The impact of zinc, calcium, and sorbitol spraying on some characteristics of the potato plant, *Solanum tuberosum* L.

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ABSTRACT

The experiment was conducted in Khalis District, Diyala Governorate, Iraq in the season 2021–2022 to study the effects of spraying with zinc, calcium, and sorbitol alcohol on the characteristics of potato growth, a cultivar of Arezona. The spraying of zinc, calcium, and sorbitol individually or together on potato plants led to a significant increase in all studied traits such as total number of tubers per plant, plant yield, tuber weight, total yield, and marketable yield. The treatments of sorbitol (10 g. L^{-1}) + Zn (0 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest total number of tubers per plant of 12.93, the sorbitol (10 g. L^{-1}) + Zn (200 mg. L^{-1}) + Ca (0.5 g. L^{-1}) gave the highest value in tuber weight of 298.6 g, the sorbitol (10 g. L^{-1}) + Zn (0 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest value in total yield of 71.10 tons, and the sorbitol (10 g. L^{-1}) + Zn (100 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest value in marketable yield of 68.20 tons.

Keywords. Potato, zinc, calcium and sorbitol alcohol

INTRODUCTION

Potato crop *Solanum tuberosum* belongs to the Solanaceae family, and it is an annual tuberous crop. It is native to Bolivia and the Andes Mountains, and it has spread widely throughout the world [20].Potato is the second crop in the Solanaceae family after tomato [13], and the fourth most important crop in the world after wheat, corn, and rice in terms of nutritional importance [2]. In 2019, 377 million tons of potatoes were produced worldwide, with China leading the way, which produced 99 million tons, followed by India with 34 million tons and Russia with 31 million tons [12]. At the end of the nineteenth century, the potato crop was introduced to Iraq, which was widely cultivated in 1960. For the calendar years 2018–2019, Iraq produced (4139.5–9808.7) tons. $hectare^{-1}$, respectively. The potato crop is grown in open fields in the spring and autumn in most governorates, particularly in the northern and central regions [9,10]. Due to its nutrient uptake and the quantity of tubers that it produces during its growth cycle, the potato is one of the vegetable crops that stresses the soil. in spite of the presence of major and minor basic elements in the soil in large quantities, which do not correspond to the necessary rate for plant growth [4]. One of the essential micronutrients for plant nutrition is zinc, which is absorbed by plants as (Zn^{+2}). It has a significant morphological, biochemical, and physiological impact on plants and helps control sugar consumption while also requiring more energy to produce chlorophyll, which is a major component of many proteins in plants, According to [1], the zinc concentration of plants ranges from 20 to 100 mg. L^{-1}, and the critical limit is 20 mg. L^{-1}, after which the plant begins to show signs of zinc insufficiency. The process of making starch will stop in plants that are deficient in zinc [3]. The Calcium element is required to maintain the unity and structure of cellular membranes, making it one of the important nutrients that the plant receives in the form of positively charged ions (Ca^{+2}), where Calcium performs several physiological tasks connected to the growth and development of the plant, it is a slow-moving element that cannot quickly transition from old growth to modern growth, therefore its deficiency leads to the appearance of deficiency symptoms in new growth first [17]. Sorbitol consists of reduction the sugar D-Glucose, and it is one of the types of sugar alcohols that belongs to the hexitol group, which is polyols of organic compounds derived from sugars, it moves easily within the bark of the plant and works to transport nutrients inside the phloem tubes in the form of a complex (di-Sorbitol brote ester) to the active zones of the plant [8]**.** The aim of this study is to evaluate the effects of spraying zinc, calcium, and sorbitol on the traits of potato growth.

MATERIALS AND METHODS

The study was carried out in Diyala Governorate, Khalis District for the agricultural season 2021-2022 to study the effect of spraying with zinc, calcium and sorbitol alcohol on the traits of potato growth, cultivar of Arezona, which is of Dutch origin, and certified in Iraq. Samples of field soil were taken from different locations randomly at a depth of 30 cm, then mixed and dried by air, then it was ground and smoothed and passed through a sieve with a hole diameter of 2 mm, and this sample was used for estimating the properties of the physical and chemical soil before planting, as shown in Table (1)**,** and the analyzes were carried out in the Central Laboratory for Soil, Water and Plant Analysis, University of Baghdad.

