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EFFECTS OF PHOSPHORUS, SILICATES AND CITRIC ACID ON GROWTH AND YIELD OF PEPPER IN GREENHOUSES

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ABSTRACT

The research was conducted in a plastic greenhouse at the College of Agricultural Engineering Sciences, University of Baghdad - Jadiriyah Campus, during the 2021-2022 season, to study the effect of phosphorus, silicon, and citric acid on pepper plants using a factorial experiment design with three replicates. The first factor had three levels of phosphorus (P_2O_5): 0 kg hectare^{-1} (P1), 160 (P2) and 320 kg h^{-1} (P3),the second factor had three levels of potassium silicate 0 kg h^{-1} (S1), 75 (S2) and 100 kg h^{-1}(S3), and the third factor had four levels of citric acid 0 kg h^{-1} (C1), 2 (C2), 4 (C3) and 6 kg h^{-1} (C4). The results of the statistical analysis showed the superiority of the P3S2C4 treatment in increasing plant height (160.20 cm plant^{-1}), the P2S3C3 treatment in leaf area (631.3 dm^2 plant^{-1}), the P2S3C4 treatment in the concentration of phosphorus in the leaf (0.470%), and the treatment P2S2C1 in the concentration of silicon in the leaf (18.50 ppm). The P3S3C4 treatment is the number of lateral roots (14.27 roots plant^{-1}). The P2S3C4 treatment is the number of fruits (48.34 fruits plant^{-1}) and the P3S3C4 treatment is the plant yield (3.48 kg plant^{-1}).

Keywords: *Capsicum annuum* L., fertilizer,p_2o_5, potassium silicate.

تأثير الفسفور والسليكات وحامض الستريك في نمو وحاصل نبات الفلفل تحت ظروف البيئة المحمية

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الخلاصة

نُفذ البحث في احد البيوت البلاستيكية/ كلية علوم الهندسة الزراعية/ جامعة بغداد– مجمع الجادرية للموسم 2021-2022 لدراسة تأثير الفسفور والسليكون وحامض الستريك على الفلفل، بتجربة عاملية وفق تصميم القطاعات الكاملة المعشاة بثلاث مكررات، العامل الاول ثلاثة مستويات من الفسفور P_2O_5 : 0 كغم هكتار$^{-1}$ (P1) و 160 (P2) و 320 (P3) والعامل الثاني ثلاثة مستويات من سيليكات البوتاسيوم: 0 كغم هكتار$^{-1}$ (S1) و 75 (S2) و 100 (S3) والعامل الثالث اربع مستويات من حامض الستريك : 0 كغم هكتار$^{-1}$ (C1) و 2 (C2) و 4 (C3) و 6 كغم هكتار$^{-1}$ (C4).أظهرت نتائج التحليل الإحصائي تفوق المعاملة P3S2C4 في زيادة إرتفاع النبات (160.20 سم نبات$^{-1}$) والمعاملة P2S3C3 في المساحة الورقية (601.3 دسم^2 نبات$^{-1}$) والمعاملة P2S3C4 تركيز الفسفور في الورقة (0.470%) والمعاملة P2S2C1 في تركيز السليكون في الورقة (18.50 ppm) والمعاملة P3S3C4 عدد الجذور الجانبية (14.27 جذر جانبي نبات$^{-1}$.) وتفوقت المعاملة P2S3C4 في زيادة عدد الثمار (48.34 ثمرة نبات$^{-1}$) والمعاملة P3S3C4 في حاصل النبات (3.48 كغم نبات$^{-1}$).

الكلمات المفتاحية: فلفل ، سماد، p_2o_5،سيليكات البوتاسيوم.

