

## IMPACT OF SILICON AND SOME RHIZOBIAL SPECIES ON GROWTH AND PRODUCTIVITY OF TOMATO UNDER DIFFERENT IRRIGATION PERIODS-NORTH SINAI

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Irrigation period is one of the significant factors affecting the growth, productivity, and yield of tomato plants. The study of increasing the period irrigation on tomato production is an important study of the effect of drought. The present investigation was carried out during the seasons of 2020/2021 in newly reclaimed arid land in the Agricultural Experimental Station of the Desert Research Center at Baloza Station, North Sinai Governorate (31° 32' 03" N and 32° 36' 03" E). The experimental results indicated that the increase in irrigation periods and foliar spraying foliar with silicon and microbial rhizobia in addition to the recommended doses of mineral fertilizers led to an increase in the yield of fresh and dry yield of tomato fruit and the nutrients content of leaves and fruits significantly increased. The average of tomato fruits accumulated in excess of biomass as total protein and total antioxidant content were increased by foliar spraying with silicon and also by inoculation of roots of the seedling by rhizobia. Proline content and water usage efficiency (WUE) in fruits were enhanced by various irrigation regimes. In comparison to the control, the irrigation water use efficiency (WUE) and proline content rose with the application of silicon and rhizobia but with less irrigation time. The microbial densities and activity under drought stress were boosted by the simultaneous application of silicon and rhizobia. It is notable that, soil dehydrogenase increased significantly with increasing irrigation period from 60 to 120 min, the highest mean values (1.031  $\mu\text{mol}$  triphenyl formazan/g dry soil) were recorded at 120 min of field capacity of water requirement.

**Keywords:** tomato, silicon, rhizobia, irrigation periods, antioxidant activity, proline content, sandy soil

## INTRODUCTION

Tomato is an important vegetable crop and is grown all over the world in open fields, greenhouses and net houses in addition to being tasty; tomatoes are a very good source of vitamins A and C (Farooq et al., 2005). Moreover, tomato is a model plant of theoretical and practical significance in research (Arie et al., 2007). Although some studies have been carried out on the photosynthesis of tomato under drought stress (Brix, 2010 and Jangid and Dwivedi, 2016), these studies are not systematic and comprehensive. Thus, in this study, the combination measurement of photosynthetic gas exchange, chlorophyll fluorescence, and antioxidant enzyme activities were used to identify key regulatory photosynthesis circuits under drought stress. Abiotic stress negatively influences plant growth and development, leading to heavy losses in global agriculture (Verma, 2016). Crop growth and productivity are both hampered by drought. People now live on a globe that is hotter and more arid due to human-caused global warming. In the next 30 years, it is anticipated that this scenario will worsen, and by 2050, it is anticipated that more than 50% of the world regions will experience water scarcity (Gupta et al., 2020).

The growth, production, and yield of tomato plants are significantly impacted by a number of environmental conditions, including drought stress. A complete understanding of this stress factor effects will be crucial in identifying the influence of climate variability on tomato growth. Physiology, growth, development, yield, and quality of the tomato crop are only a few of the processes that are impacted by drought stress. Massimi (2021) found a complex relationship between the effects of drought stress on the physiology and development of tomato plants and the uptake of nutrients. Drought stress severely hampers the plant growth and development starting from the germination until maturity. Decrease in growth occurs due to impaired cell division and elongation because of limited turgor. Germination and stand establishment are reducing due to lowered water potential and imbibition (Anjum et al., 2017). Liang et al. (2020) showed that drought inhibits the photosynthesis of tomato significantly, as shown by a clear decline in the net photosynthetic rate. Stomata limitation and nonstomatal limitation were responsible for the photosynthesis reduction.

Silicon (Si) is the second most abundant element in soil. However, Si is not considered an essential element. Recently, numerous studies have shown that treatment with Si significantly alleviated salt, drought, chilling and freezing stress in plants. The Si treatment is considered beneficial to plant growth and production (Liang et al., 2007 and Ma and Yamaji, 2008). Trenholm et al., (2004) have suggested that silicate crystals deposited in epidermal cells form a barrier that reduces water loss through the cuticles. More recently, Si benefits on salt tolerance of barley and cucumber have

been related to antioxidant enzyme activity (Liang et al., 2003; Al-aghaby et al., 2004 and Zhu et al., 2004). Silicon improves the water storage within plant tissues, which allows a higher growth rate that, in turn, contributes to salt dilution into the plant, mitigating drought toxicity effects (Mercedes et al., 2006). Results on the beneficial effects of Si in enhancing the tolerance of plants to biotic and abiotic stresses in several crops, and its relevance to the world of the agriculture have been widely described (Datnoff et al., 2001 and Ma, 2004).

Rhizobium belongs to family Rhizobiaceae and is involved in the conversion of atmospheric-N, that is,  $N_2$  into ammonia ( $NH_3$ ), the process known as biological nitrogen fixation (BNF). On the other hand, apart from the atmospheric N fixation in the legumes, rhizobacteria also play an important role in enhancing the growth and productivity of the non-legumes. As a result, they could also function as PGPR in non-nodulating plants. Antioxidants, catalase, osmolytes, stress proteins, and exopolysaccharides are most likely produced by rhizobia to survive under harsh environments particularly drought (Melo et al., 2022; Nishu et al., 2022 and Uzma et al., 2022). However, rhizobia have been observed to survive under drought up to  $-1.25$  MPa (Haghighi et al., 2022).

The ability of these Rhizospheric bacteria to survive extreme water deficits can be used to help plants adapt with drought (Haghighi et al., 2022 and Yuan et al., 2022). They can make plants more tolerant to stress by causing physical and chemical changes in them (Ben-Laouane et al., 2021). Rhizobia have been found to have a variety of stress-relieving and plant-growth-improving processes, including the synthesis of chaperons and sugars (Bogati and Walczak, 2022), synthesis of stress enzyme 1-aminocyclopropane 1-carboxylic acid (Chandwani and Amaresan, 2022), exopolysaccharides production (Zhu et al., 2022), production of low molecular weight organic compound like trehalose (Wang et al., 2022), phosphate solubilization, improved nutrient availability (Ben-Laouane et al., 2021), production of siderophores (Moon and Ali, 2022), phytohormones production (Etesami, 2022), and enhanced root respiration by influencing plant physiology. Until recently, rhizobial inoculation has only been tested in irrigated circumstances to improve the growth and productivity of cereals (rice, maize, and wheat) (Ahmad et al., 2022). As a result, rhizobia would be useful in reducing the impact of drought on wheat seedling growth (Ben-Laouane et al., 2021; Bogati and Walczak, 2022 and De Sousa et al., 2022).

Accumulation and distribution of drought in different plant organs, plant water uptake, leaf osmotic and turgor potentials and gas exchange parameters were studied in relation with plant growth of drought stressed plants supplied with and without Si. The objective of this study was to propose and discuss future challenges and directions in crop drought resistance.

## MATERIALS AND METHODS

### 1. Isolation and Identification of Efficient *Rhizobium* Isolates

Selective rhizobia were isolated from the root nodules of three legumes (*Arachis hypogaea*, *Medicago sativa* and *Pisum sativum* plants). The isolates were identified as *Bradyrhizobium* (RS1), *Sinorhizobium* *Rhizobium meliloti* (RS2) and *Rhizobium legumino-sarum* (RS3). The plants were dug up with non-rhizosphere soil to avoid damage to the roots and nodules. These plants were transferred to the laboratory in polythene bags. Non-rhizosphere soil was removed by gentle shaking and further adhering soil was removed by washing the roots with tap water. Nodules were cut from the roots with a sterilized razor blade and collected in separate Petri dishes. Disinfection of nodules was done by dipping in ethanol (95%, v/v) for 10 s and 5% (v/v) sodium hypochlorite for 10 min followed by thorough rinsing with sterilized water (Abd-Alla et al., 2012). Sterilized nodules were rolled on the Petri dishes containing autoclaved yeast extract mannitol (YEM) agar medium and incubated at  $28\pm 1^\circ\text{C}$  for 72 h to confirm the sterilization (Muzzamal et al., 2012). These surface-sterilized nodules were crushed with a sterilized glass rod in separate sterilized test tubes containing sterilized distilled water. Homogenate suspensions were streaked in Petri dishes containing autoclaved YEM agar medium and incubated at  $28 \pm 1^\circ\text{C}$  (Kenasa et al., 2014). Further streaking for isolation was performed three to four times to obtain pure cultures of the different isolates. Three fast growing isolates were collected, coded as rhizobial strain (RS) with numbers and preserved in glycerol at  $-20\pm 1^\circ\text{C}$ . These isolates were confirmed as rhizobia by streaking on congo-red agar plate (Grams test) and by studying their colony morphology. The Gram reaction of the isolates was tested by Gram staining (Arora, 2003) and biochemical tests were performed on the isolates, according to Bergey's Manual of Determinative Bacteriology (Holt et al., 1994) presented in Table (3).