Table 1. The physical and chemical properties of soil

Measurements	Value	Unit of measurement
N	54	mg. kg^{-1} or ppm
P	8.9	mg. kg^{-1} or ppm
K	134	mg. kg^{-1} or ppm
Zn	0.65	mg. kg-1 or ppm
Ph	7.80	-
CEC	17.2	Cntamol / kg
CaCo3	29.3	%
Texture of soil	Clay loam	-
Clay	36.7	%
Silt	40.5	%
Sand	22.8	%

Preparing the land for planting tubers

The experiment land was prepared on August 21, 2021 by plowing the soil perpendicularly to a depth of 30 cm, then smoothing and leveling the soil. The soil was divided into three sectors; each sector contains 18 experimental units, and the total number of experimental units is 54, then the experimental units were divided into lines for planting, and the distance between lines was 100 cm, and between plants 40 cm, the experimental unit contained 10 plants, so the total number of plants for the experiment was 540 plants, as the area of the experimental unit was 4 m^2 and the field area was 259 m^2, A drip irrigation pipes was distributed in accordance with the requirements of potato cultivation, and all crop service processes were carried out, from irrigation, fertilization, and protective control. The potato tubers of the Arezona cultivar were produced locally from the previous spring season, which were stored at a temperature of 4 ° C for 80 days in the private cold stores in Sulaymaniyah Governorate. They were taken out two weeks before the planting date and placed at room temperature, and sprayed with water every week to break the dormancy phase. Then good healthy tubers were selected and planted on 21/9/2021, where heavy irrigation was carried out two days before planting.

Experimental design

A factorial experiment was carried out using the Randomized Complete Block Design (RCBD) with three factors and three replicates, and the averages were compared according to the Duncan polynomial test at a probability level of 0.05 [6] by using the SAS program to analyze the studied traits statistically and according to the design mentioned.

Study factors

The experiment included a study of three factors. The first factor included spraying with pure zinc element (Zn) at three concentrations (0, 100, 200 mg. L^{-1}), the second factor included spraying with pure calcium element (Ca) on the leaves at three concentrations (0, 0.5, 1 g.L^{-1}), and the third factor included spraying with sorbitol $C_6H_{14}O_6$ at two concentrations (0, 10 g.L^{-1}). The spraying process was carried out until complete wetness in the morning, at a rate of two sprays, the first spraying at the stage of tuber formation and the second spraying 12 days after the first spray. The tubers were uprooted on January 26, 2022, after 130 days of planting.

Studied characteristics

Total number of tubers per plant (tuber. plant^{-1})

The total number of tubers per plant was calculated from the tuber number average of the five plants that were randomly selected and for all replicates.

Plant yield (g/plant^{-1})

Five plants were randomly selected from each experimental unit, the weight of the tubers was calculated for all the plants, and finally the average yield per plant was calculated.

Tuber weight (g. tuber^{-1}(

Tubers were selected free of mechanical damage, diseases, and deformations, and then the average of tuber weight was calculated for the treatments according to the following equation:

$$\text{Tuber weight (g. tuber}^{-1}\text{)} = \frac{\text{Yield per plant (g. plant}^{-1}\text{)}}{\text{Number of tubers per plant (tuber. plant}^{-1}\text{)}}$$

Total yield (ton. hectare^{-1})

The yield was estimated by calculating the yield of one plant for each experimental unit separately and then converting it on the basis of hectares according to the following equation:

Total yield (ton. hectare^{-1}) = yield per plant (g.plant^{-1}) x number of plants in hectares / 1000

The number of plants in hectares = the number of plants in the experimental unit * 10000/area of the experimental unit [14].

Marketable yield (ton. hectare^{-1}(

The yield of six plants for each experimental unit was sorted, the damaged and small tubers less than 35 mm in diameter were excluded, and the remainder was weighed according to the yield of one plant, and then according to the marketable yield.

RESULTS

Total number of tubers per plant (tuber. plant^{-1})

The results of Table (2) showed that the treatment of spraying calcium (1 g. L^{-1}) individually on potato plants led to a significant increase in the total number of tubers per plant and gave the highest average, reaching 11.77 (tuber. plant^{-1}), compared to the control treatment, which gave the lowest value of 9.956 (tuber. plant^{-1}), while the treatment of spraying zinc and sorbitol individually did not significantly differ in the total number of tubers per plant.

While the interaction between treatments had a significant effect in the total number of tubers per plant, the interaction between Zn (0 mg. L^{-1})+ Ca (1 g. L^{-1}) and Zn (100 mg. L^{-1})+ sorbitol (10 g. L^{-1}) and Ca (1 g. L^{-1})+ sorbitol (10 g. L^{-1}) gave the highest value, reaching (12.67, 11.11, and 12.32 tuber. plant^{-1}) respectively compared to the control treatment, reaching (8.708, 10.71, and 9.656 tuber. plant^{-1}) respectively.

As for the triple interaction between the treatments, the sorbitol (10 g. L^{-1}) + Zn (0 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest total number of tubers per plant, reaching 12.93 (tuber. plant^{-1}), while the control treatment gave the lowest value, reaching 8.020 (tuber. plant^{-1}).

