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Effect of Treatment with Some Biostimulants on the Productivity of Cucumber Crop (*Cucumis sativus*)

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Abstract **- The research was conducted in the Azaz area, located in northern Syria, about 48 km north of Aleppo City, and about 5 km from the Turkish border. The aim was to study the effect of treatment with some biological compounds (Trichoderma fungi and Penicillium fungi) and organic compounds (Seaweed) on the growth and productivity of cucumber crop (AZ55F1 variety) and to determine the best-studied treatments. The semi-field cultivation method was adopted, and 5-liter agricultural pots were used. Four treatments were used in the study (three experimental treatments + control treatment), and each pot was considered a replicate, and five replicates represented each treatment. All treatments were distributed according to a completely randomized design (CRD).**

The results showed that all treatments used in the study (Trichoderma fungus, Seaweed, Penicillium fungus) were superior to the control in all studied traits (length, diameter, size, and weight of the fruit, number of fruits per plant, and productivity of the plant). There were no significant differences between the experimental treatments (Trichoderma fungus, Seaweed, Penicillium fungus) in the traits of length and diameter of the fruit and number of fruits per plant. The treatment with Trichoderma fungus was significantly superior to the Seaweed and Penicillium treatments in the trait of fruit size and weight and total productivity per plant. The Seaweed treatment was significantly superior to the treatment with Penicillium fungus in the trait of fruit size. In conclusion, the different treatments (Trichoderma fungus, Penicillium fungus, Seaweed) achieved an increase in productivity of 78.95%, 53.85%, and 50.97%, respectively, compared to the control.

Keywords: Trichoderma, Penicillium, seaweed, cucumber, fruits, productivity.

I. INTRODUCTION

Cucumber (*Cucumissativus* L.) is an important agricultural crop due to its multiple uses in human food. It belongs to the Cucurbitaceae family and is believed to have originated in northern India, while China is one of the important centers of genetic diversity for this plant (Pursglove, 1969). Cucumber grows all over the world, preferring warm conditions, especially in tropical and subtropical climates, and has been cultivated in humid areas for thousands of years (Whitaker and Davis, 1962). Cucumber is commonly consumed fresh as part of salads and appetizers and is also pickled for use in a variety of foods (Munger and Robinson, 1991). The dry matter content of cucumber is estimated at 5%, and it contains a combination of vitamins, including vitamin C and vitamin K, in addition to minerals such as potassium and magnesium. Cucumber is low in calories and a good source of dietary fiber, making it a healthy food choice for many people around the world (Nadeem *et al.*, 2017). Cucumber contains organic acids that give it a refreshing flavor, in addition to volatile oils that give it its distinctive smell. Cucumber also contains the glycoside cucurbitacin, which is responsible for the sometimes-bitter taste (Meena *et al.*, 2017; Draie, 2019; 2022).

Fertilization is one of the key production factors that directly affect the quantity and quality of the crop. Nutritional deficiencies can lead to significant reductions in plant growth and productivity. Biostimulants are an essential part of sustainable development in modern agriculture, contributing to the enhancement of plant growth and increased crop productivity in environmentally friendly ways. Among these biostimulants are beneficial fungi such as Trichoderma and Penicillium, as well as seaweed that are widely used as growth promoters. Beneficial fungi, such as *Trichoderma harzianum* and *Penicillium chrysogenum*, are gaining increasing importance as effective tools for improving plant health and increasing productivity (Jabłonski and Berna, 2001; Chwil and Szewczuk, 2003; Malaguti *et al.*, 2003; Del Amor *et al.*, 2006; Meena *et al.*, 2017).

Trichoderma fungus:

Trichoderma is a genus of fungi that includes several effective species such as *Trichoderma harzianum* and *Trichoderma viride*, which are used to improve soil propertiesand increase crop productivity. Research has shown that Trichoderma has multiple positive effects on plant growth, stimulating root growth through several mechanisms including auxin production, as Trichoderma secretes plant hormone-like compounds such as auxins, which play an

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important role in stimulating root elongation and increasing their number (Contreras-Cornejo *et al.*, 2009), and enhancing root reproduction as the fungus helps in the formation of secondary roots, which increases the effective surface area of the roots for absorbing nutrients and water (Gravel *et al.*, 2007). Trichoderma also improves the efficiency of nutrient use as it helps in improving the absorption of nutrients in several ways such as dissolving unavailable phosphates in the soil, making them available to plants, which enhances the efficiency of phosphorus absorption (Altomare *et al.*, 1999). Trichoderma enhances microbial activity in the soil, which in turn contributes to the conversion of organic matter into nutrients absorbable by plants (Vinale*et al.*, 2008).