### 2. Plant Growth Promoting Activities

The ability of selected isolates to produce indole acetic acid (IAA) and their phosphate dissolving activity and exopolysaccharides (EPS).

#### 2.1. Indol acetic acid (IAA) production

Indole acetic acid (IAA) production was measured using spectrophotometer as described by Gusmiaty et al. (2019).

#### 2.2. Phosphate dissolving activity

The phosphorus solubilization index (PSI) and soluble P quantity were calculated on Pikovskaya medium using the methods of Page et al. (1982) and Kumar and Narula (1999). Tabatabai and Brimmer (1969) method was used phosphatase activity after three days of bacterial inoculation.

### 2.3. Exopolysaccharide (EPS) production

Rhizobium isolates were tested to produce EPS according to Damery and Alexander (1969).

### 3. Organic Acid Production

The potential to produce organic acids was discovered when the color of bromothymol blue colored agar media changed from blue to yellow/orange (Vincent, 1970).

### 4. Drought Tolerance Assay

The ability of isolates to grow in the presence of different osmotic potentials was examined; polyethylene glycol 6000 (PEG) compounds have been used to stimulate drought stress effects. The concentration of PEG-6000 for each water stress was determined using the equation of Villela et al. (1991).

$$\text{Water potential (MPa)} = (-1.18 \times 10^{-2}) C - (1.18 \times 10^{-4}) C^2 + (2.67 \times 10^{-4}) CT + (8.39 \times 10^{-7}) C^2T$$

where C is the concentration of PEG-6000 in g/l H<sub>2</sub>O and T is the temperature in Celsius degree. Bacterial isolates were cultured in test tube containing 9 ml YEM broth medium supplemented with different concentrations of PEG 6000 (60, 100 and 140 g/l) to generate osmotic potential of -0.52, -1.23 and -2.24 MPa, respectively. Tubes were incubated in an orbital shaker (100 rpm) at 30°C for 48 h and optical density was measured at 600 nm by a spectrophotometer (Jenway 6105 U.V/ V.S spectrophotometer) by measuring the absorbance (OD) at 570 nm as described previously by Esmael et al. (2021).

### 5. Screening of *Rhizobia* for Plant Growth Promoting Activity Under Drought

#### 5.1. Proline production

Proline production was estimated as described (Abou-Aly et al., 2019); 2.0 ml of bacterial supernatant and 2.0 ml of glacial acetic acid were added to 2.0 ml of acid ninhydrin (2.5 g of ninhydrin in 60 ml of glacial acetic acid and 40 ml of 6 M phosphoric acid with warming until it melted) in a glass tube, and put in a boiling bath for 1 h, moved to an ice bath. After that, 4.0 ml of toluene was mixed vigorously for 15–20 s. The absorbance was read at 520 nm and toluene was used as a blank.

#### 5.2. Antioxidant activities

For the three isolates, 0.1 ml of cell-free supernatant and under PEG 6000 stress condition (at concentration of -0.52, -1.23 and -2.24 MPa) was mixed with 3 ml of reagent solution (0.6 M sulphuric acid, 28 mM sodium phosphate and 4 mM ammonium molybdate). The tubes were incubated at 95°C for 90 min. The mixture was cooled to room temperature, and then the

absorbance of the solution was measured at 695 nm against the blank. The total antioxidant activity was expressed as ascorbic acid equivalents (AAE) in milligrams per gram of extract (Prieto et al., 1999).

### **6. Bacterial Inoculums Preparation for Plant Bacterization**

Fresh cells were grown in yeast extract mannitol (YEM) broth medium at room temperature in a shaker. From this, 100 ml of YEM broth in a 250 ml flask was inoculated and incubated for 48 h at room temperature in a rotary shaker (100 round/min). The bacterial culture was centrifuged (10000 rpm for 10 min) and the supernatant was discarded. The cell pellet was resuspended in sterile 0.85% NaCl and centrifuged again under the same conditions. The supernatant was discarded and washed bacterial cells were resuspended in sterile distilled water (SDW). The concentration of cells in the suspension was spectrophotometrically adjusted to  $10^8$  CFU/ml and used for field experiments. This experiment was conducted ones using plan treatment with cell suspensions. For seedling soaking, 40 days old tomatoes seedlings were soaked with that suspension of bacterial cells (108 cfu/ml) while control replicates were treated with water.

### **7. Field Experiment**

The present investigation was carried out during the seasons of 2020/2021 in newly reclaimed arid land in the Agricultural Experimental region of the Desert Research Center at Baloza Research Station, North Sinai Governorate (31°32'03" N and 32°36'03" E). The experiment was planned in a split-plot design with three replicates. The main plots were applying of three levels of irrigation periods as 30, 60 and 120 min. The subplots included of control, Si, mixture of rhizobial isolates (MRS) and complex of Si + MRS. Silicon was foliar sprayed one level as 500 mg Si/l and mixture of rhizobial isolates (MRS) was added with 300 ml rhizobia extract/fed.

Tomato seedlings "hybrid Marwa" were used in these experiments. Seedlings were transplanted on 20 of October 2020 when plants were 40 days old. All agriculture practices were performed as recommended by Egyptian Ministry of Agriculture and Land Reclamation for tomato cultivation under open field conditions. Tomato seedlings (*Solanum lycopersicum* L.) were sown directly in the sandy soil under drip irrigation system in rows; 1.5 m apart and 0.5 m within hills. Tomato plants were thinned after germination at two plants per hill (5600 seedling/fed). The area of the experimental plot was 22.5 m<sup>2</sup> consisted of one row with 15 m length and 1.5 m width. MRS was obtained from Micro Production Unit at the Desert Research Center, Egypt.

The MRS were applied as foliar spray before sowing using rates of 300 ml/fed. The concentrations of K-silicate (25% SiO<sub>2</sub> and 10% K<sub>2</sub>O) application were 2 ml/l. First spray of K-silicate was done when the seedlings reached the stage of 6 true fully expanded leaves (about two weeks after transplanting from the second to the fourth sprays, the application was

carried out every three weeks later from the previous one. Total number of foliar applications was four times. These treatments applying under three periods of irrigation as drip irrigation was used with drippers (4 l/h/hill) for only one hour every two days.

All treatments received 150 kg N/fed as ammonium sulphate (20.5% N) added on three doses as 25: 50: 25% from recommendation doses, 30 kg P<sub>2</sub>O<sub>5</sub> added as calcium super phosphate (15% P<sub>2</sub>O<sub>5</sub>) and K sulphate 120 kg K<sub>2</sub>O/ fed, P and K were added twice doses and compost as organic manure at rate of 20 m<sup>3</sup>/fed and was added during soil preparation. Fruit samples were taken from the three harvests at red ripe stage from each experimental plot to determine fruit quality parameters, *i.e.*, total antioxidant activity (AAE) using methanol (50%) (Prieto et al., 1999) and proline acid as described by Slinkard and Singleton (1977). Leaves were taken from the fourth upper of tomato stem of eight randomly collected plants after 90 days from transplanting, washed with distilled water, dried with paper towels, then dried at 70°C and wet digested (Van Schouwenberg and Ch, 1968) for the determination of N, P and K (A.O.A.C., 1990). Physical and chemical properties of the cultivated soil were evaluated in samples taken before tomato planting according to standard procedures reported by Chapman and Pratt (1978) and presented in Table (1).

