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Effect of Irrigation System, Planting Density and Potassium Silicate Spraying on the Growth and Quality of Tomato

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Abstract

The experiment was carried out to study the irrigation systems, planting density and potassium silicate spraying on the growth and quality of tomato. The experiments included three factors, the type of drip irrigation systems (S) as: single line irrigation (S_1) and Double line irrigation (S_2). The planting densities (D): D_1 (40 cm) (density: 12 plants); D_2 (50 cm) (density: 10 plants) and D_3 (60 cm) (density: 8 plants). The third factor was potassium silicate spraying (K): as: K_0 (control); K_1 (treated of plant with 1 mL L^{-1}) and K_2 (treated with 2 mL L^{-1}). Using a factorial experiment within a split-plot design, main plots were allocated to irrigation systems (S_1 and S_2). The results showed that, the single irrigation system (S_1) produced a significant superiority in acidity 0.560 %; vitamin C 34.958 mg; TSS 3.846 and lycopene 2.264 mg, compared with double line (S_2) which showed superiority in β-carotene pigment 2.448 mg. Planting density at a distance of 60 cm produced the highest values in TSS 3.73; fruit hardness 3.590 kg cm^{-2} , β-carotene 2.41mg, while planting at 40 cm showed superiority in lycopene pigment 2.034 mg. Treatment with potassium silicate at a concentration of 1 mL L^{-1} (K_1) was found to produce the highest lycopene and β-carotene, while a concentration of 2 mL L^{-1} had superiority in acidity and vitamin C. From the results, using the single irrigation system had superiority in producing tomato with high qualities, while planting tomato at a distance of 40 cm had superiority in most qualities characteristics.

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Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the solanaceae family (El-Den *et al*., 2022; Alwan *et al*., 2016) from 100 gender and 2500 species (Salman and Ayad, 2019). Tomatoes are produced in large quantities in the fields, in addition to being produced in smaller quantities by using protected agriculture technology (Bozo *et al.*, 2019). Producing tomatoes in the fields is one of the most widespread methods and represents the largest percentage of the crop in local markets in the central and northern regions of Iraq (Central Statistical Organization, 2019). In recent years, it has been observed a decrease in the area of fields designated for tomato production in the middle of Iraq, as a result of an increase in average temperatures and a decrease in irrigation water resources due to drought (Jawad *et al*., 2018). Temperatures higher than normal will cause a deterioration in the quantity and quality of the yield (Amarasinghe *et al.*, 2022). There is a scarcity of irrigation water resources as a result of less rainfall in central and northern Iraq (Qasim *et al.*, 2021). As climate changes and scarcity of irrigation water (Gudmundsson *et al.*, 2017; Jawad *et al.*, 2018) conditions will negatively affect the quantity and quality of tomato yield especially since water sources in Iraq have faced many threats (Al-Lami *et al*., 2023a; Al-Lami *et al.*, 2023b). Drip irrigation is a modern irrigation method that reduces water loss (Acar and Fariz, 2009; Al-Mhmdy and Al-Dulaimy, 2018). There are abiotic problems such as nutrient deficiency, high temperatures, increased light intensity, lack of water resources and other environmental damage that can affect the cultivation and production of tomatoes, as well as the poor quality of the fruits. Therefore, the use of protective materials will improve their resistance to environmental stresses and improve growth and production (Volesky *et al.,* 2023). Flowers and fruits are damaged as a result of high temperatures, which will reduce the quantity of yield and the quality of fruits. Therefore, preventive methods and materials must be used that reduce heat stress on the plants and increase their ability for higher production. (Obaid *et al.,* 2021; Volesky *et al.,* 2023). Planting density is the number of plants per unit area that will be affected by many factors such as plant type, growth condition, and appropriate climatic conditions. Studies have shown that plant density has a direct impact on the yield and directly affects the quality of the fruits. (Feng *et al.,* 2010; Maboko and Du Plooy, 2013; Ding *et al.,* 2022). Other studies have indicated that the high plant density increases the production per unit area and improves the quality characteristics of the fruits (Maboko *et al*., 2017; Madavi *et al.*, 2017). Method of intensive agriculture has been used to enhance vegetable crops production and help to increase the production for a specific area of land (Kumar *et al*., 2022), increasing the number of plants per unit area must be accompanied by appropriate management of the shoot system (pruning) and fertilization (Hasab and Al-Naqeeb, 2019; Obaid *et al.,* 2022). Controlling water loss from the plants is achieved by reducing the rate of transpiration by using anti-transpiration (Amarasinghe *et al*., 2022; Zeboon and Baqir, 2022). Treating the plants with potassium silicate has positive effects in regulating the water content of the plants during the summer season (Mohammed and Majeed, 2024; Al-waili and Al-Sahaf, 2021). Potassium is very important in regulating the osmotic potential as well as the water potential in plants and improves the plants ability to save the water (Alrawi and Aljumail, 2018; Al-Mashhadany and Amery, 2023). The study aimed to demonstrate the effects of the agricultural irrigation system, plant density, and potassium silicate spraying on the growth and quality of tomato fruits.