* **The article is taken from the doctoral thesis of the first researcher.**

INTRODUCTION

Pepper (*Capsicum annuum* L.) is one of the important summer vegetables belonging to the Solanaceae family because of its high nutritional value **(AL-Aamel & AL-Maliky, 2023)**, as it is used fresh or as a spice because its fruits contain many chemical compounds, some of which enter our food directly, such as vitamin C, A, iron minerals, calcium, and other compounds such as capsaicinoids, carotenoids, and phenolic compounds, which are used to prolong the life of industrial products, protect them from oxidation, and manufacture some therapeutic compounds for inflammation, as well as manufacture some cosmetics **(Baenas *et al*., 2018).** Mineral elements have a significant impact on increasing the productivity of vegetable crops (**Al-Dulaimi & Al-Amri, 2020)**. The solubility of the mineral elements present in the soil is affected by several factors, including humidity, ventilation, and acidity, which led the plant to adopt different mechanisms to absorb these nutrient elements, including those related to the structural construction of the roots. Its surface area and elongation increases the rate of absorption, so the basic elements must be ready and close to its roots at the beginning of its growth, such as phosphorus, because it has an important role in the growth of the primary root, as well as its activation of the growth of lateral roots and root hairs and increasing their density **(Bhatla & Lal, 2018)**. It is worth It is noteworthy that the gypsum soil of Iraq suffers from a deficiency of many elements, including phosphorus **(Muhawish & Al-kafaje, 2017)**, so it had to be added periodically because it has a role in increasing plant production **(Al-Mashhadany & Al-Mharib, 2023)** and effects in all growth indicators, such as plant height, number of branches, plant yield, and total yield **(Khanal *et al*., 2021).** As for silicon (Si), it is the second most abundant element after oxygen and constitutes about 27% of the Earth's crust and combines with oxygen to form silicates such as quartz and feldspar **(Bakhata *et al*., 2018)**, its beneficial effects are closely linked to the extent of its accumulation inside the plant **(Yan *et al*., 2018)**, as it plays a physical role by forming a layer of silica on the cell wall, increasing its solidity, and another role is represented by activating the enzymes responsible for the production of antibiotics which is produced by the plant when it is infected with diseases or insects **(Wang *et al*., 2017)** and has a direct or indirect role in many monocotyledonous or dicotyledonous plant species by giving them the ability to withstand biotic stresses such as diseases and insects, and abiotic stresses such as drought, high temperatures, and the toxicity of some Mineral elements **(Debona *et al*., 2017** and **Souri *et al*., 2020)**. The beneficial effects of silicon are not limited to plant species that accumulate it in a high percentage, as in some cereal crops, but it even affects species with a low concentration of it, as its deposition in the cell walls can To improve the ability of the cell membrane to transfer nutrients **(Sheng *et al*., 2018)**. At the level of pepper plants, some researchers have found that silicon has a role in other vegetative growth indicators, such as increasing the concentration of macro- and microelements in the leaves, increasing the number of fruits and the total yield of the plant when adding silicates **(Saleem & Joody, 2019** and **Nascimento *et al*., 2019)**. Organic materials have a positive effect on all plants, including vegetable crops, due to their role in improving the physical properties of the soil **(Al-Halfi & Al-Azzawi, 2022)**. Citric acid is an organic acid with a low molecular weight that is naturally produced in plants and is found in high concentration in citrus fruits, It is plays a role in increasing the plant's ability to withstand abiotic stress conditions such as drought, salinity, heat stress, and the toxicity of heavy elements such as cadmium and nickel, It has been observed that photosynthesis rates increase when citric acid is added to plants that suffer from these stresses. This acid has an effect in increasing cell permeability and protecting membranes from damage. The ability to reduce the toxic effect of heavy metal ions by precipitating or chelating and accumulating them in various plant organs. It also has a role in reducing the severity of oxidative stress by producing antioxidants when plants are exposed to stress **(Tahjib-Ul-Arif *et al*., 2021)**. Indeed, it was confirmed Some researchers have focused on the role of citric acid in protecting fruits from damage after immersing them in it **(Al-Hajani *et al*., 2022)**. It has a direct role in improving the growth of pepper plants, and this is what was confirmed by **Al-balawna & Abu-Abdoun (2021)** when adding citric acid to several Concentrations, including 2.5 gm for 500 gm soil, which led to an increase in the readiness of iron, manganese, copper, and zinc in the soil solution, as the concentrations of these elements reached 16.62, 45.50, 2.5, and 5.20 ppm, respectively, compared to the comparison treatment, which amounted to 4.53, 13.19, 2.0, and 4.07 ppm, respectively, The pH also decreased to reach 7.5 compared to 13.0 in the comparison treatment, The same researcher also confirmed that adding 300 grams of citric acid to pepper plants grown in an area of 1000 m^2 led to an increase in plant production to reach 150 kg in 1000 m^2 compared to 110 kg in 1000 m^2 in the control treatment. Due to the long growing season of pepper crop in greenhouses and its many nutritional requirements, the role of mineral elements such as phosphorus and silicon mentioned above in plant growth, and the importance of organic acids such as citric acid in releasing these two elements, we will rely on these three nutritional factors in this study on the pepper plant with the aim of knowing the role of phosphorus, silicon and citric acid in some indicators of vegetative growth and fruit production.

