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Effect of Calcium - Potassium Equilibrium on Tomato Plants Grown Hydroponically

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Abstract

In order to study the effect of calcium-potassium Equilibrium in hydroponics culture nutrient solution on growth, nutrient status and productivity of tomato plants (cv. Red Spring) an experiment was conducted at a private hydroponic farm in Qena Governorate through the Soils and Water department, faculty of Agriculture, South Valley University, Egypt. The site is at (latitude 26° 11' 22.2' N to Longitude 32° 44' 25.5" E), and 81 m above sea level.

Tomato plants were grown hydroponically using six types of nutrient solution: 1) standard solution adapted with nutritive needs of tomato plants (balanced in Ca and K), 2) Ca deficient solution, 3) Ca excess solution, 4) K deficient solution, 5) K excess solution and 6) Ca and K excess solution.

The obtained results showed that, compared to balanced Ca-K solutions or those deficient in Ca or K content, "Red Spring" tomato plants grown in nutrient solution rich Ca or in K or rich in both Ca and K show higher and significant growth parameters, cluster number/plant and fruit numbers/cluster. Significant differences were obtained in the mineral contents of (N, P, K, Ca, Fe and Zn) as a result of varying Ca-K equilibrium of nutrient solution. However, the antagonism between Ca, K and Mg was Clearly observed. The physical and chemical characteristics of the fruit were significantly affected by varying the Ca-K equilibrium in the nutrient solution.

Key words: Tomato, Calcium, Potassium, Hydroponics, Ca-K equilibrium.

Introduction

Hydroponics culture is one of the most modern technologies of soilless culture. This method allows us to avoid the influence of environmental factors, including climate and soil factors. Soilless cultures offer some of important advantages such as: excluding the influence of climate elements, by controlling temperatures, humidity, and lighting hours, elimination of soil elements effect on the cultivated plant, accurately provide the nutritional needs of the plants.

Additionally, this method allows for ease of conducting fertilization experiments and calculating the required quantities of each element, knowing the critical and maximum limit for each nutrient element, studying the relationship between the nutrient elements, and their effect on the plant growth and fruiting, accurately monitoring the physiological processes in the plant, producing a high quality fruit in short time, and studying the antagonism and synergic relations between the nutrient elements .

Tomato (*Solanum lycopersicum* L.) is considered as one of the most important export vegetable plants with high financial returns in the world, furthermore, global world demand for tomatoes has increased rapidly in recent years **(Michaels et al., 2022)**. Tomato fruits contain high amounts of mineral nutrients such as Potassium, Calcium, Sodium, and Iron. In addition, they are a source of vitamins as vitamin C and vitamin A and antioxidants **(Coe, 1994; Michaels et al., 2022)**. Numerous varieties of the tomato plant are widely grown in temperate climates across the world **(Moustafa & Abdelzahe, 2018)**.

It's well-known that K is one of the essential mineral elements and is classified as macro nutrient element. Even though it does not participate in the chemical structure of plants, it activates at least 60 enzymes hence playing many important regulatory roles in plant **(Moustafa & Abdelzahe, 2018)**. Potassium also neutralizes different organic anions **(Prajapati & Modi, 2012)** and can increase plant tolerance response to various abiotic stresses, including drought, high salinity, heat, cold and ion toxicity **(Kumari et al., 2021)** It regulates the stomatal opening and closing, and consequently regulating water balance in plant and the regulation of photosynthesis processes in plant may be controlled by potassium through the activation of photosynthesis enzymes **(Kadam et al., 2011).** Additionally, potassium plays an important role in water, nutrient and carbohydrates transportation through phloem to the other parts of plant **(Paliwal, 2018)**. The role of K+ in improving fruit physical and chemical quality parameters has been well studied and confirmed by **(Abo-Ali, 2019 and Ibrahim et al., 2019)**.