Materials and Methods

The experiment was carried out in the College of Agricultural Engineering Sciences, University of Baghdad during the spring season of 2023 to study the effects of irrigation systems (single row and double row systems), planting spaces (plant density), and spraying with potassium silicate on the production of tomato plants (S_{25}). A factorial experiment was designed to investigate the agricultural irrigation system, planting density, and potassium silicate spraying on the growth and quality of tomato yield in an open field. The experiment included three factors: the type of drip irrigation systems (S_1: single row drip irrigation and S_2: double row drip irrigation), tomato planting densities (D_1: 40 cm spacing with 12 plants per experimental unit, D_2: 50 cm spacing with 10 plants per experimental unit, and D_3: 60 cm spacing with 8 plants per experimental unit), and spraying of tomato plants with potassium silicate (K_0: control, K_1: spraying with 1 mL L^{-1} concentration, and K_2: spraying with 2 mL L^{-1} concentration).

Experiment design

The experiment was conducted using a factorial experiment within split-plot design. The main plots were assigned to different agricultural irrigation systems: single irrigation lines (S_1) and double irrigation lines (S_2). These main plots were randomly distributed within each replicate. Within each main plot, a factorial experiment was carried out using a randomized complete block design (RCBD) that included nine treatments. These treatments involved the interaction between three planting densities (D_1, D_2, and D_3) and three potassium silicate spraying levels (K_0, K_1, and K_2). This resulted in an experiment with 18 treatments and 48 experimental units.

Analyzed the experimental data and determined significant differences using the SAS program (SAS, 2009), with the LSD test at a 0.05 probability level (Al-Rawi and Khalafallah, 2000).

Measurements of the experiment and field operations

1- Dimensions of the experimental unit: 1 m * 2.5 m for both the single irrigation system (S_1) and double irrigation system (S_2).

2- Both systems included two cultivation lines within the experimental units as below:

a) A single irrigation line system (S_1) loaded with two tomato planting lines (one line to one side), while the distance between the planting lines was 20 cm.

b) Double irrigation line system (S_2) loaded with two tomato planting lines (one planting line to one line irrigation), while the distance between the planting lines was 40 cm.

3- Tomato seedlings were planted alternately on both sides of the irrigation line, with planting distances according to the planting density under study (D).

4- Fertilization: Nutrition of tomato plants given with drip irrigation water (Fertigation, 1g plant^{-1}), by using a commercial fertilizer Ultrasol multi- Purpose 20-20-20.

5- A drip irrigation system consisting of drip spaces of 20 cm and a drainage rate of 2.6 l h^{-1} is used.

6- Calculate the water consumption for each plant based on the type of drip irrigation system with planting densities, these calculations are important to estimating the costs of water consumption when evaluating the feasibility of the project, as well as estimating the water using efficiency.