**Table (1).** Initial status of some physical and chemical properties of the experimental soil (0-30 cm depth).

Soil depth (cm)	pH (1:2.5)	EC (dS/m) (1:2.5)	Texture Class	Soluble Cations (meq/l)				Soluble Anions (meq/l)			
				Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>	CO <sub>3</sub> <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>=</sup>	Cl <sup>-</sup>
0-30	8.23	0.73	Sandy	1.63	2.11	2.75	0.84	nil	1.31	2.71	3.33
<b>Available nutrients (mg/kg)</b>				<b>N</b>	<b>P</b>	<b>K</b>	<b>Fe</b>	<b>Mn</b>	<b>Zn</b>	<b>Cu</b>	
				12.6	4.56	54.3	5.52	2.18	0.97	0.28	

pH: acidity, soil extract (1 :2.5), EC: Electrical conductivity meq/l: milliequivalent per liter.

The following data of soil and irrigation water were analyzed at the laboratories of Desert Research Center, as shown in Tables (1 and 2). El-Salam Canal irrigation water was used, and chemical analysis of the irrigation water was presented in Table (2).

**Table (2).** Chemical analysis data of the applied irrigation water

pH	E.C (dS/m)	Soluble cations (meq/l)				Soluble anions (meq/l)				SAR
		Ca <sup>++</sup>	Mg <sup>++</sup>	Na <sup>+</sup>	K <sup>+</sup>	CO <sub>3</sub> <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>=</sup>	Cl <sup>-</sup>	
7.79	1.76	3.38	2.41	11.12	0.71	Nil	1.28	5.21	11.13	6.54

pH: acidity, soil extract (1 :2.5), EC: Electrical conductivity meq/l: milliequivalent per liter.

All data were subjected to statistical analysis using MSTAT-C software. The comparison among means of the different treatments was determined, as illustrated by Snedecor and Cochran (1982). Means of the treatments were compared by Duncan Test.

## RESULTS AND DISCUSSION

### 1. Isolation and Identification of Bacteria

From the nodules of legume plants, the bacteria that caused root nodulation were discovered. All isolates were Gram-negative and did not absorb the congo red dye when grown in YEMA. Biochemical tests were carried out to identify rhizobia bacteria and the results of these tests are reported in Table (3).

**Table (3).** Characterization of efficient rhizobium isolates.

Morphology	Rhizobial spp.		
	<i>Bradyrhizobium</i>	<i>Sinorhizobium</i>	<i>Rhizobium</i>
Gram stain	-	-	-
Shape	circular	spherical	circular
Color	whitish pink	white	white
<b>Biochemical activity</b>			
Growing N <sub>2</sub> fixing	slow	fast	fast
Catalase activity	+	+	+
Urea hydrolysis	+	+	+
Growth in 4% agar (Motility)	+	+	+
Acid reaction in litmus milk	-	-	-
Citrate utilization	-	-	-
Growth in 8% KNO <sub>3</sub>	+	+	+
Gelatin hydrolysis	-	-	-
NO <sub>3</sub> reduction	-	-	-
Oxidase activity	+	+	+
Ability to produce H <sub>2</sub> S growth on HAM	-	-	-
Acid production	+	+	+
Starch hydrolysis	-	-	-

(+) Positive result, (-) Negative result.

In this study, all three rhizobial isolates were screened *in vitro* for plant growth promoting properties such as IAA production, phosphate solubilization, EPS production, and organic acid production, as shown in Table (4). The data revealed that all three isolates were IAA producers, phosphate solubilizers, EPS producers, and organic acid producers of organic acids.



**Table (4).** Plant growth promoting characteristics of rhizobial isolates.

Testes	<i>Bradyrhizobium</i>	<i>Sinorhizobium</i>	<i>Rhizobium</i>
IAA production ( $\mu\text{g/ml}$ )	52	26	73
Phosphate dissolving activity (ppm)	122	231	126
EPS (mg/100 ml)	280	320	338
Organic acid	+	++	+

Indole acetic acid (IAA) is a phytohormone that promotes plant development directly. The amount of IAA produced varied from isolate to isolate, with relatively high amounts of 73  $\mu\text{g/ml}$  in *Rhizobium*, followed by 52  $\mu\text{g/ml}$  in *Bradyrhizobium*, and lower amounts was 26  $\mu\text{g/ml}$  in *Bradyrhizobium*. Phosphate solubilization efficiency was the highest in *Rhizobium* isolate *Sinorhizobium* (231 ppm), followed by *Rhizobium* (126 ppm) and *Bradyrhizobium* (122 ppm), respectively. *Rhizobium* (338 mg/100 ml) had the highest EPS production, followed by *Sinorhizobium* (320 mg/100 ml) and *Bradyrhizobium* (280 mg/100 ml) produced the least amount of EPS. The foregoing results clearly show that these isolates are EPS producers in large quantities. Plants benefit from exopolysaccharide production by rhizobium isolates for a variety of reasons, including drought stress relief and phosphate solubilization (Palhares Farias et al., 2022 and Szewczuk et al., 2022). Rhizobia create exopolysaccharides, which assist in the formation of biofilms in which they are protected from the elements and have access to water and nutrients (De Sousa et al., 2022). The accumulation of osmolytes and changes in cellular shape have previously been identified as potential strategies for rhizobia to protect themselves against drought stress (Lahlali et al., 2022). According to Rempel et al. (2022), EPS-producing rhizobacteria play a vital role in ameliorating the negative effects of reactive oxygen species (ROS) by enhancing antioxidant activity. All three isolates produced organic acid, which enhanced nutrient mobilization by reducing rhizosphere pH.

## 2. Drought Tolerance Assay

The isolates' optical density dropped as the PEG concentration in the medium rose (0 PEG, -0.05 MPa; % PEG, -1.23 MPa; 10% PEG, and 14 percent PEG, -2.24 MPa) (Table 5). Under standard circumstances (0 PEG), the rhizobial isolate *Sinorhizobium* outperformed *Bradyrhizobium* in terms of OD. However, isolate *Rhizobium* displayed the lowest OD when things were normal. Isolates of *Bradyrhizobium* and *Rhizobium* performed poorly under drought stress caused by 6% PEG, whereas *Sinorhizobium* stood out among the isolates. In a 10% PEG-induced drought, *Sinorhizobium* outperformed the other isolates, with *Bradyrhizobium* and *Rhizobium* coming in second and third, respectively. The pattern changed when the PEG concentration was increased to 14%, with isolate *Bradyrhizobium* emerging

as the isolate with the highest tolerance to drought, followed by isolates of *Sinorhizobium* and *Rhizobium* by separating each rhizobial isolate drought sensitivity.