MATERIALS AND METHODS

The research was carried out in a plastic house in the College of Agricultural Engineering Sciences/ University of Baghdad/ Al-Jadriya Complex in the 2021/2022 agricultural season, with an area of 463.5 m^2.house, on 10/27/2021, and the **Carisma** hybrid pepper plants were approved by planting seedlings at the age of four true leaves on 10/27/2021 and ended. The experiment is on 9/1/2022.

FACTORS OF STUDY

Three factors were added to the soil as follows: P_2O_5 (P) at three concentrations: 0, 160, and 320 kg ha^{-1}. Potassium silicate (52.8% SiO_2) (S): 0, 75, and 100 kg ha^{-1}. Citric acid (C): 0, 2, 4, and 6 kg ha^{-1}. After interfering with the study factors (P) Plant roots are watered with a solution. The research was carried out as a factorial experiment according to a randomized complete block design (RCBD), and the data were analyzed using the Genstat program, and the means were compared with the least significant difference (L.S.D.). At a 5% probability level. The following indicators were measured:

1. Plant height (cm $plant^{-1}$): The height of all plants was measured at the end of the season from the soil surface level up to the highest growing tip using a tape measure.

2. leaf area (dm^2 $plant^{-1}$): Five leaves were selected from each plant, then photographed and their area was calculated using the Digimizer program. The average area of one leaf was taken and multiplied by the total number of leaves on the plant.

3. phosphorus in the leaves (%): It was estimated according to the method mentioned in **AOAC (1980)**.

4. silicon in the leaves (ppm): Concentration was estimated according to the **AOAC (1980)** method.

5. Number of lateral roots in the plant (plant root^{-1}).

6. Number of fruits (plant^{-1})

The total number of fruits of the plants of the experimental unit was calculated in all the fairies and divided by the number of plants of the experimental unit according to the following equation:

Number of fruits per plant = total number of fruits / number of experimental unit plants.

7. Yield plant (kg plant^{-1}): The cumulative production amount of the plants of the experimental unit was calculated, then the result was divided by the number of plants to obtain the productivity of one plant.

RESULTS AND DISCUSSION

1. Plant height (cm plant^{-1})

We conclude from Table 1 that treatment P3 increased the plant height to 144.84 cm plant^{-1}, with a significant difference from treatment P2 and the comparison treatment P1. The treatment S3 excelled in the height plant (143.35 cm plant^{-1}), but not significantly different from treatment S2, and when citric acid was added to treatment C4, the plant height increased to 146.89 cm plant^{-1}, with a significant difference from treatments C3 and C1. As for the triple intervention, the P3S2C4 treatment was superior in increasing plant height to 160.20 cm plant^{-1}, but with a non-significant difference from some treatments.

