to the plant at three different developmental stages.

REFERENCES

- Acet S., (2023), “Bitki Büyümesini Teşvik Edici Özelliğe Sahip Bakterilerin Buğday Rizosferinden İzolasyonu, Saflaştırılması, Biyokimyasal Ve Moleküler Biyolojik Yöntemlerle Tanımlanması”, Yüksek Lisans Tezi, Gebze Teknik Üniversitesi.
- Bhattacharyya P. N., Jha D. K., (2012), “Plant growth-promoting rhizobacteria (PGPR): emergence in agriculture”, *World Journal of Microbiology and Biotechnology*, 28(4), 1327–1350.
- Boyacı S., Abacı Bayar A. A., Başak H., (2022), “Evaluation of harvest waste in soilless agriculture tomato cultivation”, *Infrastruktura i Ekologia Terenów Wiejskich*, (I/1), 29–42.
- Canton H., (2021), “Food and agriculture organization of the United Nations—FAO”, in *The Europa Directory of International Organizations 2021*, 297–305.
- Carril P., Ghorbani M., Azarnejad N., Anselmi S., Renzi M., Loppi S., (2025), “Promoting early growth in tomato (*Solanum lycopersicum* L.) by co-application of biochar and beneficial bacteria”, *Journal of Soil Science and Plant Nutrition*, 1–11.
- Cedeño J. M., Magán J. J., Thompson R. B., Fernández M. D., Gallardo M., (2024), “Comparison of methods to determine nutrient uptake of tomato grown in free-draining perlite substrate—key information for optimal fertigation management”, *Horticulturae*, 10 (3), 232.
- Chen Q., Li X., Zhang W., Xue D., Sun Q., Xing H., Wu C., (2025), “Impact of volcanic slag on cucumber yield, quality, and rhizosphere soil environment”, *Plants*, 14 (9), 1328.
- Denaya S., Yulianti R., Pambudi A., Effendi Y., (2021), “Novel microbial consortium formulation as plant growth promoting bacteria (PGPB) agent”, *IOP Conference Series: Earth and Environmental Science*, Vol. 637, No. 1, p. 012030, IOP Publishing.
- Desai S., Bagyaraj D. J., Ashwin R., (2020), “Inoculation with microbial consortium promotes growth of tomato and capsicum seedlings raised in pro trays”, *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, 90 (1), 21–28.
- Etesami H., Adl S. M., (2020), “Plant growth-promoting rhizobacteria (PGPR) and their action mechanisms in availability of nutrients to plants”, in *Phyto-Microbiome in Stress Regulation*, 147–203.
- Fernández J. A., Eichert T., (2009), “Foliar uptake of mineral nutrients”, in M. Pessarakli (Ed.), *Handbook of Plant and Crop Physiology*, pp. 357–373, CRC Press/Taylor & Francis.

Gautam R., Singh P. K., Kumar P., Singh M. C., Dhital S., Rani M., Kumar J., (2021), “Advances in soilless cultivation technology of horticultural crops”, *The Indian Journal of Agricultural Sciences*, 91 (4), 503–508.

Gen-Jiménez A., Flores-Félix J. D., Rincón-Molina C. I., Manzano-Gomez L. A., Rogel M. A., Ruíz-Valdiviezo V. M., Rincón-Rosales R., (2023), “Enhance of tomato production and induction of changes on the organic profile mediated by *Rhizobium* biofortification”, *Frontiers in Microbiology*, 14, 1235930.

Glick B. R., (2012), “Plant growth-promoting bacteria: mechanisms and applications”, *Scientifica*, 2012 (1), 963401.

Horwitz, W. (Ed.). (1995). *Official methods of analysis* (16th ed.). Association of Official Analytical Chemists.

Incrocci L., Thompson R. B., Fernandez-Fernandez M. D., De Pascale S., Pardossi A., Stanghellini C., Gallardo M., (2020), “Irrigation management of European greenhouse vegetable crops”, *Agricultural Water Management*, 242, 106393.