Table 1. Water consumption with respect to irrigation and planting density

Irrigation system	Water consumption during the season (L per 2.5 m^2)	The plant's share of the water during the season according to planting density*			
		D_1 (12 Plants)	D_2 (10 Plants)	D_3 (8 Plants)	Consumption average
S_1	1360 L	113.33 L	136 L	170 L	139.78 L
S_2	2720 L	226.66 L	272 L	340 L	279.55 L

* Water Consumption during the season (Lm^2)/ Planting densities.

Properties studied

1- Fruits quality parameters

a- Acidity (%): Total acidity was estimated as stated in Ranganna (1977).

b- vitamin C (%): Determination of vitamin C by the direct colorimetric method described in Abbas and Abbas (1992) c- T.S.S (%): Estimated by using a hand refractometer.

d- Fruits hardness (kg cm^{-2}): Estimated by using a manual pressure tester.

e- Pigment contents: Lycopene pigment and β-Carotene pigment (mg $100g^{-1}$ wet weight).

Estimated according to the method of Ranganna (1977).

2- Percentage of nutrients in leave

a- **Nitrogen**: Determination by using the Micro Kjeldahl device as mentioned in Jackson (1958).

b- **Phosphorus**: determined using ammonium molybdate and ascorbic acid using a UV-VIS Spectrophotometer, model 80 D, at a wavelength of 662 nm (Olsen and Sommers, 1982).

c- **Potassium**: using a flame photometer as mentioned in (Al-Sahhaf, 1989).

d- **Percentage of sunscald on the fruits**: estimated by using the equation that by Kalatippi *et al.* (2022):

$$\text{Percentage of sunscald} = \frac{Number\ of sunscalded\ fruits\ per\ plant}{Total\ number\ of\ fruits\ per\ plant} * 100$$

Results and Discussion

1- **Effect of the experiment factors in fruits quality characteristics**

The results in Table 2 showed a significant superiority in most of the fruits quality characteristics when planting was done by using single row irrigation system (S_1) and reached high values in acidity 0.560 %; vitamin C 34.958 mg; TSS 3.846 %; fruits hardness 3.555kg cm^{-2} and lycopene pigment 2.264 mg, compared with double-row irrigation system (S_2), which produced high value in the β-carotene 2.448 mg. Planting of tomato at a distance of 50 cm (D_2) (density: 10 plants per experiment $unit^{-1}$) produced high values in fruits acidity 0.591 % and vitamin C 34.52 mg, compared with the planting distance of 60 cm having 0.516 % fruits acidity and 32.616 mg Vit. C. The plants planted at a distance of 50 cm (10 plants, D_2) produced significant superiority in acidity 0.591 % and vitamin C 34.521 mg, while the plants planted at a distance of 40 (12 plants, D_1) was found superior in lycopene pigment 2.034 mg. Planting of tomato at a distance of 60 (8 plants, D_3) had significant superiority in TSS in the fruit 3.733 %, fruit hardness 3.59 kg cm^{-2} and beta-carotene 2.41 mg. Treating tomato plants with potassium silicate at different concentrations significantly impacts various fruit quality parameters. When treated with potassium silicate at a concentration of 2 mL L^{-1}, the tomatoes exhibited the highest values in acidity 0.555 %, vitamin C content 33.823 mg, and total soluble solids 3.761 kg cm^{-2}. On the other hand, treatment with a lower concentration of 1 mL L^{-1} resulted in superior fruit hardness 3.525 kg cm^{-2} and the highest lycopene 1.956 mg and beta-carotene content 2.358 mg. These findings suggest that while a higher concentration of potassium silicate enhances acidity, vitamin C content, and total soluble solids, a lower concentration is more effective in improving fruit hardness and lycopene content. The results showed that using a single-line irrigation system with tomato plants.