**Table (5).** Effect of different PEG 6000 concentrations (MPa) on optical density, proline and antioxidant.

Isolates	Properties	PEG 6000 (%)			
		0	6	10	14
<i>Bradyrhizobium</i>	Optical density	1.24	0.92	0.75	0.71
	Proline	38.50	39.10	41.90	80.80
	Antioxidant	39.70	56.70	40.70	21.70
<i>Sinorhizobium</i>	Optical density	1.35	1.15	1.02	0.57
	Proline	26.20	31.70	46.30	66.00
	Antioxidant	32.60	36.80	30.50	13.20
<i>Rhizobium</i>	Optical density	1.19	0.82	0.68	0.22
	Proline	36.30	52.10	78.10	96.60
	Antioxidant	21.70	30.10	26.70	9.70

### 3. Proline Accumulation Under Drought Stress

Table (5) shows the production of proline by drought-tolerant bacterial isolates under unstressed conditions (NS) and various PEG 6000 stressed concentrations (-0.52, -1.23 and -2.24 MPa). When comparing proline production at different PEG concentrations to that under unstressed settings, proline production increased. Isolate *Rhizobium* produced the highest amounts of proline in unstressed circumstances and media supplemented with varying doses of PEG. Proline by *Rhizobium* was higher than that of the other isolates in this regard. Meanwhile, *Sinorhizobium* reported the lowest proline levels. Proline accumulation is one of the stress response mechanisms, and plants with high proline content have been found to have improved drought tolerance. Amine-Khodja et al. (2022) reported that a large number of researches have shown that soluble sugar, proline, and antioxidant buildup increases plant drought resistance (Kaur et al., 2022 and Sita et al., 2022). Plants store ions and metabolites, primarily proline, in their vacuoles, which lower the osmotic potential of plant cells and keep turgor pressure high, allowing plants to sustain their metabolic and physiological processes (Jiménez-Mejía et al., 2022 and Rajput et al., 2022). Proline is an antioxidative defense and signaling molecule in addition to being an osmolyte. Plants inoculated with rhizobial isolates had higher proline levels when water was scarce. The up-regulation of the proline biosynthetic pathway resulted in a larger concentration of proline in the cell, which aids in the preservation of the cell water status and protects the membranes during drought stress (Saha et al., 2022).

#### 4. Antioxidants Activity Under Drought Stress

The antioxidant activity of the isolates increased as the PEG concentration was raised (0 PEG, -0.05 MPa; 6% PEG) but decrease in the presence of -1.23 MPa; 10% PEG, and 14% PEG, -2.24 MPa of the medium (Table 5). *Bradyrhizobium*, a rhizobia isolate, produced the most antioxidant 39.7 to 56.7 µg/ml under 0 and 6% PEG conditions, followed by *Sinorhizobium* (32.6 to 36.8 µg/ml). The antioxidant content in isolate *Rhizobium*, on the other hand, was the lowest 21.7 to 30.1 µg/ml. At 10% and 14% PEG, *Bradyrhizobium* performed best among the isolates (40.7 to 21.7 µg/ml), followed by *Sinorhizobium* (30.5 to 13.2 µg/ml) and *Rhizobium* (26.7 to 9.7 µg/ml). Drought tolerance was best achieved by isolate *Bradyrhizobium*, then isolates *Sinorhizobium* and *Rhizobium*, in that order. The direst problems of oxidative stress occur at the cellular level, and this injury is caused by an imbalance between the synthesis and detoxification of ROS. Plants produce antioxidant enzymes such as catalase, superoxide dismutase, peroxidase, glutathione peroxidase, and ascorbate peroxidase, which detoxify reactive free radicals at the cellular level by SOD (Zandi and Schnug, 2022). Catalase is found in cell peroxisomes and protects cells by catalyzing the breakdown of H<sub>2</sub>O<sub>2</sub> into O<sub>2</sub> and H<sub>2</sub>O. Higher plants have peroxidase (POD), which catalysis the oxidation of phenolic substrates and protects plant cells from harm (Rangseekaew et al., 2022). The action of antioxidant enzymes was altered in the presence of stress. Damage to the leaves can indicate a variety of pressures, such as an increase in membrane lipid peroxidation due to a decrease in antioxidant enzyme activity (Haghighi and Saharkhiz, 2022).

#### 5. Fruits Fresh Yield and Dry-Matter Production

There was interaction between irrigation periods (T) and fertilizer as recommended doses from mineral fertilizers only or with Si application or/and rhizobia [(recommended doses from mineral fertilizers (R.D.) or R.D. + Si or R.D. + rhizobia or R.D. + Si + rhizobia)]; in particular, the individual factors of irrigation or fertilizers affected fruits yield, all fruit dry-matter and yield in highly significant way ( $p < 0.05$ ) (Fig. 1 and 2). Fruit dry-matter and fresh yield were more sensitive to irrigation than fertilizers.

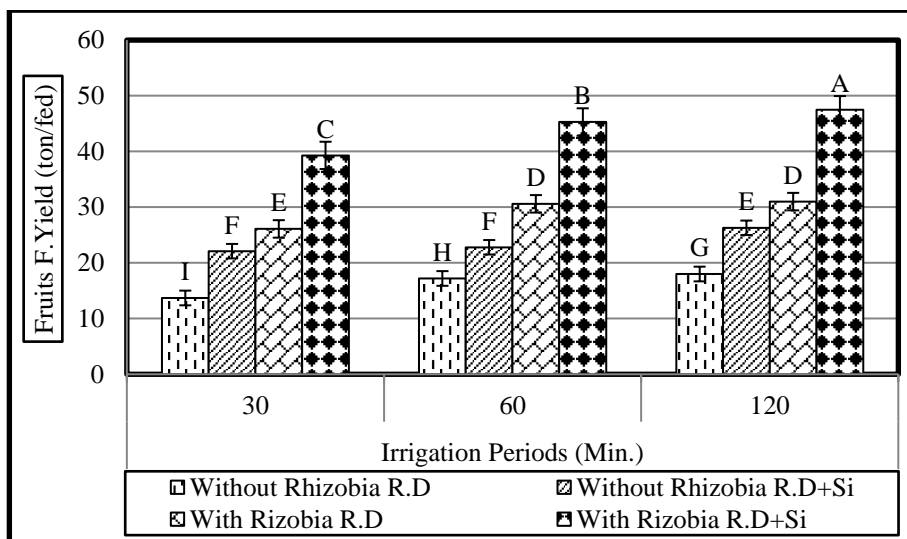
Regarding the effect of irrigation periods on fruits fresh and dry-matter yield, results in Fig. (1 and 2) show that increasing irrigation periods significantly increased the fruits fresh and dry-matter yield. The increases reached to about 14.6 and 21.5% by raised irrigation periods 60 and 120 min, respectively. This result back up to improves the nutrient uptake and must enhance the efficient use of both soil water and nutrient fertilizer.

There was effect of fertilizers on fruits fresh and dry-matter yield, results showed that increasing application of Si and rhizobia with R.D. of mineral fertilizers increased the fruits fresh and dry-matter yield. The

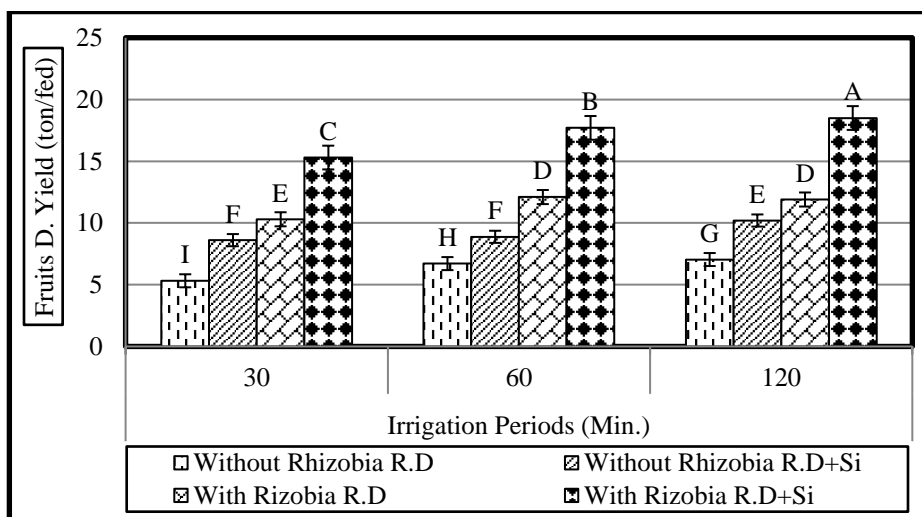
increases of the fresh and dry-matter yield of tomato fruits reached by 45.6 or 79 or 170% at addition of R.D. + Si or R.D. + rhizobia or R.D. + Si + rhizobia, respectively. It was noticed that the highest fruits dry-matter and fresh yield were 17.2 and 44.1 ton/fed, respectively, when fertilizing by R.D. + Si + rhizobia of tomato plants compared with control treatment. This is due to that Si treatments have been beneficial to plant growth and production (Liang et al., 2007 and Ma and Yamaji, 2008). As indicated by Mercedes et al. (2006), about the role that Si plays in plant, it improves plant tissues, improves its water storage capacity, and in turn contributes to the dilution of salt in the plant, which mitigates the effects of drought toxicity. Also, it was found that microorganisms regulate plant resistance to drought by regulating the physiological and biochemical properties of the plant. Due to the limitations of traditional technology, the gene network through which rootstock microorganisms regulate host plant drought resistance is unclear (Zhang et al., 2021).