Jones D. L., (2021), “Advances in soilless agriculture systems for sustainable urban farming”, *Journal of Sustainable Agriculture*, 45 (3), 215–230.

Kannan K., (2010), “Effects of microbial inoculants on plant growth and soil health: A review”, *Journal of Agricultural Science*, 5 (2), 45–53.

Lee B., Cho J., Park S., Ahn J., Chung S., (1997, October), “Effects of substrates on the growth and fruit quality of hydroponically grown tomatoes, *Lycopersicon esculentum* Mill. Cv. Katinka”, in *International Symposium on Vegetable Quality of Fresh and Fermented Vegetables*, 483, pp. 147–154.

Liu J., Li H., Yuan Z., Feng J., Chen S., Sun G., Hu T., (2024), “Effects of microbial fertilizer and irrigation amount on growth, physiology and water use efficiency of tomato in greenhouse”, *Scientia Horticulturae*, 323, 112553.

Megali L., Glauser G., Rasmann S., (2014), “Fertilization with beneficial microorganisms decreases tomato defenses against insect pests”, *Agronomy for Sustainable Development*, 34 (3), 649–656.

Musa B. M. A., Saeed A. B., Ahmed S. B., (2023), “Effect of fertilizing method, silt soil, and application of effective microorganism on growth and yield of tomato (*Lycopersicon esculentum*) in a greenhouse”, *International Journal of Innovative Approaches in Agricultural Research*, 7 (1), 53–73.

Nguyen T. T., Lee D. S., Kim J. H., (2021), “Effects of foliar fertilization on nutrient uptake and growth performance of tomato plants”, *Journal of Plant Nutrition*, 44 (5), 675–688.

Ok E., (2025), “Physical, chemical, and microbiological properties of various soilless media combinations and their impact on the vegetative growth and nutrient composition of hempedu bum.”

Salisbury F. B., Ross C. W., (1992), *Plant Physiology* (4th ed.), Wadsworth Publishing.

Subramani T., Gangaiah B., Baskaran V., Swain S., (2020), “Effect of soilless growing media on yield and quality of tomato (*Solanum lycopersicum* L.) under tropical island condition”, *International Journal of Current Microbiology and Applied Sciences*, 9(5), 2084–2090.

Tilman D., Balzer C., Hill J., Befort B. L., (2011), “Global food demand and the sustainable intensification of agriculture”, *Proceedings of the National Academy of Sciences*, 108(50), 20260–20264.

Wang T., Xu J., Chen J., Liu P., Hou X., Yang L., Zhang L., (2024), “Progress in microbial fertilizer regulation of crop growth and soil remediation research”, *Plants*, 13(3), 346.

Yadav S., Kumar P., Singh R., Sharma A., (2020), “Role of microbial fertilizers in sustainable agriculture: A review”, *International Journal of Agricultural Science and Research*, 10(3), 45–57.

Zhao S. Y., Meng Y. L., Yang Z. H., Li B. L., Li Y. Y., Han H., Chen Z. J., (2025), “Rhizosphere microbiome metagenomics in PGPR-mediated alleviation of combined stress from polypropylene microplastics and Cd in hybrid *Pennisetum*”, *Frontiers in Microbiology*, 16, 1549043.

BIOGRAPHY

After completing his high school education at ÇEAŞ Anatolian High School, she started her undergraduate education at Istanbul Medeniyet University, Department of Molecular Biology and Genetics in 2018. In 2023, she completed her undergraduate education and started her master's degree at Gebze Technical University, Department of Molecular Biology and Genetics in the same year.

PUBLICATIONS AND PRESENTATIONS FROM THE THESIS

Tepe Z., (2025), “Assessment of influence of microbial fertilizer on production of tomato”, Gebze Technical University Graduate School of Natural and Applied Sciences 9th Graduate Research Symposium, Kocaeli, 26-27 May.