Table 2. Effect of experimental factors in Fruit quality characteristics

Treatments	Acidity %	Vitamin C (mg 100 g^{-1} wet weight)	T.S.S. %	Fruits hardness Kg cm^{-2}	Lycopene (mg 100 g^{-1} wet weight)	beta-Carotene
S_1	0.560	34.958	3.846	3.555	2.264	1.988
S_2	0.551	32.467	3.448	3.397	1.452	2.448
LSD	**0.0289**	**0.8722**	**0.2080**	**0.1288**	**0.1405**	**0.043**
D_1	0.559	34.001	3.636	3.390	2.034	2.169
D_2	0.591	34.521	3.572	1.914	2.076	3.449
D_3	0.516	32.616	3.733	3.590	1.627	2.410
LSD	**0.0354**	**1.0682**	**0.255**	**0.1578**	**0.1721**	**0.0538**
K_0	0.568	33.654	3.652	3.451	1.763	2.220
K_1	0.543	33.661	3.527	3.525	1.956	2.358
K_2	0.555	33.823	3.761	3.453	1.856	2.076
LSD	**0.0354**	**1.0682**	**0.255**	**0.1578**	**0.1721**	**0.0538**
S_1D_1	0.580	35.384	3.816	3.432	2.696	1.921
S_1D_2	0.611	35.484	3.866	3.558	2.421	1.758
S_1D_3	0.488	34.007	3.855	3.676	1.675	2.286
S_2D_1	0.538	32.618	3.455	3.347	1.373	2.417
S_2D_2	0.572	33.559	3.277	3.340	1.406	2.394
S_2D_3	0.543	31.225	3.611	3.503	1.578	2.533
LSD	**0.0558**	**1.6038**	**0.3727**	**0.3586**	**0.3477**	**0.3302**
S_1K_0	0.576	35.527	3.827	3.521	2.215	2.111
S_1K_1	0.548	34.709	3.700	3.746	2.221	2.124
S_1K_2	0.554	34.639	4.011	3.400	2.357	1.730
S_2K_0	0.560	31.781	3.477	3.381	1.310	2.329
S_2K_1	0.538	32.613	3.355	3.303	1.354	2.591
S_2K_2	0.555	33.007	3.511	3.506	1.692	2.423
LSD	**0.0558**	**1.6038**	**0.3727**	**0.3586**	**0.3477**	**0.3302**
D_1K_0	0.575	33.998	3.758	3.288	1.945	2.232
D_1K_1	0.561	34.056	3.583	3.693	1.800	2.698
D_1K_2	0.541	33.950	3.566	3.188	2.358	1.577
D_2K_0	0.608	34.093	3.666	3.521	1.910	1.949
D_2K_1	0.585	35.226	3.366	3.288	2.047	1.996
D_2K_2	0.581	34.247	3.683	3.538	1.784	2.283
D_3K_0	0.521	32.872	3.533	3.543	1.432	2.480
D_3K_1	0.485	31.704	3.633	3.593	2.023	2.380
D_3K_2	0.541	33.274	4.033	3.633	1.425	2.369
LSD	**0.0734**	**2.5411**	**0.5071**	**0.429**	**0.7125**	**0.378**
$S_1D_1K_0$	0.583	36.316	4.083	3.410	2.647	2.204
$S_1D_1K_1$	0.573	36.253	3.566	3.753	2.471	2.497
$S_1D_1K_2$	0.583	33.584	3.800	3.133	2.969	1.062
$S_1D_2K_0$	0.606	35.142	3.833	3.400	2.554	1.797
$S_1D_2K_1$	0.636	35.652	3.700	3.443	2.170	1.531
$S_1D_2K_2$	0.590	35.658	4.066	3.833	2.540	1.946
$S_1D_3K_0$	0.540	35.123	3.566	3.753	1.444	2. 334
$S_1D_3K_1$	0.436	32.225	3.833	4.043	2.021	2.345
$S_1D_3K_2$	0.490	34.675	4.166	3.233	1.562	2.181
$S_2D_1K_0$	0.566	31.680	3.433	3.166	1.244	2.260
$S_2D_1K_1$	0.550	31.859	3.600	3.633	1.128	2.900
$S_2D_1K_2$	0.500	34.316	3.333	3.243	1.748	2.093
$S_2D_2K_0$	0.610	33.043	3.500	3.643	1.267	2.102
$S_2D_2K_1$	0.533	34.799	3.033	3.133	1.923	2.460
$S_2D_2K_2$	0.573	32.835	3.300	3.243	1.028	2.620
$S_2D_3K_0$	0.503	30.621	3.500	3.333	1.420	2.626
$S_2D_3K_1$	0.533	31.184	3.433	3.143	2.025	2.415
$S_2D_3K_2$	0.593	31.872	3.900	4.033	1.288	2.558
LSD	**0.0947**	**2.5347**	**0.6444**	**0.4512**	**0.811**	**0.382**