With respect to the interactions, results show a significant effect on the yield of both fresh and dry fruits. For the interaction of irrigation periods and fertilizers, it is noticed that the longest irrigation periods  $T_{(120 \text{ min.})}$  and fertilizing by R.D. + Si + rhizobia revealed that the highest yield of fresh and dry fruits reached 47.5 and 18.5 ton/fed, respectively, indicating an increase by about 248% compared with control treatments (R.D.), while there were no significant difference between  $T_{(120 \text{ and } 60 \text{ min.})}$  with R.D. + rhizobia treatments. Also, there were no significant difference between  $T_{(120 \text{ min.})}$  with R.D. + Si and  $T_{(120 \text{ min.})}$  with R.D. + rhizobia treatments, while being no significant difference between  $T_{(60 \text{ and } 30 \text{ min.})}$  with R.D. + Si treatments. This result back up to Si role in the plant, as it improves plant tissues, improves its ability to store water and in turn, contributes to salt dilution into the plant, mitigating drought toxicity effects (Mercedes et al., 2006).

These results agree with Wang et al., (2019), who studied the effect of mineral fertilization under irrigation regimes on fruit of tomato yield. The reasons for these results were interaction between water use and nutrients techniques usually rely on management skills but the concurrent yield improvement must also be taken as a combined effect of soil factors and root characteristics. It is a well-known fact that most plant roots require an adequate and continues supply of soil water and nutrients to grow, develop, and function normally. Furthermore, good agronomic management must improve the nutrient uptake and must enhance the efficient use of both soil water and nutrient fertilizer. Yield was significantly increased by the increase of the irrigation amount from  $T_{(30 \text{ min.})}$  to  $T_{(120 \text{ min.})}$ .



**Fig. (1).** Effect of different irrigation periods, silicon and rhizobia mixture on fresh yield of fruits.



**Fig. (2).** Effect of different irrigation periods, silicon and rhizobia mixture on dry yield of fruits.

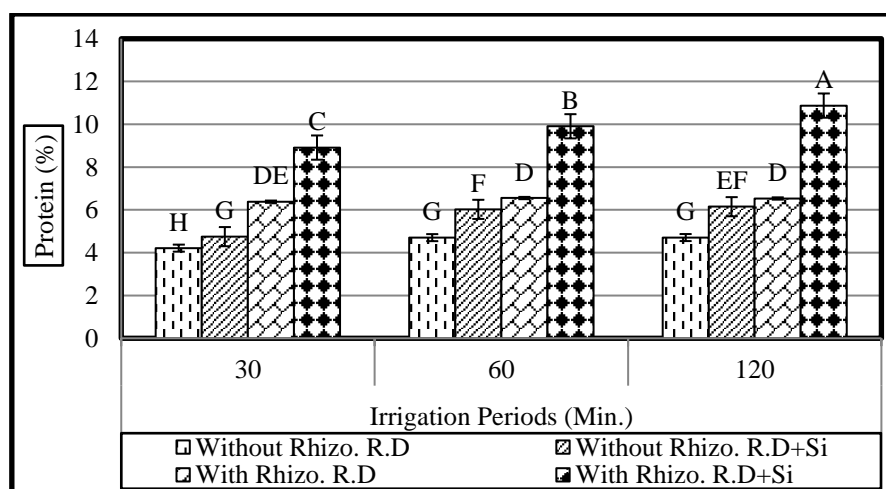
**6. Fruits Biochemical Content**

Tomato is well known for its response to fertilization and irrigation water. So, the individual factors of the irrigation, rhizobia or Si affected protein content, total antioxidant (AAE) and proline content. However, there were significant differences in the protein content between irrigation levels.

By extending watering times to 60 and 120 min, respectively, the increases reached 12 and 16.5%, respectively. This outcome supports the increased nutrient uptake and must improve the effective use of both soil water and fertilizer containing nutrients. Because of this, nitrate-N leaching throughout the growth season can be considerably reduced with proper irrigation management (Quemada et al., 2013). Furthermore, a precise N supply combined with good irrigation may not only reduce nitrate-N leaching loss but may also help the roots system to grow healthily and with better nutrient uptake, thus ensuring an increase in yields (Wang et al., 2019).

There was an effect of fertilizers on protein content of fruits; results showed that increasing application of Si and rhizobia with R.D. of mineral fertilizers increased the fruits protein yield. The increases of the protein yield of tomato fruits reached 24.4 or 43 or 118% at addition of R.D. + Si or R.D. + rhizobia or R.D. + Si + rhizobia, respectively. Rhizobia led to significant increase in the protein content in the fruits by 61% compared with control treatment because to the role of plant growth-promoting rhizobacteria as a type of bacteria that live in the rhizosphere or as epiphytes in roots and have positive effects on the growth, nutrient uptake, and systemic stress resistance of their host plants (Vurukonda et al., 2016). Moreover, Si application raised protein by 40.8% compared with other due to that Si treatments were considered beneficial to plant growth and production (Liang et al., 2007 and Ma and Yamaji, 2008).

With respect to interaction effect of fertilizers with irrigation levels on protein results (Fig. 3) showed that it reached 158% with  $T_{(120 \text{ min.})}$  and fertilizing by R.D. + Si + rhizobia, compared with control treatment. Nevertheless, protein content was similar with  $T_{(60 \text{ min.})}$  and  $T_{(120 \text{ min.})}$ .



**Fig. (3).** Effect of different irrigation periods, silicon and rhizobia mixture on protein content of fruits.

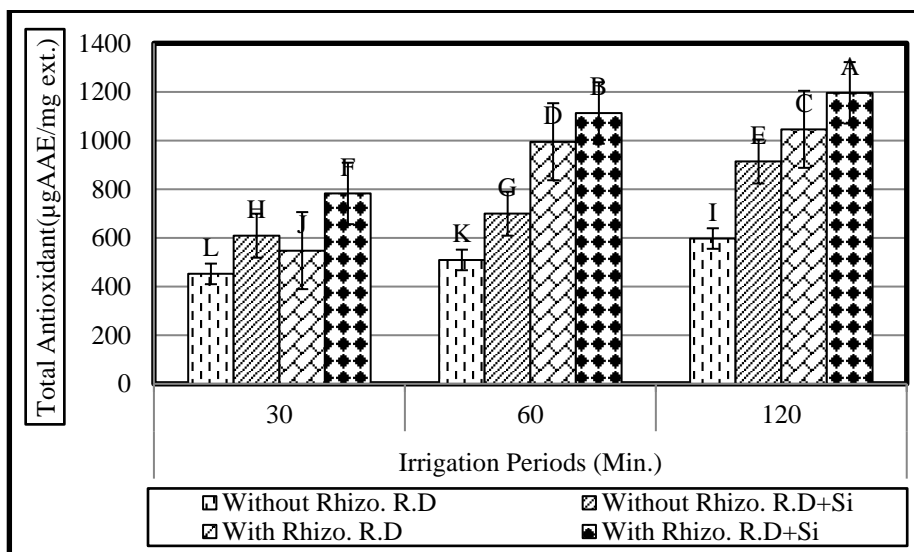
The interaction between rhizobia, Si application and  $T_{(120 \text{ min.})}$  gave (10.9%) the highest protein concentration of fruits, while there were no significant difference between  $T_{(120, 60 \text{ and } 30 \text{ min.})}$  with R.D. + rhizobia treatments; it is due to the role that rhizobia for systemic stress resistance of their host plants. Also, there were no significant difference between  $T_{(120 \text{ and } 60 \text{ min.})}$  with R.D. + Si treatments and it was found that no significant difference was observed between  $T_{(30 \text{ min.})}$  with R.D. + Si treatments and  $T_{(60 \text{ and } 120 \text{ min.})}$  with R.D. It is due to that Si plays a role in reducing the effect of stress on the plant, as previously mentioned. This agrees with (Melo et al., 2022 and Nishu et al., 2022), who studied the role of rhizobia on plants under water stress conditions, they found that rhizobia has an effective role in the production of stress proteins to survive under harsh environments particularly drought.