Trichoderma fungi are characterized by their ability to protect plants from fungal diseases by producing enzymes that degrade the cell walls of pathogenic fungal species, which reduces their activity and enhances plant resistance to diseases (Woo *et al.*, 2014a). Among the enzymes secreted by Trichoderma fungi are lytic enzymes, which play a key role in combating pathogenic fungi by degrading their cell walls. These enzymes include chitinase, an enzyme that targets chitin, a major component of the cell walls of pathogenic fungi. Chitinases break down the glycosidic bonds in chitin, which leads to the degradation of the cell wall and the destruction of the fungal cell structure, which weakens the pathogenic fungi and inhibits their ability to grow and reproduce, and thus weakens their ability to infect the plant (El-Katatny*et al.*, 2000). β-Glucanases, which target the glycosidic bonds in glucan, another component of fungal cell walls, cause the cell wall of pathogenic fungi to weaken and degrade, making them more susceptible to attacks by the plant's immune system, thus stopping the infection (Lorito*et al.*, 2010). Also, proteases, which are enzymes that degrade proteins in fungal cell walls by breaking the peptide bonds in these proteins, leading to the disintegration of the cell wall and the collapse of the cellular structure of pathogenic fungi, thus reducing their ability to reproduce and spread infection (Harman *et al.*, 2004). The work of enzymes and secondary compounds secreted by Trichoderma and their effect on plant disease resistance is evident from stimulating natural plant defenses through biochemical induction. This leads to the production of antifungal compounds such as phytoalexins and pathogenesis-related proteins (Yedidia*et al.*, 1999).

Trichoderma fungi play an important role in the cycle of organic matter in the soil and improve its fertility, by producing a variety of enzymes that decompose complex organic materials such as cellulose, hemicellulose, and pectin into simpler materials. These enzymes include cellulases, which break down cellulose into glucose that plants and other soil microorganisms can use as an energy source (Kredics*et al.*, 2005), and pectinases, which decompose pectin present in the walls of dead plant cells, which help in the decomposition of dead plant matter and converting organic matter into available nutrients (Lorito*et al.*, 2010). Important nutrients such as nitrogen, phosphorus, and potassium are released and made readily available to plants, which contributes to a significant increase in soil fertility (Harman *et al.*, 2004).

Trichoderma also plays a major role in enhancing biological activity in the soil and encouraging the growth of beneficial microorganisms, such as nitrogen-fixing bacteria and other fungi that contribute to improving soil fertility. This effect results from competition for resources as it limits the growth of harmful fungi and pathogenic microorganisms, allowing beneficial microorganisms to dominate the environment surrounding the roots (Vinale*et al.*, 2008). It also contributes to improving the soil structure increasing its capacity to retain water and air, and increasing microbial activity, which enhances optimal growth conditions for plants (Woo *et al.*, 2014b). Trichoderma stimulates root growth, which increases the interaction of roots with the soil (root interaction effect) and improves the ability of plants to absorb nutrients (Contreras-Cornejo *et al.*, 2009). The increased interaction between roots and soil thanks to Trichoderma increases the availability of nutrients and improves their absorption by plants, which contributes to enhancing soil fertility (Altomare *et al.*, 1999).