Table 2. Effect of spraying with zinc, calcium, and sorbitol on total number of tubers per plant (tuber. plant^{-1})

Ca (g. L^{-1})	Sorbitol (g. L^{-1})	Zn (mg. L^{-1})			Ca+ Sorbitol
		0	100	200	
0	0	8.020 e	10.70 b c d	10.23 c d	9.656 c
	10	9.395 d e	10.29 c d	11.08 a b c d	10.25 b c
0.5	0	11.70 a b c	10.89 a b c d	10.29 i	10.96 b
	10	10.81 b c d	10.12 c d	9.354 e d	10.10 b c
1	0	12.40 a b	10.06 c d	11.18 a b c d	11.21 b
	10	12.93 a	12.89 a	11.14 a b c d	12.32 a
					Ca
Ca+Zn	0	8.708 d	10.49 b c	10.66 b c	9.956 B
	0.5	11.26 b	10.52 b c	9.822 c d	10.53 B
	1	12.67 a	11.47 a b	11.16 b c	11.77 A
					Sorbitol
Sorbitol+ Zn	0	10.71 a	10.55 a	10.57 a	10.61 A
	10	11.04 a	11.11 a	10.52 a	10.89 A
Zn		10.88 A	10.83 A	10.55 A	

Plant yield (g.plant^{-1})

The results of Table (3) showed that the treatments of spraying zinc, calcium, and sorbitol individually on potato plants led to a significant increase in plant yield, where the treatments of Zn (100 mg. L^{-1}), Ca (1 g. L^{-1}) and sorbitol (10 g. L^{-1}) gave the highest average, reaching (2623.6, 2587.9, and 2522.7 g. plant^{-1}) respectively.

The interaction between treatments had a significant effect on plant yield, with the interaction between Zn (100 mg. L^{-1})+ Ca (0.1 g. L^{-1}) and Zn (100 mg. L^{-1})+ sorbitol (0 g. L^{-1}) and Ca (1 g. L^{-1})+ sorbitol (10 g. L^{-1}) giving the highest value in plant yield, reaching (2675.3, 2635.6, and 2635.3 g.plant^{-1})

As for the triple interaction between the treatments, the sorbitol (0 g. L^{-1}) + Zn (0 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest value in plant yield, reaching 2816.0 g. plant^{-1}, while the control treatment gave the lowest value, reaching 1515.0 g. plant^{-1}.

Table 3. Effect of spraying with zinc, calcium, and sorbitol on plant yield (g.plant^{-1})

Ca (g. L^{-1})	Sorbitol (g. L^{-1})	Zn (mg. L^{-1}) 0	100	200	Ca+ Sorbitol
0	0	1515.0 d	2555.0 a b c	1794.7 d	1854.9 c
	10	2784.0 a b	2558.7 a b c	1758.0 d	2366.9 b
0.5	0	1710.0 d	2790.3 a b	1678.7 d	2059.7 c
	10	2375.3 b c	2560.3 a b c	2762.3 a b	2566.0 a b
1	0	2816.0 a	2561.3 a b c	2244.3 c	2540.6 a b
	10	2383.0 b c	2716.0 a b	2807.0 a	2635.3 a
					Ca
Ca+Zn	0	2149.5 b	2556.8 a	1626.3 c	2110.8 C
	0.5	2042.7 b	2675.3 a	2220.5 b	2312.8 B
	1	2599.5 a	2638.7 a	2525.7 a	2587.9 A
					Sorbitol
Sorbitol+ Zn	0	2013.7 b	2635.6 a	1805.9 c	2151.7 B
	10	2514.1 a	2611.7 a	2442.4 a	2522.7 A
Zn		2263.8 B	2623.6 A	2124.1 B	

Tuber weight (g. tuber^{-1}(

The results of Table (4) showed that the treatments of spraying zinc, calcium, and sorbitol individually on potato plants led to a significant increase in tuber weight, where the treatments of Zn (100 mg. L^{-1}), Ca (0.5 g. L^{-1}) and sorbitol (10 g. L^{-1}) gave the highest average, reaching (245.3, 224.5, and 232.0 g.tuber^{-1}) respectively compared to the control treatment, which gave the lowest value of (200.5, 202.4, and 201.6 g. tuber^{-1}) respectively.

While the interaction between treatments had a significant effect on tuber weight, the interaction between Zn (100 mg. L^{-1})+ Ca (0.5 g. L^{-1}) and Zn (100 mg. L^{-1})+ sorbitol (0 g. L^{-1}) and Ca (0.5 g. L^{-1})+ sorbitol (10 g. L^{-1}) produced the highest value, reaching (257.2, 251.1, and 257.7 g. tuber^{-1}).