The results obtained from the estimation of total antioxidants in tomato fruits indicated that there is a clear relationship between the concentration of antioxidants and irrigation periods. It was found that the increase in the duration of irrigation led to an increase in total antioxidant (TAA) by 38.7 and 57% by raised irrigation periods to 60 and 120 min, respectively. This result back up to improve the nutrient uptake and must enhance the efficient use of both soil water and nutrient fertilizer. Also, the relationship of fertilization with Si and rhizobia with the concentration of antioxidants in fruits was a direct relationship, as the results shown in Fig. (4) show that fertilizing with Si and rhizobia, in addition to adding the recommended rates of mineral fertilization to a significant increase in the concentration of antioxidants by 42.6, 66 and 98% with addition R.D. + Si or R.D. + rhizobia or R.D. + Si + rhizobia, respectively.

The double interaction between irrigation levels with fertilizers by Si and rhizobia, in addition to adding the recommended rates of mineral fertilization to a significant increase in the concentration of antioxidants by increased TAA by 165% with  $T_{(120 \text{ min.})}$  compared with  $T_{(30 \text{ min.})}$ . Silicon application with inoculation by rhizobia under third irrigation level increased TAA by 1196 ( $\mu\text{g AAE/mg ext.}$ ). Also, there was no increasing of total antioxidant clearly between  $T_{(60 \text{ min.})}$  (1113  $\mu\text{g AAE/mg ext.}$ ) and  $T_{(120 \text{ min.})}$  (1196  $\mu\text{g AAE/mg ext.}$ ). The values of total antioxidant in tomato fruits were significantly greater in  $T_{(60 \text{ and } 120 \text{ min.})}$  than  $T_{(30 \text{ min.})}$  with rhizobia and Si application.

According to the application of these rhizobia, Si and irrigation management promotes the accumulation of osmolytes and antioxidants to maintain osmotic balance and scavenge ROS, thereby ensuring the stability of membrane structures, enzymes, and other macromolecules under drought stress. These results agree with Melo et al. (2022) and Uzma et al. (2022), who studied the role of rhizobia on plants under water stress conditions, they found that rhizobia has an effective role in the production of antioxidants

(catalase), osmolytes and exopoly-saccharides to survive under harsh environments particularly drought.



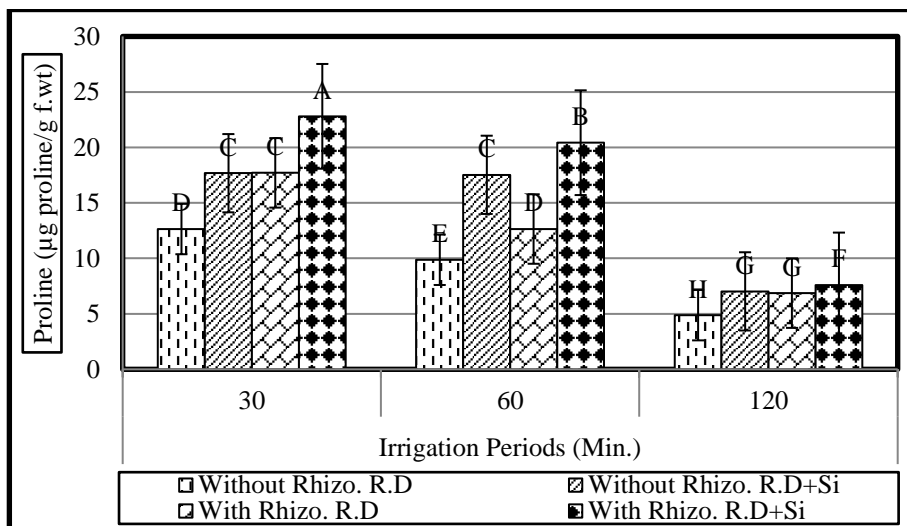
**Fig. (4).** Effect of different irrigation periods, silicon and rhizobia mixture on total antioxidant content of fruits.

The overall estimation of the concentration of proline in tomato fruits proved that there is an inverse relationship between the proline concentration and the increasing in the irrigation periods. The concentration increased by 129 and 168% by regime irrigation periods of 60 and 30 min compared to the average of 120, respectively. Averaging across fertilizers by Si and inoculation with rhizobium, in addition to adding the recommended rates of mineral fertilization led to a significant increase in the concentration of proline by 35.8, 54 and 85.5% with the addition of R.D. + Si or R.D. + rhizobia or R.D. + Si + rhizobia, respectively.

With respect to the interaction between irrigation levels with fertilizers by Si and rhizobia, in addition to adding the recommended rates of mineral fertilization, Fig. (5) shows that the concentration of proline significantly increased by 367% with  $T_1$  compared with  $T_{(120 \text{ min.})} + \text{R.D.}$ . This is a result of the mechanism that takes place inside the plant, as it stimulates the plant to raise the secretion of this acid to enhance the plant ability against drought stress. Therefore, a rise in the concentration of proline was found in cases of dieting during periods of irrigation. Also, Si and rhizobia play a role in raising the plant ability to withstand stress, as previously mentioned. It is worth noting that the addition of Si and rhizobia maintained the concentration of proline in the case of irrigation for 30 min, so that the effect of both of them was insignificant on the concentration of proline in tomato



fruits. They also had the same effect, but with 120 min. Plants accumulate some ions and some metabolites in their vacuoles mainly proline, that decrease osmotic potential of the plant cells and maintain turgor pressure at high level and help plants to maintain their metabolic and physiological process (Jiménez-Mejía et al., 2022 and Rajput et al., 2022).

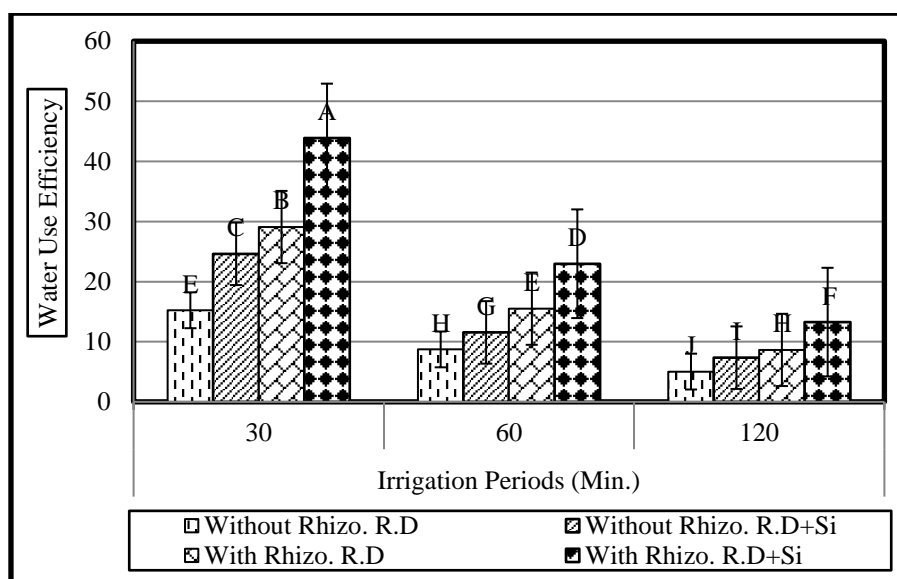


**Fig. (5).** Effect of different irrigation periods, silicon and rhizobia mixture on proline content of fruits.

**7. Water Use Efficiency (WUE)**

There is an inverse relationship between the WUE and the increase in the irrigation periods. Fig. (6) shows that the water use efficacy increased by 71 and 229% by regime irrigation periods of 60 and 30 min compared to the average of 120, respectively. Averaging across fertilizers by Si and inoculation with rhizobium, in addition to adding the recommended rates of mineral fertilization led to a significant increase in the water use efficacy by 50, 38.6 and 176% with the addition of R.D. + Si or R.D. + rhizobia or R.D. + Si + rhizobia, respectively.