Table (1): Effect of phosphorus, silicon, and citric acid on height of plant (plant cm^{-1}).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	C2 (2)	C3 (4)	C4 (6)	
P 1 (0)	S1 (0)	112.80	128.20	125.73	154.67	130.35
	S2 (75)	121.73	128.33	155.00	151.37	139.11
	S3 (100)	132.77	143.17	154.33	136.67	141.73
P 2 (160)	S1 (0)	145.00	140.33	129.87	140.00	138.80
	S2 (75)	143.40	146.00	125.13	141.00	138.88
	S3 (100)	145.87	125.83	144.40	131.67	136.94
P 3 (320)	S1 (0)	137.77	133.67	140.10	157.90	142.36
	S2 (75)	141.67	123.33	138.00	160.20	140.80
	S3 (100)	156.67	152.83	147.47	148.53	151.37
L.S.D. 0.05		15.11				7.56
(P)		C1	C2	C3	C4	Means P
P1		122.43	133.23	145.02	147.57	137.06
P2		144.76	137.39	133.13	137.56	138.21
P3		145.37	136.61	141.86	155.54	144.84
L.S.D. 0.05		8.73				4.36
(S)		C1	C2	C3	C4	Means S
S1		131.86	134.07	131.90	150.86	137.17
S2		135.60	132.56	139.38	150.86	139.60
S3		145.10	140.61	148.73	138.96	143.35
L.S.D. 0.05		8.73				4.36
Citric acid (C)		137.52	135.74	140.00	146.89	
L.S.D. 0.05		5.04				

2. leaf area (dm^2 $plant^{-1}$)

Treatment P2 had a significant effect represented by, as it reached 454.2 $dm^2 plant^{-1}$ (Table2) compared to the comparison treatment, but it did not differ significantly from treatment P3 (449.6 dm^2 $plant^{-1}$). As for silicon, treatment S3 (462.6 dm^2 $plant^{-1}$) was superior, with a significant difference from the rest of the treatments. While citric acid concentrations did not have a significant effect. When the three-way interaction between the study factors occurred, the P2S3C3 treatment outperformed all the treatments, reaching 631.3 dm^2 $plant^{-1}$, but without a significant difference from the P2S3C1 treatment, which amounted to 601.3 dm^2 $plant^{-1}$.

Table (2): Effect of phosphorus, silicon, and citric acid on leaf area (dm^2 $plant^{-1}$).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	C2 (2)	C3 (4)	C4 (6)	
P 1 (0)	S1 (0)	210.7	274.4	295.5	341.9	280.6
	S2(75)	381.8	459.4	428.4	395.8	416.4
	S3 (100)	452.5	387.0	443.2	422.8	426.4
P 2 (160)	S1 (0)	377.9	365.3	323.2	411.5	369.5
	S2(75)	449.3	526.3	463.3	425.7	466.2
	S3 (100)	601.3	377.5	631.3	497.7	527.0
P 3 (320)	S1 (0)	499.2	502.7	473.6	459.0	483.6
	S2(75)	417.4	449.5	408.4	448.0	430.8
	S3 (100)	411.2	430.2	474.0	422.3	434.4
L.S.D. 0.05		66.6				33.3
(P)		C1	C2	C3	C4	Means P
P1		348.3	373.6	389	386.8	374.5
P2		476.2	423.1	472.6	445.0	454.2
P3		442.6	460.8	452.0	443.1	449.6
L.S.D. 0.05		38.4				19.2
(S)		C1	C2	C3	C4	Means S
S1		362.6	380.8	364.1	404.1	377.9
S2		416.2	478.4	433.4	423.2	437.8
S3		488.3	398.2	516.2	447.6	462.6
L.S.D. 0.05		38.4				19.2
Citric acid (C)		422.4	419.2	437.9	425.0	
L.S.D. 0.05		N.S				

3. phosphorus in the leaves (%)

The addition of superphosphate fertilizer increased the concentration of phosphorus in the leaves, as treatment P2 was superior (Table 3) and reached 0.428% compared to the control treatment, but without a significant difference from treatment P3 (0.421%). Treatment S2 also excelled, and the phosphorus concentration in its leaves reached 0.413% compared to the comparison treatment, but without a significant difference from treatment S3. Treatment C4 (0.414%) was superior to treatments C2 and C3, but without a significant difference. When interacting between phosphorus, silicon, and citric acid, the P2S3C4 treatment excelled (0.470%), but without a significant difference from some treatments.