S_1: Single line irrigation system; S_2: Double lines irrigation system; D_1:12 Plants; D_2:10 Plants; D_3: 8Plants per experimental unit;
K_0: Control; K_1: 1 mL L^{-1}; K_2: 2 mL L^{-1}.

Spacing 40 cm apart (S_1D_1) significantly increased the lycopene content of the fruits to 2.696 mg. per 100 g of wet weight. The treatment S_1D_2 (single-line with tomato plants spacing 50 cm apart) significantly increased the acidity percentage 0.611% and total soluble solids (TSS) to 3.866 %. Additionally, using the single-line irrigation system without potassium silicate (S_1K_0) produced a higher acidity percentage 0.576 % and vitamin C content 35.527 mg. The highest TSS percentage 4.011 % and lycopene content 2.358 mg were achieved using the single-line irrigation system with plants treated with potassium silicate at a concentration of 2 ml L^{-1} (S_1K_2).

The triple overlap of the studied factors (Table 2) demonstrated significant improvements in most of the fruit quality characteristics while using the single-row irrigation system in conjunction with other treatments. Specifically, $S_1D_2K_1$ produced the highest acidity 0.636%, $S_1D_1K_0$ recorded the highest vitamin C content (36.316 mg), and $S_1D_3K_2$ resulted in the highest percentage of total soluble solids 4.166%. The highest lycopene pigment content was found in the treatment $S_1D_1K_2$, with 2.696 mg per 100 g of wet weight. Overall, the highest beta-carotene pigment content was observed in treatments using the double-row irrigation system, with the highest carotene content reaching 2.90 mg per 100 g of wet weight in treatment $S_2D_1K_1$.

The results in Table 2 showed the superiority of tomato fruits with a single row irrigation system (S_1) in most of the quality characteristics (acidity. vitamin C, TSS, fruits hardness and lycopene), compared with double row irrigation system (S_2), This superiority is due to the efficiency of the irrigation system for delivering the appropriate amount of water (Table 1) as well as the increase in the water use efficiency (WUE), and the increasing efficiency of using fertilizers (Fertigation), which helped to improve the overall plant growth and tomato fruits quality (Ali, 2012). On the other hand, the double row irrigation system (S_2) pumps more water than the plants need, by washing the nutrients away from the root system, and there was irrigation without fertilization between one nutrition process and another. The results in Table 2 indicated that the intensive cultivation of tomato plants (D_1: 12 plants per experimental unit) leads to the deterioration in fruit quality characteristics, except for the increase in the lycopene content. This deterioration is attributed to the reduced amount of nutrients per plant due to the higher number of plants per unit area. In contrast, a moderate planting density (D_2:10 plants per experimental unit) produced fruits with superior acidity and vitamin C content. This is likely because this density achieves a balance between nutritional and lighting requirements necessary for the accumulation of organic acids and vitamin C (Maboko *et al.,* 2017; Obaid *et al.,* 2022).