Based on previous studies, it is well known that calcium plays a major role in plant growth, development, and fruiting. **(El Habbasha and Faten, 2015)** recorded that calcium plays a resistance role in the plants to diseases due to the protection of the cell wall. Additionally, calcium activates several enzymatic systems. Plant leaves contain the highest concentration of Ca, and this may be due to formation of the calcium pectate in the middle lamella of cells. Calcium is associated with N transport and interacts with potassium and phosphorus. Abiotic stress often leads to an increase in free calcium in the cytoplasm of cells which leads to gene expression that activates biochemical responses that allow the plant to adapt to adverse conditions of various kinds. By regulatory mechanisms plants can make adjustments under stress such as high temperature, water deficiency and salinity **(El Habbasha and Faten, 2015).**

The present study focused on variation of Ca – K equilibrium and its effect on growth, mineral status, production and fruit quality of Red Spring tomato plants grown hydroponically.

Materials and Methods

The current experiment was conducted under greenhouse conditions during two successive seasons (November 2021-2022 and November 2022-2023) on "Red Spring Tomato" (*Solanum lycopersicum* L.).

Plant material: "Red Spring" tomato seeds were cultivated in trays filled with mixture of soil and compost. When the plants growth reached a length of 15 cm, they were transported to plastic pots filled with the nutrient solutions used in the experiment.

Nutrient solutions

Six nutrient solutions have been prepared as follows:

1): Standard nutrient solution adapted to the nutritive needs of tomato plants, Hoagland-Arnon modified solution **(Sonneveld & Voogt, 2009)**. The control nutrient solution contained the following macro and micronutrients (in meq/L): 8.8 NO_3, 1.0 H_2PO_5, 2.0 SO_4, 1.0 NH4, 7.0 K, 7.0 Ca, 2.0 Mg and micro-nutrients: 6 Fe, 2.0 Mn, 0.1 Mo, 1.5 B, 0.7 Zn, 0.40 Cu.

2): Ca deficient solution: The same standard solution, except adjusted the concentration of Ca to be 2.0 meq/L.

3): Ca excess solution: The same standard solution, except adjusted the concentration of Ca to be 14.0 meq/L.

4): K deficient solution: The same standard solution, except adjusted the concentration of K to be 2.0 meq/L.

5): K excess solution: The same standard solution, except adjusted the K concentration to be 14.0 meq/L.

6): Ca and K excess solution: The same standard solution, except adjusted concentration of Ca and K to be 14.0 meq/L.

The pH of the nutrient solutions was adjusted to 7.0, using HCl or NaOH 0.1 N solutions. The nutrient solutions were changed periodically every 10 days, during the experimental work.

Experimental work: Under greenhouse conditions, the seedlings were transplanted to 5-liter plastic pots that had been washed with acid and filled with aerated nutrient solutions. The pots were covered with plastic covers, and three small holes were bored in each cover: one for an air tube and the other two for fixing two tomato plants. Each pot was occupied by two plants, and the experiment included six treatments, corresponding to the six types of nutrient solutions. Each treatment was replicated three times, and each pot was occupied by two plants. The treatments were randomly assigned to the pots in a completely randomized design.

Different measurements: The following characteristics were measured during the two experimental seasons:

Plant growth parameters: At the end of the experiment the length of plants length (cm) was recorded. The leaves of each plant were collected in three separate groups: young leaves, adult leaves and aged leaves. Additionally, the root system of each plant was separated. The fresh weight (F.W.) of the leaves and root system as well as the number of leaves in each group were recorded. Subsequently, the leaves and roots were dried overnight in an oven at 70° C and the dry weight (D.W) was recorded.

Foliar diagnosis: The petioles of dried mature leaves grinded to fine powder as described by **Ibrahim et al. (2019).** Calcium and magnesium were determined volumetrically by titration using the EDTA, Potassium was measured by the flame photometry method according to **Jackson, (1973).**

Fe, Mn, and Zn were determined using atomic absorption spectrophotometry **(Perkin Elmer 280).** The total N was determined by the Kjeldahl method, as described by **Jackson (1973),** while the percentage of phosphorus was determined colorimetrically using the chlorostannous-phosphomolybdic acid method, also described by **Jackson (1973).**

During the two experimental seasons, the number of clusters per plant and the number of fruits per cluster were counted and recorded. At harvest time, the weight of each fruit was also recorded, and the average fruit weight (in grams) was calculated.