Table (3): Effect of phosphorus, silicon, and citric acid on phosphorus concentration in leaves (%).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	C2 (2)	C3 (4)	C4 (6)	
P 1 (0)	S1 (0)	0.313	0.330	0.343	0.353	0.335
	S2(75)	0.310	0.413	0.413	0.403	0.385
	S3 (100)	0.313	0.400	0.403	0.393	0.377
P 2 (160)	S1 (0)	0.433	0.410	0.423	0.430	0.424
	S2(75)	0.413	0.420	0.430	0.433	0.424
	S3 (100)	0.433	0.423	0.423	0.470	0.437
P 3 (320)	S1(0)	0.410	0.430	0.413	0.390	0.410
	S2(75)	0.443	0.423	0.423	0.433	0.430
	S3 (100)	0.390	0.453	0.430	0.420	0.423
L.S.D. 0.05		**0.050**				**0.025**
(P)		**C1**	**C2**	**C3**	**C4**	**Means P**
P1		0.312	0.381	0.386	0.383	0.365
P2		0.426	0.417	0.425	0.444	0.428
P3		0.414	0.435	0.422	0.414	0.421
L.S.D. 0.05		**0.029**				**0.014**
(S)		**C1**	**C2**	**C3**	**C4**	**Means S**
S1		0.385	0.39	0.393	0.391	0.390
S2		0.388	0.418	0.422	0.423	0.413
S3		0.378	0.425	0.418	0.427	0.412
L.S.D. 0.05		**0.029**				**0.014**
Citric acid (C)		0.384	0.411	0.411	0.414	
L.S.D. 0.05		**0.016**				

4. silicon in the leaves (ppm)

Research factors have a role in increasing the silicon concentration in plant leaves, as the second concentration of phosphorus (P2) increased the silicon concentration to 15.50 ppm (Table 4) compared to the P3 treatment, but without a significant difference from the comparison treatment. Treatment (S3) excelled in increasing the concentration to 15.54 ppm compared to the comparison treatment, but without a significant difference from treatment S2 (15.17 ppm). With regard to citric acid, the significant superiority was for the control treatment (15.94 ppm), but without a significant difference from treatment C3 (15.61 ppm). As for the triple intervention, treatment P2S2C1 was superior (18.50 ppm), while treatment P2S1C2 recorded the lowest silicon concentration (12.50 ppm).

5. Number of lateral roots in the plant (Root plant $^{-1}$).

Lateral roots arise internally from the cells of the pericycle in the root to perform their role in stabilizing the plant and absorbing water and nutrients. They are one of the important indicators because increasing their number leads to improving the efficiency of absorbing water and nutrients. This is confirmed by the results in Table 5, as treatment P2 excelled (10.41 plant roots^{-1}) Compared to the comparison treatment, but with a non-significant difference from treatment P3. Silicon had a significant effect in increasing the number of lateral roots to 11.23 plant roots^{-1} in treatment S3, with a significant difference from treatments S2 and S1. As for citric acid, treatment C4 was superior (10.58 plant roots^{-1}) compared to treatments C3 and

C1, but with a non-significant difference from treatment C2. The triple intervention resulted in the P3S3C4 treatment being significantly superior to all treatments in increasing the number of lateral roots to 14.27 plant roots^{-1}.