Studies indicate that the use of Trichoderma can significantly improve crop productivity by increasing root growth, which enables plants to absorb more nutrients and water from the soil, leading to an increase in plant size and thus increased productivity (Harman *et al.*, 2004). Increased root growth (due to Trichoderma stimulation) promotes vegetative (e.g. leaf and stem) and floral (increased number of flowers) growth, which contributes to increased crop yield. Ousley *et al.* (1994) showed that treatment with Trichoderma increased yield by up to 20-30% in tomato and cucumber, respectively. Harman *et al.* (2004) also confirmed that the application of Trichoderma increased crop yield by up to 20-30%, due to improved plant growth and disease control. Trichoderma improves crop quality by enhancing plant resistance to fungal and microbial diseases due to its immune effect and stimulation of the plant's natural defenses. This reduces crop damage due to diseases and increases the quality of these crops (Woo *et al.*, 2014b). Trichoderma helps improve the efficiency of resource use such as water and nutrients due to its ability to improve nutrient uptake, which leads to improved nutrient content of crops and increased quality (Benítez *et al.*, 2004). Finally, Trichoderma has the potential to improve the tolerance of plants to environmental stresses such as drought and salinity, which helps in achieving better productivity in non-optimal conditions (Sharma *et al.*, 2012). The use of Trichoderma may also accelerate seed

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germination and early plant growth, which contributes to improving overall productivity (Harman *et al.*, 2004).

Penicillium fungus:

Penicillium fungi are a natural source of antibiotics that protect plants from microbial diseases. Research has shown that this fungus contributes to improving soil properties by releasing nutrients bound to organic compounds, which increases the availability of nutrients to plants and enhances their growth (Frisvad and Samson, 2004). Penicillium fungi have significant positive effects on plant growth and productivity, mainly due to improving the efficiency of nutrient absorption and stimulating vegetative growth. This effect depends largely on the enzymes secreted by the fungus, which play a crucial role in improving soil properties and increasing nutrient availability. It also plays a major role in increasing the efficiency of nutrient absorption from the soil, by decomposing organic compounds and making nutrients available to plants. A study by Pimentel *et al.* (2011) showed that the use of Penicillium extracts in soil led to an increase in the available phosphorus content, an essential nutrient that supports root growth and development, which contributes to improving vegetative growth of plants. Penicillium fungi also stimulate vegetative growth by secreting a variety of enzymes that improve soil structure and increase the ability of roots to absorb water and nutrients. A study by Sivakumar *et al.* (2013) showed that the application of Penicillium fungi leads to an increase in stem length and leaf mass in treated plants, through the secretion of enzymes such as cellulases and pectinases, which decompose organic matter in the soil, which improves the soil structure and increases its ability to retain water and nutrients and increases their availability to plants.

Among the enzymes secreted by Penicillium are cellulases that break down cellulose, which contributes to improving the availability of nutrients in the soil and increasing the activity of beneficial microorganisms. Pectinases also break down pectin in plant cell walls, which improves the soil structure and increases its ability to retain water and nutrients. Proteases contribute to the breakdown of proteins into amino acids, which improves the availability of nitrogen in the soil, which is an essential element for leaf and stem growth. Hemicellulases break down hemicellulose, which improves the soil structure and enhances the ability of roots to absorb nutrients. The enzymes secreted by Penicillium improve the soil structure, which enhances its ability to retain water and nutrients. They also increase the availability of essential nutrients such as nitrogen and phosphorus, which enhances root growth and increases stem length and leaf mass in plants, thus increasing crop productivity. A study by Sundararajan *et al.* (2015) showed that the use of Penicillium in soil increased the availability of phosphorus and potassium. Phosphorus plays a role in root formation, and flower and fruit formation, while potassium enhances plant resistance to diseases and is involved in regulating photosynthesis. The availability of these elements in the soil increases its fertility, which improves crop growth and productivity.

Penicillium fungi are known for their ability to produce natural antibiotics, which can inhibit the growth of fungal pathogens. These antibiotics kill or inhibit the growth of pathogenic fungi such as *Fusarium* and *Rhizoctonia*, which improves plant health and reduces the incidence of fungal diseases. A study by Ahmed *et al.* (2017) found that Penicillium was effective in reducing the incidence of plant pathogenic fungi such as Fusarium and Rhizoctonia. Penicillium fungi also play a role in enhancing plant immunity, which is manifested by improving the immune response of plants against a wide range of bacterial and fungal diseases. Studies by Khan *et* Rizvi (2019) and Khan *et al.* (2019) showed that the use of Penicillium in soil improved the immune response of plants. These studies confirmed that the fungus stimulates the natural defense system of plants, which enhances their ability to resist diseases and reduce the damage they suffer. This effect is attributed to improving the biological balance in the soil and increasing the effectiveness of antifungals produced by the fungus.