Fruit physical and chemical properties: the following physical and chemical properties of the fruits were recorded: Average fruit weight (g) fruit dimensions (longitudinal and equatorial in cm) percentage of total soluble solids (TSS%) determined by handy refractometer **(A.O.A.C, 2000).** Percentage of total acidity according to **the (A.O.A.C, 2000**) methods and vitamin C contents (mg/100g F.W.) determined by volumetric titration with 2,6-Dichlorophynol indophenol Pigment, according to **Ranganna, (1977).**

Results and Discussion

1-Effect of Ca-K equilibrium on growth parameters

Data concerning the effect of Ca – K equilibrium in the nutrient solution on plant height (cm) as well as the fresh and dry weight of leaves and roots during 2021 and 2022 seasons are presented in Table (1). From the obtained data, it is evident that varying concentration of Ca and K in nutrient solution significantly affects all plant growth parameters (i.e., plant height, F.W. of young, adult and aged leaves and F.W. of root system). Tomato plants grown in solution with low Ca or low K content exhibited the lowest plant growth parameters. However, plants grown in solutions reach in Ca or K exhibited significantly higher values of growth parameters. The plants grown in solutions rich in calcium and potassium present the highest values of all growth parameters.

Calcium plays a leading role in plant growth and development. **Tanveer et al. (2019)** found that the application of Ca+2 enhanced the growth of tomato plants under saline conditions. Additionally, increasing the concentration of calcium either alone or in combination with salt significantly increased plant growth and germination, improved root and shoot fresh and dry weight, relative water content and leaf area. These essential roles of Ca^{+2} nutrition can explain the positive effect of calcium nutrition in our study. Furthermore, the role of potassium in enhancing plant growth parameters can be explained by its important functions such as it plays many important roles in plant may be led to enhancing plant growth such as activating some important enzymes **(Moustafa & Abdelzahe, 2018)** and neutralize different undesirable anion **(Prajapati & Modi, 2012)**. It can also regulate the photosynthesis processes by activating photosynthesis enzymes **(Kadam et al., 2011)** and plays K+ significant role in many physiological processes in plants **(Rawat et al, 2022). (Paliwal, 2018)** confirmed that K+ plays an important role in water and nutrient absorption and transport, and also, activates protein synthesis **(Prajapati & Modi, 2012).**

2- Effect of Ca-K equilibrium on leaves and root dray weight

The data presented in Table (2) shows the effect of Ca - K equilibrium on the dry weights of the leaves and roots of Red Spring tomato grown hydroponically, during (November 2021-2022 and November 2022-2023) seasons. Red Spring tomato plants grown in nutrient solutions poor in Ca or K had lower dry weights of leaves (young, adult and aged leaves) and roots during the two experimental seasons Table (2), compared to those grown in nutrient solution rich in Ca or K or those grown in Ca-K equilibrium solutions. Furthermore, Red Spring tomato plants grown in nutrient solutions with excess Ca and K exhibited the highest dray weight of leaves and root system.

Related results were obtained by Hossain and Nonami, (2012) on some tomato cultivars grown hydroponically under stress conditions.