Regarding to interaction between irrigation levels with fertilizers by Si and rhizobia, in addition to adding the recommended rates of mineral fertilization led to a significant increase in the WUE by 772% with  $T_{(30 \text{ min.})}$  compared with  $T_{(120 \text{ min.})} + \text{R.D.}$ . Therefore, The WUE raised in cases of reduced irrigation periods. Also, Si and rhizobia play a role in raising the plant ability to withstand stress, as previously mentioned.



**Fig. (6).** Effect of different irrigation periods, silicon and rhizobia mixture on water use efficiency.

### 8. Leaves and Fruits Nitrogen, Phosphorus and Potassium Content

The irrigation, rhizobia and Si application effects on N, P and K concentration of leaves and fruits of the experiment summarized in Table (6). The individual treatments of irrigation or rhizobia or Si significantly affected the N, P and K concentrations of leaves and fruits. Increasing the duration of irrigation led to an increase in N content in fruits by 12 and 17%; leaves by 19 and 21% by raised irrigation periods to 60 and 120 min, respectively. Also, fertilizing with Si and rhizobia, in addition to adding the recommended rates of mineral fertilization led to a significant increase in the concentration of N in fruits by 24, 43 and 118%; leaves by 19, 18 and 53% with the addition of R.D. + Si, R.D. + rhizobia and R.D. + Si + rhizobia, respectively. This result back up to improve the nutrient uptake and enhances the efficient use of both soil water and nutrient fertilizer. These results agree with Massimi (2021).

The double interaction between irrigation levels with fertilizers by Si and rhizobia, it was found that adding the recommended rates of mineral fertilization to a significant increase in the concentration of N of fruit content by 158% and leaves N increased by 134% with  $T_{(120 \text{ min.})}$  compared with  $T_{(30 \text{ min.})}$ . The use of Si or rhizobia reduced the effect of dieting in the irrigation water, which made the increase in N concentration in fruits and leaves no significant. However, in general, there was a significant increase in N concentration in fruits and leaves when using Si and rhizobia together with the increase in irrigation periods.

**Table (6).** Effect of different irrigation periods, silicon and rhizobia mixture on nutrients content of plant during 2020/2021.

Irrigation periods	Treatments		Leaves			Fruits		
	Bio.	Si	N	P	K	N	P	K
			(%)					
T <sub>1</sub>	Without	R.D.	0.72 <sup>I</sup>	0.15 <sup>G</sup>	1.09 <sup>I</sup>	0.67 <sup>H</sup>	0.16 <sup>F</sup>	2.26 <sup>E</sup>
		R.D.+Si	1.11 <sup>H</sup>	0.17 <sup>EFG</sup>	1.37 <sup>H</sup>	0.76 <sup>G</sup>	0.17 <sup>F</sup>	2.80 <sup>D</sup>
	With	R.D.	1.34 <sup>F</sup>	0.19 <sup>DE</sup>	1.44 <sup>G</sup>	1.02 <sup>DE</sup>	0.20 <sup>DE</sup>	3.33 <sup>BC</sup>
		R.D.+Si	1.62 <sup>C</sup>	0.22 <sup>BC</sup>	2.26 <sup>C</sup>	1.43 <sup>C</sup>	0.25 <sup>B</sup>	4.03 <sup>A</sup>
T <sub>2</sub>	Without	R.D.	1.26 <sup>G</sup>	0.15 <sup>G</sup>	1.34 <sup>H</sup>	0.75 <sup>G</sup>	0.16 <sup>F</sup>	3.05 <sup>CD</sup>
		R.D.+Si	1.40 <sup>E</sup>	0.17 <sup>EFG</sup>	1.97 <sup>E</sup>	0.96 <sup>F</sup>	0.18 <sup>E</sup>	3.11 <sup>CD</sup>
	With	R.D.	1.34 <sup>F</sup>	0.20 <sup>D</sup>	1.82 <sup>F</sup>	1.05 <sup>D</sup>	0.22 <sup>CD</sup>	3.72 <sup>AB</sup>
		R.D.+Si	1.65 <sup>B</sup>	0.24 <sup>AB</sup>	2.54 <sup>B</sup>	1.59 <sup>B</sup>	0.26 <sup>B</sup>	4.12 <sup>A</sup>
T <sub>3</sub>	Without	R.D.	1.26 <sup>G</sup>	0.17 <sup>FG</sup>	1.35 <sup>H</sup>	0.75 <sup>G</sup>	0.16 <sup>F</sup>	3.06 <sup>CD</sup>
		R.D.+Si	1.41 <sup>E</sup>	0.18 <sup>EF</sup>	1.99 <sup>E</sup>	0.98 <sup>EF</sup>	0.21 <sup>D</sup>	3.67 <sup>AB</sup>
	With	R.D.	1.46 <sup>D</sup>	0.20 <sup>CD</sup>	2.07 <sup>D</sup>	1.05 <sup>D</sup>	0.23 <sup>C</sup>	3.90 <sup>A</sup>
		R.D.+Si	1.68 <sup>A</sup>	0.25 <sup>A</sup>	2.99 <sup>A</sup>	1.74 <sup>A</sup>	0.28 <sup>A</sup>	4.12 <sup>A</sup>

\*R.D.= Recommended Mineral Fertilization Doses, Si= K-Silicate by Rates (500ppm), Bio= Inoculated with Rhizobium, Under Irrigation periods as T<sub>1</sub> (30), T<sub>2</sub> (60) and T<sub>3</sub> (120 min).

Regarding K concentration in the plants, there was a direct relationship between irrigation periods and K concentration, which increased from 13 to 19% in fruits and from 24 to 36% in leaves, by increasing the irrigation period from 60 to 120 min, respectively. On the other hand, fertilization with Si or rhizobia directly affected the concentration of nutrients in plants such as K, it increased by a significant percentage to up to 14, 31 and 47% in fruits and approximately 40.7, 41 and 106% in leaves with plants treated by Si, rhizobia and Si + rhizobia, respectively.

Concerning the interaction between irrigation levels with Si fertilization and rhizobia, the application of using Si with rhizobia significantly increased the K concentration, reaching 4.12% in fruits, and 2.99% in leaves with long irrigation periods, an increase of up to 82 and 174% for fruits and leaves, respectively, compared to the comparison. From the statistical analysis of K concentration in fruits, it was found that the addition of both Si with rhizobia increased the ability of the plant to absorb K under drought conditions, so the increasing of K became non-significant between irrigation levels.

Despite the importance of irrigation water for the plant and its role in absorbing nutrients and completing vital processes, spraying the plant with Si reduced the effect of drought on the K concentration in the plant. So the differences between T<sub>(60 and 120 min.)</sub> were nun significantly. A similar result was obtained for total K content in leaves and fruits. These results agree with

Wang et al. (2019), they studied effect of nitrogen fertilization under irrigation regimes on fruit yield.

Owing to effective role that P plays, it was interesting to study the effect of each of the study factors on plant uptake of P from the soil. The results in Table (6) show that the increase in irrigation periods led to a significant increasing in P concentration in the plant, where the concentration of P in fruits increased by 4.5, 13% and 3.9, 9.6% in leaves compared to the minimum irrigation period.

As for the role of fertilization by Si or rhizobia or both together increased the plant ability to absorb P concentration reached to 18.6, 35, and 64% in the fruits and in leaves also increased to 9.4, 24.5 and 50% respectively. So, the increasing was significantly compared to the control treatment. Fertilization with Si and rhizobia together increased the uptake of available P from the soil by increasing the duration of irrigation, where it increased from 0.16 to 0.28 by increasing the irrigation period from 60 to 120 min, with an increase of up to 77%, in the fruits and in the leaves, P increased by 66%, too. Treating tomato plants with Si reduced the effect of drought on the plant ability to absorb nutrients, including P. Therefore, the increasing in P concentration in fruits was non-significant when the irrigation period was reduced from 120 to 60 min. As for fertilizing with Si and rhizobia, the results showed that the increase in P concentration in the plant as a result of the increase in the irrigation period was not significant due to the role of fertilization on reducing the effect of drought on P uptake.