Penicillium improves soil structure by increasing biological activity. Microbiological analysis of soil has shown that Penicillium increases the number of beneficial microorganisms, such as bacteria and other fungi that support the decomposition of organic matter and improve soil structure, aeration, and moisture retention. A study by Mehta *et al.* (2016) showed that Penicillium enhances soil structure, improves aeration, and increases its moisture-holding capacity. Improving soil structure includes increasing the pore volume of the soil, which contributes to better drainage and prevents the formation of heavy soil that can negatively affect root growth. Good aeration also improves root health and increases the efficiency of nutrient uptake.

Seaweeds:

Seaweeds enhance photosynthesis and improve water use efficiency in plants, due to their richness in minerals and organic matter. Studies have shown that the use of seaweed extracts enhances plant resistance to environmental stresses such as drought and salinity, leading to increased crop yields (Khan *et al.*, 2009a; Craigie, 2011a). A study by Craigie (2011b) showed that seaweeds contain plant hormones such as auxins, cytokinins, and gibberellins, in addition to amino acids. These compounds improve root growth, which enhances their ability to absorb nutrients such as nitrogen, phosphorus, and potassium. Plant hormones also help improve the internal

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distribution of nutrients within the plant, which enhances the plants' use of available nutrients in the soil.

A study by El-Beltagi *et al.*, (2019) showed that applying seaweed extracts to peanut plants increased the nitrogen content in the leaves by up to 25% compared to the control. Nitrogen is an essential nutrient that plays a crucial role in the formation of proteins and nucleic acids, which directly affects plant growth and productivity. This increase in nitrogen content indicates that seaweed enhances the availability of nitrogen in the soil and increases the effectiveness of its absorption by plants. A study by Parvez *et al.* (2017) confirmed that seaweed extracts increased leaf length and plant mass in tomatoes by up to 20%. Auxins in seaweed enhance the process of cell expansion and increase the rate of cell division, which contributes to improving the vegetative growth of plants. Improved vegetative growth includes an increase in stem length and leaf mass, which enhances the ability of plants to photosynthesize and store nutrients. A study by Tantawy *et al. (*2021) showed that applying seaweed extracts to sweet pepper plants increased productivity by 18%, and this effect can be attributed to improving plant growth, increasing their ability to absorb nutrients, and enhancing their resistance to diseases. A study by Zhu *et al.* (2019) showed that using seaweed extracts contributed to increasing corn yield by up to 30%. The study attributed this increase in yield to improving root growth, increasing the availability of nutrients in the soil, and improving the vegetative growth of plants.

Seaweed also contributes to improving the quality of crops by increasing their content of nutrients and vitamins. Studies by Pérez-Alfocea *et al.* (2018; 2020) confirmed that the use of seaweed extracts increased the vitamin C content in sweet peppers by 15%. Vitamin C is an important antioxidant that plays a role in improving the general health of plants and enhancing their resistance to environmental stresses. Seaweed contains a group of biological compounds that work to improve the response of plants to environmental stresses and harsh conditions by enhancing the plant's ability to maintain water balance and repair cellular damage. A study by Khan *et al.* (2009b) showed that plants treated with seaweed extracts showed a 30% higher level of drought tolerance compared to untreated plants. The study attributed this to the fact that seaweed contains amino acids and sugar compounds that improve the ability of plants to retain water and reduce its loss, which enhances their ability to adapt to drought conditions. A study by Luo *et al.* (2021) found that seaweed extracts increased plants' resistance to salinity by 25%. The study confirmed that seaweed contains compounds that modify the concentration of ions inside plant cells, which reduces the effect of sodium and enhances the ability of plants to tolerate salty conditions. Seaweed also plays an important role in enhancing plant health by improving the nutritional balance in the soil and enhancing plant defense systems, which helps reduce symptoms resulting from fungal diseases. A study by El-Nakhel *et al.* (2020) showed that the use of seaweed extracts reduced the symptoms of fungal diseases by up to 20%.