Table (1): Effect of Calcium-potassium equilibrium on plant height (cm) and fresh weight of young, adult and old leaves as well as root system fresh weight of "Red Spring" tomato grown hydroponically, during (November **2021-2022 and** November **2022-2023).**

Treatments	Plant height (cm)		F.W. young leaves (g)		F.W. adult leaves (g)		F.W. of old leaves (g)		F.W. of root system (g)	
	First season November **2021-2022**	**Second season** November **2022-2023)**	**First season** November **2021-2022**	**Second season** November **2022-2023**	**First season** November **2021-2022**	**Second season** November **2022-2023**	**First season** November **2021-2022**	**Second season** November **2022-2023**	**First season** November **2021-2022)**	**Second season** November **2022-2023**
Equilibrium solution	**110.2 C**	**107.5 B**	**112.5 C**	**115.6 C**	**122.5 C**	**133.5 C**	**89.3 C**	**84.6 B**	**139.2 C**	**147.7 C**
Ca deficient solution	**65.4 D**	**61.3 C**	**88.1 D**	**75.2 D**	**93.7 D**	**82.5 E**	**82.7 C**	**79.2 B**	**112.5 D**	**114.3 D**
Ca excess solution	**135.7 AB**	**142.9 A**	**129.6 B**	**132.4 B**	**143.7 B**	**152.7 B**	**103.9 B**	**120.4 A**	**160.6 A**	**122.5 D**
K deficient solution	**74.9 D**	**72.6 C**	**75.2 D**	**85.5 D**	**101.3 D**	**99.9 D**	**71.2 D**	**80.6 B**	**105.7 D**	**111.6 D**
K excess solution	**134.3 B**	**139.8 A**	**134.9 B**	**122.5 B**	**149.9 B**	**83.4 E**	**95.4 BC**	**79.6 B**	**154.3 B**	**162.5 B**
Ca & K excess solution	**147.4 A**	**152.5 A**	**155.4 A**	**178.7 A**	**169.3 A**	**184.8 A**	**119.8 A**	**121.8 A**	**173.7 A**	**189.8 A**

Table (2): Effect of Calcium-potassium equilibrium on leaves and root dry weight of "Red Spring" tomato grown hydroponically, during (November 2021-2022 and November 2022-2023).

Treatments	D.W. young leaves (g)		D.W. adult leaves (g)		D.W. old leaves (g)		D.W. of root system (g)	
	First season November (2021-2022)	**Second season November (2022-2023)**	**First season November (2021-2022)**	**Second season November (2022-2023)**	**First season November (2021-2022)**	**Second season November (2022-2023)**	**First season November (2021-2022)**	**Second season November (2022-2023)**
Equilibrium solution	**24.2 C**	**24.6 C**	**26.7 CD**	**29.9 C**	**20.3 B**	**19.2 B**	**34.7 B**	**31.3 B**
Ca deficient solution	**19.5 D**	**15.1 D**	**22.2 D**	**17.7 E**	**18.7 C**	**17.6 B**	**28.0 BC**	**25.1 B**
Ca excess solution	**25.9 C**	**28.7 B**	**27.5 C**	**34.5 B**	**22.7 BC**	**26.8 A**	**40.1 AB**	**43.3 A**
K deficient solution	**15.7 D**	**16.6 D**	**23.3 D**	**22.8 D**	**16.4 C**	**18.2 B**	**26.2 C**	**27.8 B**
K excess solution	**31.8 B**	**27.5 BC**	**33.3 B**	**27.1 C**	**23.7 B**	**24.2 A**	**38.9 AB**	**40.5 A**
Ca & K excess solution	**36.9 A**	**39.1 A**	**39.2 A**	**44.0 A**	**29.9 A**	**27.3 A**	**43.3 A**	**47.3 A**