Table (4): Effect of phosphorus, silicon, and citric acid on silicon concentration in leaves (ppm).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	**C2 (2**	**C3 (4)**	**C4 (6)**	
P 1 (0)	**S1 (0)**	14.50	15.50	16.50	14.00	15.12
	S2(75)	16.50	17.50	16.00	14.00	16.00
	S3 (100)	15.00	15.00	16.00	12.50	14.62
P 2 (160)	**S1 (0)**	16.00	12.50	16.50	13.00	14.50
	S2(75)	18.50	15.00	14.50	15.00	15.75
	S3 (100)	16.00	16.50	16.50	16.00	16.25
P 3 (320)	**S1(0)**	16.00	15.50	14.50	13.50	14.88
	S2(75)	14.50	13.00	14.00	13.50	13.75
	S3 (100)	16.50	15.00	16.00	15.50	15.75
L.S.D. 0.05		**1.91**				**0.95**
(P)		**C1**	**C2**	**C3**	**C4**	**Means P**
P1		15.33	16.00	16.17	13.5	15.25
P2		16.83	14.67	15.83	14.67	15.50
P3		15.67	14.5	14.83	14.17	14.79
L.S.D. 0.05		**1.10**				**0.55**
(S)		**C1**	**C2**	**C3**	**C4**	**Means S**
S1		15.50	14.50	15.83	13.50	14.83
S2		16.50	15.17	14.83	14.17	15.17
S3		15.83	15.50	16.17	14.67	15.54
L.S.D. 0.05		**1.10**				**0.55**
Citric acid (C)		15.94	15.06	15.61	14.11	
L.S.D. 0.05		**0.63**				

6. Number of fruits (plant^{-1})

It is one of the important indicators of pepper yield, which is affected by the nutritional aspect of the plant, as the P3 treatment outperformed the rest of the treatments in increasing the number of fruits to 41.81 fruits plant^{-1} (Table 6). Silicon also had a positive effect, with treatment S3 being significantly superior in increasing the number of fruits to 41.71 fruits plant^{-1} compared to the comparison treatment, but without a significant difference from treatment S2 (40.47 fruits plant^{-1}). Regarding the effect of citric acid, the significant superiority of treatment C4 was observed in increasing the number of fruits to 40.64 fruits plant^{-1}. The triple interaction led to the significant superiority of the treatment P2S3C4 in increasing the number of fruits to 48.34 fruits plant^{-1}, but without a difference significant about some transactions.

Table (5): Effect of phosphorus, silicon, and citric acid on the number of lateral roots (plant root^{-1}).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	C2 (1)	C3 (2)	C4 (3)	
P 1 (0)	S1 (0)	7.33	8.37	8.00	8.57	8.07
	S2(75)	8.50	9.50	10.53	10.87	9.85
	S3 (100)	9.53	8.90	9.10	10.50	9.51
P 2 (160)	S1 (0)	8.40	9.83	8.00	10.00	9.06
	S2(75)	10.27	10.67	9.93	9.50	10.09
	S3 (100)	11.00	13.67	12.43	11.27	12.09
P 3 (320)	S1 (0)	8.83	9.50	8.67	9.77	9.19
	S2(75)	9.00	10.10	10.00	10.50	9.90
	S3 (100)	11.20	11.3	11.63	14.27	12.10
L.S.D. 0.05		1.50				0.75
(P)		C1	C2	C3	C4	Means P
P1		8.46	8.92	9.21	9.98	9.14
P2		9.89	11.39	10.12	10.26	10.41
P3		9.68	10.30	10.10	11.51	10.40
L.S.D. 0.05		0.87				0.43
(S)		C1	C2	C3	C4	Means S
S1		8.19	9.23	8.22	9.44	8.77
S2		9.26	10.09	10.16	10.29	9.95
S3		10.58	11.29	11.06	12.01	11.23
L.S.D. 0.05		0.87				0.43
Citric acid (C)		9.34	10.20	9.81	10.58	
L.S.D. 0.05		0.50				

7. Yield plant (kg plant^{-1})

The pepper plant is a fruit-bearing vegetable. Therefore, the plant yield indicator is very important because it represents the sum of plant produced during its growing season, affected by several factors, including nutrition with mineral elements. The results in Table 7 confirmed the significant effect of phosphorus in treatment P3 in increasing the plant yield to 3.09 kg plant^{-1} compared to treatments P2 and P1. As for silicon, the results showed that treatment S3 was significantly superior in increasing the yield to 3.04 kg plant^{-1} compared to the comparison treatment, but with a non-significant difference from treatment S2 (2.99 kg plant^{-1}). With regard to citric acid, treatment C4 was superior in increasing plant yield to 2.95 kg plant^{-1}, with a significant difference from the rest of the treatments, with the exception of treatment C3 (2.86 kg plant^{-1}). As for the triple intervention, the P3S3C4 treatment (3.48 kg plant-1) was superior to all treatments, but it was not significantly different from some treatments.