Hence, the importance of using agricultural biotechnologies as a sustainable solution to improve plant health and increase productivity. Scientific research shows that beneficial fungi such as *Trichoderma harzianum* and *Penicillium chrysogenum*, in addition to seaweeds, can be effective tools in enhancing plant growth, increasing disease resistance, and improving soil fertility. Given the potential benefits of these biostimulants, it becomes necessary to conduct accurate studies to evaluate their actual impact on cucumber growth and production. Therefore, this study aims to evaluate the impact of using *Trichoderma harzianum*, *Penicillium chrysogenum* and seaweed, and to determine the best treatment among them in the growth and productivity of cucumber plants.

II. MATERIALS AND METHODS

2.1 Experimental Location

The experiment was conducted in the Azaz area, which is in northern Syria, near the Turkish border, and is administratively affiliated to Aleppo Governorate. It is about 48 km north of Aleppo city and only about 5 km from the Turkish border. Summers are hot and dry, with an average temperature of 28.5 °C, and winters are cold and humid with an average temperature of 5 °C. The average annual rainfall is about 377 mm and is mostly concentrated in the winter months.

2.2 Plant Material

The Turkish cucumber variety A-Z-55 F1 Oturak Tarla Hiyari was used in the experiment. It has a long growing season, medium growth vigor, short internodes, and close nodes. It is resistant to powdery and downy mildew. The fruit length is 17-18 cm. It is suitable for planting in spring, summer, and autumn.

2.3 Experimental Treatments

Three treatments were applied in the experiment on the studied cucumber variety as follows:

1. Foliar spraying and irrigation with Trichoderma fungus solution (concentration 1 g/L).
2. Foliar spraying and irrigation with Penicillium fungus solution (concentration 1 g/L).

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3. Foliar spraying and irrigation with seaweed extraction (concentration 1 g/L).
4. In addition to the control (spraying with water only).

2.4 Experimental Stages

1. Cucumber seedlings were transferred from the protected nursery in the Faculty of Agriculture at Sham University to the designated planting site.
2. The seedlings were thirsty for 2 days before immersion to ensure absorption of the treatment material.
3. The solutions were prepared (one solution for each treatment), which are a solution containing Penicillium fungus, a solution containing Trichoderma fungus, and a solution containing seaweed (according to the previously determined concentration of 1 g/L for all extracts).
4. The roots of the seedlings were immersed (before planting), according to the designated treatment for 10 minutes.
5. 20 pots with a capacity of 5 liters were prepared, one pot for each seedling of the studied cucumber variety.
6. The pots were numbered, and the replicates were determined for each treatment, then the treated seedlings were planted in their pots (5 replicates for each treatment, each pot is one replicate for the treatment). Then the pots were distributed randomly in the experimental location.
7. The soil was collected in advance from one area (on 15 April 2024), and organic fertilizers were added to it, at a rate of (10% v/v), and mixed well before planting.
8. Four 2-liter sprayers were prepared (one sprayer was allocated for each treatment in addition to a sprayer containing only water for the control treatment), and the solution allocated for each treatment was sprayed according to the following:
   - Penicillium treatment: 5 pots were sprayed and irrigated with Penicillium solution.
   - Trichoderma treatment: 5 pots were sprayed and irrigated with Trichoderma solution.
   - Seaweed treatment: 5 pots were sprayed and irrigated with seaweed solution.
   - Control: 5 pots were sprayed and irrigated with water only.
9. The experimental treatments (Trichoderma fungus, Penicillium fungus, seaweed, and control) were sprayed periodically every week from the date of planting until the end of the season, while the control was sprayed with water only. The soil of each replicate was also irrigated with the same solution designated for spraying (so that 2 liters were consumed each time).
10. Watering operations were followed up by repeating one irrigation every two days from the date of planting 15 April 2024 until 31 May 2024, then irrigation was carried out daily from 1 June 2024 until the end of the planting season, where the irrigation process was carried out when the sun was completely absent from the plants.
11. All plants were fertilized with microelements (foliar spray on the green group, at a rate of one spray every 15 days).
12. All treatments were foliar sprayed with calcium (1 g/L) until the plant was completely wet on 15 June 2024 and 15 July 2024.
13. After planting, the plant growth was monitored and the necessary service operations were carried out, especially removing flowers in the early stages of planting manually. All lateral growths were removed, the plant was raised vertically, and the plants were fixed using climbing threads and special fixing clips.
14. All treatments were sprayed with the necessary pesticides, fungicides, insecticides, and acaricides until the plant was completely wet (Lambda-cyhalothrin 0.5 ml/L on 10 May 2024, Difenoconazole 0.7 ml/L on 15 June 2024, Abamectin 20 g/L on 20 July 2024), where the spraying process was carried out when the sun was completely absent from the plants.