Effect of treatments on the percentage of NPK in leaves and Percentage of sunscald on fruits

The results of Table 3, regarding the percentages of NPK elements in the leaves and the percentage of fruits affected by sunscald, shows that the irrigation system has no significant effect on the NPK content in the leaves. However, the single-row irrigation system (S_1) significantly reduced the percentage of sunscald on the fruits to 1.384 %, compared to 1.918 % for the double-row irrigation system (S_2). Similarly, the plant density factor did not significantly affect the NPK content in the leaves. However, the planting of tomatoes at a distance of 40 cm (D_1), with a density of 12 plants per experimental unit, significantly decreased the percentage of sunscald to 1.492 %, compared to 1.952 % at a distance of 60 cm.

Table 3. Effect of treatments on the percentage of NPK in leaves and sunscald (%) on the fruits

Treatments combinations	Nitrogen in leaf (%)	Potassium in leaf (%)	Phosphorus in leaf (%)	Sunscald on the fruits (%)
S_1	2.223	1.315	0.231	1.384
S_2	2.211	1.322	0.225	1.918
LSD	**0.1749**	**0.1445**	**0.0226**	**0.1636**
D_1	2.177	1.370	0.230	1.492
D_2	2.262	1.350	0.235	1.510
D_3	2.211	1.236	0.220	1.952
LSD	**0.2142**	**0.177**	**0.0277**	**0.2004**
K_0	2.229	1.377	0.227	1.629
K_1	2.239	1.321	0.241	1.733
K_2	2.182	1.258	0.217	1.591
LSD	**0.2142**	**0.177**	**0.0277**	**0.2004**
S_1D_1	2.257	1.376	0.232	1.268
S_1D_2	2.197	1.395	0.244	1.265
S_1D_3	2.214	1.173	0.218	1.620
S_2D_1	2.097	1.364	0.227	1.715
S_2D_2	2.327	1.304	0.225	1.754
S_2D_3	2.207	1.300	0.222	2.285
LSD	**0.2625**	**0.2592**	**0.0387**	**0.424**
S_1K_0	2.254	1.423	0.220	1.435
S_1K_1	2.217	1.214	0.253	1.120
S_1K_2	2.197	1.307	0.222	1.598
S_2K_0	2.204	1.332	0.234	1.823
S_2K_1	2.261	1.427	0.228	2.347
S_2K_2	2.167	1.208	0.212	1.584
LSD	**0.2625**	**0.2592**	**0.0387**	**0.424**
D_1K_0	2.213	1.303	0.226	1.803
D_1K_1	2.206	1.435	0.243	1.453
D_1K_2	2.113	1.373	0.220	1.220
D_2K_0	2.316	1.541	0.218	1.346
D_2K_1	2.306	1.243	0.251	1.636
D_2K_2	2.165	1.265	0.235	1.546
D_3K_0	2.158	1.288	0.236	1.738
D_3K_1	2.205	1.285	0.228	2.111
D_3K_2	2.270	1.136	0.196	2.008
LSD	**0.3346**	**0.3111**	**0.0462**	**0.5997**
$S_1D_1K_0$	2.243	1.290	0.230	1.446
$S_1D_1K_1$	2.276	1.403	0.233	1.1361
$S_1D_1K_2$	2.253	1.436	0.233	1.223
$S_1D_2K_0$	2.356	1.160	0.213	1.283
$S_1D_2K_1$	2.206	1.626	0.280	0.926
$S_1D_2K_2$	2.030	1.400	0.240	1.586
$S_1D_3K_0$	2.163	1.353	0.216	1.576
$S_1D_3K_1$	2.170	1.080	0.246	1.296
$S_1D_3K_2$	2.310	1.086	0.193	1.986
$S_2D_1K_0$	2.183	1.316	0.223	2.160
$S_2D_1K_1$	2.136	1.466	0.253	1.770
$S_2D_1K_2$	1.973	1.310	0.206	1.216
$S_2D_2K_0$	2.276	1.456	0.223	1.410
$S_2D_2K_1$	2.406	1.326	0.223	2.346
$S_2D_2K_2$	2.300	1.300	0.230	1.506
$S_2D_3K_0$	2.153	1.223	0.256	1.900
$S_2D_3K_1$	2.240	1.490	0.210	2.926
$S_2D_3K_2$	2.230	1.186	0.200	2.030
LSD	**0.5093**	**0.4545**	**0.0676**	**0.6795**