Table (6): The effect of phosphorus, silicon, and citric acid on the number of fruits (plant^{-1}).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	C2 (1)	C3 (2)	C4 (3)	
P 1 (0)	S1 (0)	23.38	24.70	33.44	30.88	28.10
	S2(75)	36.88	42.01	40.58	40.04	39.88
	S3 (100)	40.17	39.33	41.64	32.54	38.42
P 2 (160)	S1 (0)	36.00	37.57	37.92	40.50	38.00
	S2(75)	38.21	38.72	39.14	39.31	38.85
	S3 (100)	40.96	39.76	43.87	48.34	43.23
P 3 (320)	S1 (0)	39.72	38.59	37.97	40.84	39.28
	S2(75)	36.57	45.73	42.60	45.79	42.67
	S3 (100)	39.86	47.41	39.03	47.56	43.47
L.S.D. 0.05		6.08				3.04
(P)		C1	C2	C3	C4	Means P
P1		33.47	35.35	38.55	34.49	35.47
P2		38.39	38.68	40.31	42.72	40.03
P3		38.72	43.91	39.87	44.73	41.81
L.S.D. 0.05		3.51				1.75
(S)		C1	C2	C3	C4	Means S
S1		33.03	33.62	36.44	37.41	35.13
S2		37.22	42.15	40.77	41.72	40.47
S3		40.33	42.17	41.51	42.81	41.71
L.S.D. 0.05		3.51				1.75
Citric acid (C)		36.86	39.31	39.58	40.64	
L.S.D. 0.05		2.02				

Table (7): Effect of phosphorus, silicon, and citric acid on plant yield (kg plant^{-1}).

Phosphorus (P) kg Ha^{-1}	Silicon (S) kg Ha^{-1}	Citric acid (C) kg Ha^{-1}				P × S
		C1 (0)	C2 (2)	C3 (4)	C4 (6)	
P 1 (0)	S1 (0)	1.60	1.90	2.19	2.36	2.01
	S2(75)	2.72	3.02	3.10	2.92	2.94
	S3 (100)	2.79	2.70	2.90	2.63	2.75
P 2 (160)	S1 (0)	2.81	2.63	2.56	2.94	2.74
	S2(75)	3.07	2.78	2.79	2.98	2.91
	S3 (100)	3.01	2.94	3.21	3.14	3.08
P 3 (320)	S1 (0)	2.96	2.92	2.83	2.93	2.91
	S2(75)	2.86	3.21	3.02	3.20	3.07
	S3 (100)	3.24	3.32	3.12	3.48	3.29
L.S.D. 0.05		0.37				0.19
(P)		C1	C2	C3	C4	Means P
P 1		2.37	2.54	2.73	2.64	2.59
P 2		2.97	2.78	2.85	3.02	2.91
P 3		3.02	3.15	2.99	3.20	3.09
(L.S.D. 0.05		0.21				0.11
(S)		C1	C2	C3	C4	Means S
S1		2.46	2.48	2.53	2.75	2.56
S2		2.89	3.00	2.97	3.03	2.99
S3		3.01	2.99	3.08	3.08	3.04
L.S.D. 0.05		0.21				0.11
Citric acid (C)		2.79	2.82	2.86	2.95	
L.S.D. 0.05		0.12				