2.5 Measured Parameters

A. Fruit length (cm): The length of the fruit was measured using a 50 cm graduated ruler.
B. Fruit diameter (cm): The diameter of the fruit was measured using a 50 cm graduated ruler.
C. Fruit volume (cm^3): The volume of the fruit was calculated using the displaced water method using a 1-liter cylinder.
D. Weight of fruit (g): The weight of one fruit was calculated using a sensitive balance (with an accuracy of 4 digits after the decimal point).
E. Number of fruits/plant: The fruits were counted for all treatments, and all replicates were done according to the average number of fruits per plant for each treatment.
F. Weight of fruits/plant (kg): The productivity of fruits per plant (weight of fruits per plant) was calculated by calculating the number of fruits per plant and multiplying it by the average weight of one fruit per plant.

2.6 Experimental design and statistical analysis

All treatments were distributed according to a completely randomized design (CRD). Cucumber plants (AZ55F1 variety) were planted in 5-liter pots. Each pot was considered a replicate. Four treatments were used in the study (three treatments + control), and each treatment was represented by five replicates. The total number of experimental plants was: one cucumber variety × four treatments × five replicates = 20 plants. The results were analyzed using the statistical analysis

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program (Genstat-12), and the comparison between the means was made by the least significant difference (LSD) test at the significance level (0.05).

III. RESULTS AND DISCUSSION

The fruits were collected once they reached the typical consumer size for the variety, and the necessary parameters were taken on these fruits. Then the results were tabulated and statistically analyzed, as shown in Table (1).

Table 1: Effect of experimental treatments on cucumber fruit parameters

Treatment	Length (cm)	Diameter (cm)	Size (cm^3)	Weight (g)	Fruits /Plant	Yield
Control	11.07 b	2.75 b	93.33 d	91.83 c	12.00 c	1102.00 c
Penicillium	12.43 a	3.15 a	107.75 c	102.75 b	16.50 b	1695.38 b
Trichoderma	12.60 a	3.34 a	126.67 a	116.00 a	17.00 a	1972.00 a
Seaweed	12.63 a	3.22 a	117.67 b	107.33 b	15.50 b	1663.67 b
Mean	12.18	3.12	111.35	104.48	15.25	1608.26
L.S.D. (5%)	0.36	0.23	5.43	5.22	1.63	61.12
C.V. (%)	3.4	3.9	8.6	9.7	4.8	16.55

3.1 Fruit length (cm)

Table 1 shows the positive effect of experimental treatments on increasing the length of cucumber fruit (AZ55F1), as all experimental treatments significantly outperformed the control in the fruit length trait, as the fruit length in the seaweed, Trichoderma and Penicillium treatments reached 12.63 cm, 12.60 cm and 12.43 cm, with an increase of 14.1%, 13.8% and 12.3% over the control, respectively. While the fruit length in the control reached 11.07 cm. Although the seaweed treatment gave the highest fruit length, followed by the Trichoderma treatment and then the Penicillium treatment, there were no significant differences between these three treatments.

From the previous results, we note that all experimental treatments (seaweed, Trichoderma, and Penicillium) showed a significant increase in fruit length compared to the control. The highest increase in fruit length was in the seaweed treatment by 14.1%. These results are consistent with previous studies that demonstrated the role of seaweed in improving fruit growth by enhancing the absorption of nutrients and stimulating the hormonal growth of plants.