S_1: Single line irrigation system; S_2: Double lines irrigation system; D_1:12 Plants; D_2:10 Plants; D_3:8Plants per experimental unit; K_0: Control; K_1: 1 mL L^{-1}; K_2: 2 mL L^{-1}.

The combination of planting tomatoes at a distance of 40 cm with single drip irrigation (S_1D_1) produced the lowest sunscald percentage 1.265 %, while the highest percentage was recorded for the treatment S_2D_3 at 2.285 %. The interaction between the planting irrigation system and spraying with potassium silicate (Table 3) revealed a significant effect on the rate of sunscald infection on the fruits. The lowest sunscald rate 1.120 % was recorded in single-row irrigation system with potassium silicate at a concentration of 1 mL L^{-1} (S_1K_1), compared to the highest infection rate 2.347 % in the same concentration in a double-row irrigation system (S_2K_1).

Additionally, planting tomatoes at a distance of 50 cm without spraying potassium silicate (D_2K_0) resulted in a significant increase in the potassium content of leaves 1.541% and the lowest percentage of 1.136% was recorded when the plants are planted at a distance of 60 cm with potassium silicate applied at 2 mL L^{-1} (D_3K_2). The results from Table 3 indicated that the lowest percentage of sunscald 1.220 % was recorded for plants grown at a distance of 40 cm and treated with potassium silicate at a concentration of 2 mL L^{-1} (D_1K_2). The highest sunscald rate 2.111 % was observed in the D_3K_1 treatment and the data showed no significant effect on the nitrogen content in tomato leaves. The triple interaction of the study factors revealed the highest percentage of potassium in tomato leaves 1.626 % and the highest phosphorus percentage 0.280 %. The lowest sunscald percentage 0.926 % occurred when using a single-row irrigation system with a planting distance of 50 cm, and treating with potassium silicate at 1 mL L^{-1} ($S_1D_2K_1$). In contrast, the highest sunscald percentage, 2.926 %, was recorded with a double-row irrigation system, planting at 60 cm, and treated with potassium silicate at 1 mL L^{-1} ($S_2D_3K_1$).

The lowest planting density (D_3: 8 plants per experimental unit) resulted in fruits with superior TSS%, fruit hardness, and carotene pigment content. This is likely due to an increased share of nutrients per plant, which positively impacts fruit quality, increasing hardness and TSS%. The higher beta-carotene content and deterioration of lycopene pigment in fruits grown at the lowest density (D_3) are attributed to excessive solar radiation exposure. This radiation causes the dominant lycopene pigment to degrade at full maturity, leading to the appearance of beta-carotene. Additionally, fruits at this density suffer from the highest percentage of sunscald damage, as they are more exposed to harmful ultraviolet solar radiation, which damages fruit tissues and makes them unsuitable for marketing (Volesky *et al.,* 2023).

Conclusions

1- The single irrigation line (S_1) planting system was more efficient in using drip irrigation water to produce high-quality fruits, whereas the double-line irrigation system (S_2) led to quality issues in tomato fruits.
2- The intensive cultivation method of tomatoes (D_1) contributed to achieving the characteristic mature color (lycopene) and reduced sunscald infection in the fruits. However, it also led to a decrease in acidity percentage and vitamin C content in the tomatoes.
3- Treating tomato plants with potassium silicate at a concentration of 1L (K_1) was more effective than other concentrations in improving fruit quality indicators.

Conflicts of Interest

The researchers support that this work does not conflict with the interests of others.

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