3- Effect of Ca-K equilibrium on growth parameters

The data obtained during the two experimental seasons, as shown in Table (3) indicated that, increasing the concentration of Ca (from 7 to 14 meq/L) or K (from 7 to 14) in the nutrient solution, as well as decreasing the concentration of Ca from 7 to 2 meq/L and K from 7 to 2 meq/L significantly varied mineral contents of the leaves, during the two experimental seasons. Increasing the concentration of Ca alone or both Ca and K in the nutrient solution significantly decreased the concentration of P, Mg, Ze and Fe in the leaves. Similarly, increasing the concentration of potassium alone or both calcium and potassium in nutrient solution had a negative effect on the concentration of P, Mg, Fe and Zn in tomato leaves. However, the combined increase of these two cations in the nutrient solution was more effective than the single effect of each one alone Table (3). On the contrary, the nutrient solution poor in Ca or K enhanced the absorption of other cations such as Mg. Zn and Fe, leading to a significant increase in their contents in the leaves Table (3). On the opposite side, increasing the concentration of Ca or K as well as increasing the concentration of both cations (Ca and K) in the nutrient solution caused a significant increase in the N content in the leaves, this trend was observed during the two experimental seasons. However, increasing the concentration of two cations (Ca and K) in the nutrient solution had a more pronounced effect on the contents N, Ca and K in the leaves. It is clear from the obtained data that the plants grown in nutrient solutions rich in calcium and potassium had the highest N, Ca and K contents during the two experimental seasons.

The occurrence of Ca and K antagonism in tomato plants has been reported in many scientific literatures such as **Paliwal, (2018).** The competition between Ca and K, as well as other cations, which observed in this study has already been confirmed by some previous studies on tomato nutrition, whether under field cultivation or soilless culture. **Pujos & Morard, (1997)** studied the effect of Ca and K antagonism on growth and fruiting of tomato plants grown hydroponically and confirmed that there is a strong competition between these cations in uptake and transport which may lead to the appearance of deficiency symptoms on tomato plants. Furthermore, **Nazarideljou et al., (2019).** confirmed that the exchange of Ca and K negatively charged binding sites in the xylem cell walls is not dependent on simple mass flow. The exchange sites of Ca and K remain in equilibrium with the transpiration stream and total Ca or K exchange capacity of individual xylem cells depends on the inner surface areas, as well as the ultra-structural and chemical composition of its cell walls.

Table (3): Effect of Calcium-potassium equilibrium on adult leaves macro and micronutrient contents of "Red Spring" tomato grown hydroponically during 2021 and 2022 seasons.

Treatments	N %		P %		K %		Ca %		Mg %		Fe (ppm)		Zn (ppm)		Mn (ppm)	
	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)	First season November (021-022)	Second season November (022-023)
Equilibrium solution	2.6 A	2.8 A	0.66 B	0.62 C	1.9 C	1.8 B	1.5 B	1.2 B	0.7 A	0.8 A	30 B	29 B	19 B	18 BC	13 A	12 A
Ca deficient solution	2.0 C	2.4 B	0.73 A	0.79 A	2.3 B	2.1 B	0.5 C	0.4 C	0.8 A	0.9 A	35 A	39 A	22 A	25 A	13 A	14 A
Ca excess solution	2.6 A	2.7 A	0.48 C	0.51 D	1.8 CD	1.7 C	1.8 A	1.7 A	0.5 B	0.5 B	18 CD	17 C	14 C	15 C	13 A	14 A
K deficient solution	2.1 BC	2.0 C	0.73 A	0.74 B	1.5 D	1.0 D	1.9 A	1.8 A	0.8 A	0.8 A	20 C	25 B	24 A	23 AB	14 A	13 A
K excess solution	2.2 BC	2.3 B	0.49 C	0.44 E	2.6 AB	2.4 AB	1.4 B	1.3 B	0.6 AB	0.5 B	22 C	21 BC	17 BC	19 BC	13 A	14 A
Ca & K excess solution	2.3 B	2.1 B	0.45 C	0.43 E	2.7 A	2.6 A	1.8 A	1.9 A	0.4 B	0.4 B	14 D	16 C	16 BC	18 BC	16 A	14 A

4- Effect of Ca-K equilibrium on tomato fruiting

It is clear from the obtained data presented in Table (4) that varying Ca-K equilibrium in the nutrient solution significantly affected the number of clusters/plant and the number of fruit/clusters compared to standard equilibrium solution, during the two experimental seasons. Decreasing the concentration of Ca or K in the nutrient solution from 7.0 to 2.0 meq/L significantly decreased the number of clusters during the first experimental season. In the second experimental season the number of clusters /plants was reduced from 6 to 4 clusters and the number of fruits/clusters was reduced from 6 to 3 fruits.