The study by Craigie (2011b) showed that seaweed contains hormonal compounds such as auxins and cytokinins that enhance fruit growth. The treatment with Trichoderma fungi also achieved an increase in fruit length by 13.8% compared to the control. This is consistent with previous studies that showed that Trichoderma fungi enhance the longitudinal growth of fruits by improving the absorption of nutrients and increasing tolerance to environmental stresses on plants (Harman *et al.,* 2004). Penicillium treatment also increased the length of the fruits by 12.3%, indicating its effect in improving the environmental conditions of the plants and increasing the length of the fruits. This is supported by Sivakumar *et al.* (2013), who pointed out the role of enzymes secreted by Penicillium in improving the absorption of nutrients and plant growth.

3.2 Fruit diameter (cm)

Table (1) shows that all experimental treatments were significantly superior to the control in fruit diameter. The fruit diameter value in the Trichoderma, seaweed, and Penicillium treatments was 3.34 cm, 3.22 cm, and 3.15 cm, respectively, while the fruit diameter in the control was 2.75 cm. The experimental treatments achieved increases over the control of 21.45%, 17.1%, and 14.54%, respectively. There were no significant differences between the experimental treatments. The Trichoderma treatment came first, followed by the seaweed treatment and then the Penicillium treatment.

We note from the previous results that all treatments led to a significant increase in fruit diameter compared to the control. The Trichoderma treatment achieved the highest increase in fruit diameter by 21.5%, and this result is consistent with what was mentioned by Woo *et al.* (2014b) about the effect of Trichoderma in improving fruit quality by enhancing vegetative growth. As for seaweed, it showed an increase in fruit diameter by 17.1%, which is consistent with the study by Parvez *et al.* (2017) which showed that seaweed improves fruit diameter by enhancing vegetative growth and increasing nutrient absorption. In contrast, the Penicillium group showed an increase of 14.5%, indicating that Penicillium plays a role in improving fruit size as well, as indicated by the study by Pimentel *et al.* (2011).

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3.3 Fruit size (cm³)

Table 1 shows that the Trichoderma treatment was significantly superior to all experimental treatments in the fruit size trait (by calculating the volume using the displaced water method using a 1-liter cylinder). The fruit size in the Trichoderma treatment was 107.75 cm³, with an increase of 35.72% over the control. The seaweed treatment was significantly superior to both the Penicillium treatment and the control, as the fruit size in the seaweed treatment was 117.67 cm³, with an increase of 26.08% over the control. The Penicillium treatment was also significantly superior to the control treatment in the fruit size trait with a value of 107.75 cm³, and the increase in fruit size was 15.45% over the control. The fruit size in the control was 93.33 cm³, behind all experimental treatments.

The previous results show the importance of all treatments in increasing fruit size compared to the control. Plants treated with Trichoderma fungi recorded the highest increase in fruit size by 35.72% compared to the control, which reflects the ability of the fungus to enhance fruit growth by improving soil biological activity and increasing water and nutrient absorption. These results are consistent with the findings of Meena *et al.* (2017), which showed a positive effect of Trichoderma in increasing fruit size and productivity. On the other hand, seaweed recorded a 26.1% increase in fruit size, which supports what was found by Tantawy *et al.* (2021) that the use of seaweed extracts increases fruit size. As for the treatment with Penicillium fungi, it achieved an increase in fruit size by 15.5% compared to the control, which is consistent with the results shown by studies related to improving soil fertility and increasing fruit size using Penicillium fungi (Sundararajan *et al.*, 2015).

3.4 Fruit weight (g)

Table 1 shows the superiority of the Trichoderma treatment over the other experimental treatments in the fruit weight trait. The fruit weight value in this treatment reached 116 g, and the percentage of increase in it over the seaweed, Penicillium, and control treatments reached 8.08%, 12.9%, and 26.32%, respectively. The seaweed and Penicillium treatments significantly outperformed the control treatment, with values reaching 107.33 g and 102.75 g, respectively. The percentages of increase in fruit weight reached 16.88% and 11.89% over the control, respectively. While the control treatment gave the lowest average fruit weight with a value of 91.83 g.

We note from the previous results that all treatments achieved an increase in fruit weight compared to the control. The plants treated with Trichoderma fungi recorded the highest increase at 26.4%, and this result is consistent with what was indicated by Kazemi (2013), who stated that treatment with Trichoderma fungi increases fruit weight in plants. As for the seaweed treatment, it showed an increase of 16.88%, which is in line with the study by El-Beltagi *et al.* (2019), which showed that seaweed improves fruit weight by enhancing the absorption of nutrients. As for the treatment with Penicillium fungi, it achieved an increase of 11.9%, indicating its positive role in improving the environmental conditions of plants and increasing fruit weight, as supported by the study of Sivakumar *et al.* (2013).