The results of the tables presented above demonstrated the positive effects resulting from the addition of phosphorus. This may be attributed to its involvement in the synthesis of the nuclear acids RNA, DNA, and phospholipids, and in the synthesis of the energy compounds ATP and ADP **(Ali & Majeed, 2016** and **Lambers, & Oliveir, 2019)**. It has a role in cell division, elongation, and activation of roots, this explains the findings of the research. After adding triple superphosphate fertilizer periodically from the time of transplanting until the stage of fruit production, which led to an increase in the number of lateral roots (Table 5), the absorption of elements increased accordingly, including phosphorus, the concentration of which increased in leaves (Table 3), and its role in activating many enzymes **(Xu *et al*., 2019)**, all of which led to an increase in cell division, especially in the apical meristem region towards the longitudinal growth of the branches, leading to an increase in plant height (Table 1). Adding silicon in the form of potassium silicate fertilizer to pepper plants in several batches from after transplanting until the fruit production stage led to the activation of the root system, and this was confirmed by the results of the research, as the number of lateral roots increased (Table 5). This is consistent with the findings of **Lee *et al*., 2010** and **Kim *et al*., 2013** of the effect of silicon in stimulating the root system by increasing the surface area of the roots and increasing their diameter, length, and biomass, as some researchers emphasized the role of silicon in stimulating the roots to produce the hormone IAA **(Kaushal & Wani, 2015 and Qin *et al*., 2016**). In turn, it encouraged the plant to form roots, especially lateral roots **(Roopa *et al*., 2023)**. Citric acid affected the measured vegetative growth indicators, including the concentration of phosphorus and silicon in the leaves (Tables 3 and 4). This is due to the contribution of citric acid in increasing the readiness of the elements in the soil solution through a temporary decrease in the degree of soil acidity during the addition of this acid with the irrigation water. The organic acids produced by the plant in its roots affected the release of elements such as phosphorus from primary minerals **(Teodoro *et al*., 2019)**. Therefore, the addition of citric acid led to an increase in the concentration of some elements, including phosphorus, which led to the activation of the shoot, which reflected positively on the development of the plant. As the acid played an important role in increasing the number of lateral roots (Table 5), the plant's ability to absorb water and ions increased, and as a result, the plant's height increased (Table 1). On the other hand, the positive effect of phosphorus in increasing the number of fruits may be directly due to its role in stimulating the plant to flower **(Aljuboori & Mohammed, 2021)** or indirectly through increasing all indicators of vegetative growth **(Zainaldeen & Rasool, 2018)**, thus increasing the leaf area of the plant. It led to an increase in photosynthesis rates, which led to an increase in carbohydrates in plant tissues, and it may have led to an increase in the number of flowers and an increase in the percentage of set, and then this increase occurred in the number of fruits for plants treated with phosphorus (Table 6), and this agreed with **Al-Amery *et al*. (2020)** The role of phosphorus in increasing plant height (Table 1) may be an indirect reason for increasing the number of fruits, and there is no doubt that this leads to an increase in plant yield. As for silicon, it also had a major role in stimulating the root system (Table 5) and the vegetative system of the pepper plant (Table 1, 2, 3, 4 and 5), which led to an increase in the number of fruits and plant yield. The research results also showed that citric acid has a role in increasing plant productivity, as it increased the number of fruits (Table 6) and plant yield (Table 7). This brings us back to the indirect role of this acid in stimulating vegetative growth, represented by reducing the degree of soil interaction (pH) so that the medium becomes acidic. Which leads to an increase in the readiness of the elements in the soil solution, including nitrogen and its important role in stimulating growth **(Al-Rukabi & Al-Jebory, 2020)**, so the plant began to absorb them so that these elements perform their physiological role in forming a strong vegetative system, and the nutritional stock resulting from the process of photosynthesis increased, motivating the plant. To form flowers and then fruits.

CONCLUSION

Dissolving phosphorus, silicon, and citric acid fertilizers in water and adding them to pepper plants in solution forms led to an increase in plant height, leaf area, concentration of phosphorus and silicon in the leaves, number of lateral roots, number of fruits, and plant yield, due to the influence of the study factors individually and the two- and three-way interaction between them.

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