No significant response in the number of clusters /plant was observed as a result of individually increasing the Ca or K concentrations (from 7.0 to 14 meq/L) in the nutrients solution during the two seasons. On the contrary, increasing the individual concentration of Ca or K in the nutrient solution led to a significant increase in fruit numbers/cluster the number of fruits/clusters of Red Spring tomatoes, during the two experimental seasons. Furthermore, increasing the concentration of both cations (Ca and K) in the nutrient solution led to significant increase in the number of clusters/plant (from 5 to 7 in 2021 and 6 to 8 cluster in 2022) and the fruits number/plant (from 6 to 8 in 2021 and from 6 to 9 fruits in 2022), during the two experimental seasons.

This promotion of increasing the number cluster/plant and number of fruit/clusters in the nutrient solution was associated with increasing concentration of both Ca and in the nutrient solution under hydroponic culture. However, negative effect on the number of cluster/plant and number of fruits/clusters of tomato as result of decreasing Ca or K concentration in nutrient solution was reported by other authors such as: **(Njira, K. O., & Nabwami, J, 2015); (Shirko et al., 2018) and (Nazarideljou et al., 2019).**

K^+ also plays an important role in water and nutrient transport **(Paliwal, 2018 and Shirko et al., 2018).** K activates the protein synthesis **(Prajapati & Modi, 2012, Pujos, 1996)** explained the importance role of calcium in following points: Calcium treatment delays ripening, senescence and abscission of fruits, it improves fruit and vegetable quality, alters geotropic response, a-amylase secretion, photosynthesis, plane an essential role in some essential processes in plants such as cell division, cytoplasm streaming and cell enlargement. Ca is essential for maintaining structural integrity of membranes and cell walls and reducing the harmful toxicity effects of heavy metals. Furthermore, calcium deficiency causes some disorder in tomato fruiting such as bitter pit, end rot in tomatoes and tip burn in lettuce **(Nazarideljou et al., 2019)**.

Table (4): Effect of Calcium-potassium equilibrium on cluster number/plant and fruit number/cluster on "Red spring" tomato grown hydroponically, during 2021 and 2022 seasons.

Treatments	Clusters no./plant		Fruit no. per cluster	
	First season November (2021-2022)	Second season November (2022-2023)	First season November (2021-2022)	Second season November (2022-2023)
Equilibrium solution	5 B	6 B	6 B	6 BC
Ca deficient solution	3 C	4 C	4 C	5 C
Ca excess solution	5 B	6 B	7 A	7 B
K deficient solution	3 C	4 C	4 C	5 C
K excess solution	5 B	5 BC	8 A	8 AB
Ca & K excess solution	7 A	8 A	8 A	9 A

5- Effect of Ca-K equilibrium on fruit physical and chemical properties

The data illustrated in Table (5) show the effect of different concentrations of Ca-K equilibrium on physical (fruit weight, fruit height and fruit diameter) and chemical properties (TSS%, total acidity and vitamin C) of "Red Spring" tomato fruit, during 2021 and 2022 seasons. The obtained data reveal that the plant grown in nutrient solution rich in Ca or K contents had higher fruit weight (g), fruit length (cm) and fruit diameter (cm) than those grown in the standard solution or those grown in poor Ca or K solutions. However, the plants grown in solution rich in both Ca and K contents gave the best results in term of fruit physical properties (125 & 127g for fruit weigh, 7.4 & 7.2 cm for fruit height and 5.2 & 5.5 cm for fruit diameter), during the two experimental seasons, respectively.