3.5 Number of fruits per plant

Table 1 shows that all experimental treatments were significantly superior to the control in the number of fruits per plant, as the number of fruits reached 17, 16.50, and 15.50 fruits in the Trichoderma, Penicillium, and seaweed treatments, respectively. The percentages of increase over the control in the treatments reached 41.67%, 37.5%, and 29.17%, respectively. There were no significant differences between the treatments themselves. The control gave the lowest number of fruits, with a value of 12 fruits/plant.

We note that all treatments showed an increase in the number of fruits per plant compared to the control. The Trichoderma treatment recorded the highest increase in the number of fruits, at 41.7%. This result is consistent with the study of Woo *et al.* (2014b), which indicated the effect of Trichoderma fungi in increasing the number of fruits by improving the environmental conditions of plants and reducing their impact on environmental stresses. As for the treatment with Penicillium fungi, it achieved a 37.5% increase in the number of fruits, which reflects its positive effect in increasing the number of fruits by improving soil fertility and biological activity (Sundararajan *et al.*, 2015). As for seaweed, it showed a 29.2% increase in the number of fruits, which supports the findings of the study by Tantawy *et al.* (2021) on the effect of seaweed in increasing the number of fruits.

3.6 Total productivity/plant (g)

Table 1 shows that the Trichoderma treatment was significantly superior to all other treatments in the total productivity trait per plant, with a value of 1972 g/plant, and an increase in productivity of 12.59% over the seaweed treatment, 16.32% over the Penicillium treatment, and 78.95% over the control. The Penicillium and seaweed treatments also outperformed the control treatment with values of 1695.38 g/plant and 1663.67 g/plant respectively, without significant differences between them, and with an increase in productivity rates of 53.85% and 50.97% over the control. While the control treatment gave the lowest productivity with a value of 1102 g/plant.

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We note that the results of the experiment showed a significant increase in various productive traits of plants treated with seaweed, Trichoderma fungi, and Penicillium compared to the control, indicating a clear effect of these treatments in enhancing growth and productivity. The treatment with Trichoderma fungi achieved the greatest effect in increasing the total productivity of the plant compared to the control, with an increase of 78.95%, which supports what was stated by Meena *et al.* (2017) that Trichoderma enhances total productivity by improving fruit growth and total weight. The Penicillium fungus treatment also achieved an increase of 53.85% over the control, indicating the role of Penicillium in improving total productivity by enhancing the absorption of nutrients and improving the environmental conditions of plants (Sundararajan *et al.*, 2015). As for seaweed, it increased total productivity by 50.97% compared to the control, which supports the study of Tantawy *et al.* (2021) which indicated the effect of seaweed in increasing productivity.

IV. CONCLUSIONS

The previous results show that all treatments used in the study (Trichoderma fungus, seaweed, Penicillium fungus) outperformed the control in all studied traits (length, diameter, size, and weight of the fruit, number of fruits per plant, and productivity per plant). There were no significant differences between the experimental treatments (Trichoderma fungus, seaweed, Penicillium fungus) in the traits of length and diameter of the fruit and number of fruits per plant. The treatment with Trichoderma fungus significantly outperformed the seaweed and Penicillium treatments in the trait of fruit size, weight, and total productivity per plant. The seaweed treatment also significantly outperformed the treatment with Penicillium fungus in the trait of fruit size. Finally, the different treatments (Trichoderma fungus, Penicillium fungus, seaweed) achieved an increase in productivity of 78.95%, 53.85%, and 50.97%, respectively, compared to the control. These results demonstrate the great effectiveness of seaweed, Trichodermafungi, and Penicillium fungi in improving the productive characteristics of plants, both in terms of increasing the length, diameter, and size of fruits and in terms of the weight and number of fruits per plant and thus the total productivity per plant. These results are also largely consistent with previous scientific research, which confirms the importance of using these biological and organic treatments as part of sustainable strategies to improve agricultural production.

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