The interaction between the draught and fertilization by rhizobia or Si application were recorded as being highly significant ( $p < 0.05$ ) for the N, P and K concentration for fruits and leaves. There was a duple interaction among the Si, rhizobia and irrigation for total N, P and K of leaves and fruits were significantly. Intriguingly, Data in Table (6) show that N, P and K concentrations were more sensitive to irrigation amounts than to rhizobia or Si application. The appearance of the similarity between the average concentrations of N, P and K in leaves and fruits despite the use of the irrigation regime is due to the active role played by Si in accordance with the effect of rhizobia. The effect of the interaction of Si and rhizobia increased the plant ability to tolerate water deficiency. The activities of the rhizosphere microbiome release nutrients for plant growth and determine the balance between C respiration and stabilization in the soil. In addition, the microbiome interacts directly with plants in the rhizosphere by feeding on (or infecting) roots, forming symbiotic relationships, or promoting plant growth through phytohormone production or the reduction of plant stress signaling (de Vries et al., 2020). Silicon improves the water storage within plant tissues, which allows a higher growth rate that, in turn, contributes to salt dilution into the plant, mitigating drought toxicity effects (Mercedes et al., 2006).

### 9. Evaluation of Soil Microbial Activities in the Tomato Plant Rhizosphere Soil

Table (7) shows the effect of varied irrigation levels, Si and rhizobial isolates on microbial density. Drought stress had a negative impact on overall microbial counts as well as soil dehydrogenase activity, according to the findings. Drought and excessive salinity are the major limiting conditions for microbial growth in desert environments (Clark et al., 2009). Drought reduces microbial activity and biomass, as well as changing the organization of microbial communities, according to numerous research (Meisner et al., 2018 and Yaseen and Yossif, 2019). The use of halotolerant bacteria with PGP characteristics increased soil microbial biomass by increasing osmolyte production (Yasin et al., 2018). Under drought stress, combining Si and rhizobia increased microbial populations and activity. The highest mean values (1.031 mol triphenyl formazan /g dry soil) were recorded at 120 min. Soil dehydrogenase increased significantly with increasing irrigation period from 60 to 120 min and decreased significantly with decreasing irrigation period from 60 to 30 min. This finding supported a previous idea that drier climate change circumstances could drive microbial breakdown in moist soils (Freeman et al., 1996).

**Table (7).** Effect of different irrigation periods, silicon and rhizobia mixture on microbial activities in tomato rhizosphere in during 2020/2021.

Irrigation period	Bio.	Si	Total microbial counts $\times 10^5$ cfu/g dry soil	Dehydrogenase ( $\mu$ g) triphenyl formazan/g dry soil
T1	Without	R.D	42 <sup>K</sup>	0.082 <sup>K</sup>
		R.D+Si	60 <sup>H</sup>	0.293 <sup>G</sup>
	With	R.D	77 <sup>G</sup>	0.311 <sup>G</sup>
		R.D+Si	82 <sup>F</sup>	0.210 <sup>I</sup>
T2	Without	R.D	48 <sup>J</sup>	0.161 <sup>J</sup>
		R.D+Si	81 <sup>F</sup>	0.513 <sup>F</sup>
	With	R.D	90 <sup>E</sup>	0.725 <sup>D</sup>
		R.D+Si	153 <sup>B</sup>	0.859 <sup>C</sup>
T3	Without	R.D	56 <sup>I</sup>	0.267 <sup>H</sup>
		R.D+Si	95 <sup>D</sup>	0.688 <sup>E</sup>
	With	R.D	140 <sup>C</sup>	0.883 <sup>B</sup>
		R.D+Si	185 <sup>A</sup>	1.031 <sup>A</sup>

Initial total microbial counts was  $33 \times 10^5$  cfu/g dry soil. Initial dehydrogenase  $\mu$ g triphenyl formazan /g dry soil was 0.038.

## CONCLUSION

Increasing irrigation periods and spraying foliar by Si and mix of rhizobia with the addition of recommended doses from mineral fertilizers led to the increase of fresh and dry yield of tomato fruit, nutrients content of leaves and fruits significantly. The biomass accumulation of tomato fruits as protein content and total antioxidant were increased by foliar spraying Si and inoculation of seedling roots by rhizobia, too. Different irrigation regimes increased proline content and WUE in fruits. The water use efficiency (WUE) of irrigation water and proline content increased by less irrigation periods but increased with the application of Si and rhizobia compared with the control. Co-application of Si and rhizobia increased the microbial densities and their activities under drought stress. In the general, applying Si and rhizobia mixture increased the plant ability to tolerate the reducing irrigation periods.

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## تأثير إضافة السليكون وبعض أجناس الريزوبيا على نمو وإنتاجية الطماطم تحت فترات ري مختلفة - شمال سيناء

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مدة الري هو أحد العوامل الهامة التي تؤثر على نمو وإنتاجية نباتات الطماطم. عند تحديد تأثير تغيير المناخ على نمو الطماطم يكون التقييم شامل تأثير عامل الإجهاد. أقيمت تجربة حقلية خلال مواسم ٢٠٢١/٢٠٢٠ في الأراضي الرملية المستصلحة حديثاً في محطة بحوث بالوظة بشمال سيناء (٣١° ٣٢' ٠٣ شمالاً و٣٢° ٣٦' ٠٣ شرقاً) التابعة لمركز بحوث الصحراء. تم تطبيق ثلاث مستويات من فترات الري (القطع الرئيسية) وهي (٣٠، ٦٠، ١٢٠ دقيقة). وتشتمل (القطع الفرعية) على الرش الورقي (الكنترول، السيليكون، الريزوبيا، السيليكون + الريزوبيا) بمستوى واحد من مستخلص السيليكون والريزوبيا بقيمة ٥٠٠ مجم / لتر و ٣٠٠ مل من خلاصة الريزوبيا للفدان، على التوالي. أظهرت النتائج أن التسميد بالريزوبيا والسيليكون مع استخدام الأسمدة المعدنية الموصى بها والري لمدة ١٢٠ دقيقة أعطى أعلى إنتاجية من ثمار الطماطم الطازجة. لكنه لا توجد فروق اقتصادية واضحة عند تقليص مدة الري من ١٢٠ إلى ٦٠ دقيقة في وجود الريزوبيا و رش السيليكون مقارنة بالكنترول. كما أظهرت النتائج أنه بزيادة مدة الري مع استخدام الخليط من الريزوبيا والسيليكون أدى إلى زيادة في المحتوى المعدني للأوراق والثمار من النيتروجين والفسفور والبوتاسيوم. وتوضح النتائج أن الفروق غير معنوية في تركيز العناصر الغذائية بالأوراق أو الثمار بين مواعيد الري المختلفة نتيجة الإدارة المتكاملة لعمليات ري النباتات المسمدة بالريزوبيا ورشها بالسيليكون. ارتفع متوسط تراكم الكتلة الحيوية في ثمار الطماطم كمحتوى البروتين ومضادات الأكسدة الكلية عند استخدام الريزوبيا والسيليكون. كما أدت أنظمة الري المختلفة إلى زيادة محتوى البرولين في الثمار حيث كانت ٢٢.٨ و ٢٠.٤ مع ٣٠ و ٦٠ دقيقة على التوالي من ٧.٦ مع ١٢٠ دقيقة. كما ارتفعت كفاءة استخدام مياه الري (WUE) كلما انخفضت مدة الري من ١٢٠ إلى ٣٠ دقيقة عند التسميد بالسيليكون والريزوبيا لترتفع قيمتها من ٥.٠٣ إلى ٤٣.٩٪.