Fruit chemical properties (i.e., TSS%, total acidity % and vitamin C "mg/100g F.W.") of "Red Spring" tomato fruits significantly varied as a result of varying the concentration of Ca or/and K in the nutrient solution as shown in Table (5). Increasing the concentration of Ca or K from 7.0 to 14.0 meq/L was associated with a significant increase in TSS% and vitamin C contents and a significant decrease in the total acidity was observed. However, decreasing the concentration of Ca or K from 7 to 2.0 meq/L caused a significant decrease in TSS% and vitamin C contents and significantly increasing the total acidity, these trends were observed during the two experimental seasons. Table (5) shows that the plants grown in the nutrient solution rich in Ca and K concentration had the best results, with the highest values of TSS% (6.5 & 6.8 %) and vitamin C (55 & 54 mg/100) and the lowest total acidity % (0.499 & 0.466 %), during the two seasons respectively. On the contrary, the plants grown in the nutrient solution poor in K had the lowest TSS% and vitamin C contents and the highest total acidity during the two experimental seasons. Similar outcomes were achieved by other researchers, including **Shirko et al. (2018) and Nazarideljou et al. (2019).**

Table (5): Effect of Calcium potassium equilibrium on some tomato fruit physical and chemical properties, during 2021 and 2022 seasons.

Treatments	Fruit weight (g)		Fruit height (cm)		Fruit diameter (cm)		TSS %		Total acidity %		Vitamin C (mg/100g F.W.)	
	First season November (2021-2022)	Second season November (2022-2023)	First season November (2021-2022)	Second season November (2022-2023)	First season November (2021-2022)	Second season November (2022-2023)	First season November (2021-2022)	Second season November (2022-2023)	First season November (2021-2022)	Second season November (2022-2023)	First season November (2021-2022)	Second season November (2022-2023)
Equilibrium solution	100.4 C	103.5 B	5.9 C	5.6 C	4.0 C	4.4 B	4.2 B	4.1 C	0.654 B	0.636 C	43 B	40 B
Ca deficient solution	79.5 D	73.4 C	4.8 C	4.3 E	3.3 D	3.2 C	3.7 C	3.2 D	0.611 C	0.672 B	28 C	22 C
Ca excess solution	115.8 AB	119.7 A	6.6 B	6.9 A	5.1 A	5.3 A	4.4 B	4.9 B	0.678 B	0.658 BC	44 B	49 A
K deficient solution	87.4 D	84.4 C	5.1 D	5.0 D	3.5 D	3.3 C	3.1 D	3.3 D	0.873 A	0.899 A	21 C	20 C
K excess solution	112.3 B	113.9 B	6.9 AB	6.8 B	4.8 B	5.2 A	6.9 A	6.8 A	0.438 E	0.489 DE	51 AB	52 A
Ca & K excess solution	125.5 A	127.8 A	7.4 A	7.2 A	5.2 AB	5.5 A	6.6 A	6.9 A	0.499 D	0.466 E	55 A	54 A

Conclusions

In this study, we demonstrated the effects of equilibrium Ca-K in the nutrient solution and its antagonism on the growth, nutritional statues, productivity and fruit quality of Red Spring tomato. grown under hydroponic culture conditions. Compared to reference Ca-K equilibrium solution or those poor in Ca or K, the "Red Spring" tomato plants grown in the nutrient solution rich in Ca or in K both cations (Ca and K) had higher and significant vegetative growth parameters and dry weight of shoot and root system as well as number of cluster/plant and the number of fruits/clusters. Significant differences were noticed in the mineral leaves contents (N, P, K, Ca, Fe and Zn) because of varying the equilibrium of nutrient solution, during the two experimental seasons. However, the antagonism between Ca, K and Mg was clearly observed. Fruit physical and chemical characteristics significantly affected by changing Ca or K concentrations in the nutrient solution.

Conflicts of Interest/ Competing interest

This manuscript has no conflicts of interest.

Conflicts of Interest/ Competing interest

All authors declare that they have no conflicts of interest.

Data availability statement:

All data sets collected and analyzed during the current study are available from the corresponding author on reasonable request.

List of Abbreviations

A.O.A.C	Association of Official Agricultural Chemists
EDTA	Ethylenediaminetetraacetic acid
D.W	Dry weight
F.W.	Fresh weight
TSS	Total soluble solids

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