As for the triple interaction between the treatments, the sorbitol (10 g. L^{-1}) + Zn (200 mg. L^{-1}) + Ca (0.5 g. L^{-1}) gave the highest value in tuber weight, reaching 298.6 g. tuber^{-1}, while the control treatment gave the lowest value, reaching 146.1 g. tuber^{-1}.

Table 4. Effect of spraying with zinc, calcium, and sorbitol on tuber weight (g. tuber^{-1}(

Ca (g. L^{-1})	Sorbitol (g. L^{-1})	Zn (mg. L^{-1})			Ca+ Sorbitol
		0	100	200	
0	0	146.1 f	239.1 b c	147.6 f	177.6 d
	10	272.3 a b	250.6 a b c	158.5 e f	227.1 b
0.5	0	149.3 f	259.7 a b c	164.8 d e f	191.3 c d
	10	219.7 b c	254.8 a b c	298.6 a	257.7 a
1	0	249.2 a b c	254.6 a b c	204.5 c d e	236.1 a b
	10	166.6 d e f	213.0 c d	254.6 a b c	211.4 b c
					Ca
Ca+Zn	0	209.2 b c	244.8 a b	153.1 d	202.4 B
	0.5	184.5 c d	257.2 a	231.7 a b	224.5 A
	1	207.9 b c	233.8 a b	229.5 a b	223.7 A
					Sorbitol
Sorbitol+ Zn	0	181.5 c	251.1 a	172.3 c	201.6 B
	10	219.5 b	239.4 a b	237.2 a b	232.0 A
Zn		200.5 B	245.3 A	204.8 B	

Total yield (ton. hectare^{-1})

The results of Table (5) showed that the treatments of spraying zinc, calcium, and sorbitol individually on potato plants led to a significant increase in total yield, where the treatments of Zn (100 mg. L^{-1}), Ca (1 g. L^{-1}) and sorbitol (10 g. L^{-1}) gave the highest average in total yield, reaching (65.76, 66.59, and 63.01 tons. hectare^{-1}) respectively, compared to the control treatment, reaching (56.21, 50.23, and 52.86 tons. hectare^{-1}) respectively.

Whereas the interaction between treatments had a significant effect on total yield, the interaction between Zn (100 mg. L^{-1})+ Ca (1 g. L^{-1}) and Zn (100 mg. L^{-1})+ sorbitol (10 g. L^{-1}) and Ca (1 g. L^{-1})+ sorbitol (10 g. L^{-1}) gave the highest value, reaching (69.98, 66.33, and 70.76 tons. hectare^{-1}) respectively compared to the control treatment, reaching (48.62, 46.37, and 41.37 tons. hectare^{-1}) respectively.

As for the triple interaction between the treatments, the sorbitol (10 g. L^{-1}) + Zn (0 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest value in total yield, reaching 71.10 tons. hectare^{-1}, while the control treatment gave the lowest value, reaching 29.54 tons. hectare^{-1}.

Table 5. Effect of spraying with zinc, calcium, and sorbitol on total yield (ton. hectare^{-1})

Ca (g. L^{-1})	Sorbitol (g. L^{-1})	Zn (mg. L^{-1}) 0	100	200	Ca+ Sorbitol
0	0	29.54 i	57.20 c d e	37.37 h	41.37 d
	10	67.70 a b	63.96 a b c	45.61 g	59.09 b
0.5	0	47.36 f g	69.45 a b	47.63 f g	54.81 c
	10	59.38 c d e	64.00 a b c	54.18 e f	59.19 b
1	0	62.21 b c d	68.93 a b	56.10 d e	62.41 b
	10	71.10 a	71.03 a	70.17 a	70.76 a
					Ca
Ca+Zn	0	48.62 d	60.58 c	41.49 e	50.23 C
	0.5	53.37 d	66.72 a b	50.91 d	57.00 B
	1	66.65 b	69.98 a	63.13 b c	66.59 A
					Sorbitol
Sorbitol+ Zn	0	46.37 c	65.19 a	47.03 c	52.86 B
	10	66.06 a	66.33 a	56.65 b	63.01 A
Zn		56.21 B	65.76 A	51.84 C	

Marketable yield (ton. hectare^{-1}(

The results of Table (6) showed that the treatments of spraying zinc, calcium, and sorbitol individually on potato plants led to a significant increase in marketable yield, where the treatments of Zn (100 mg. L^{-1}), Ca (1 g. L^{-1}) and sorbitol (10 g. L^{-1}) gave the highest average in total yield, reaching (51.93, 50.01, and 48.67 tons. hectare^{-1}) respectively, compared to the control treatment, reaching (38.61, 41.92, and 41.86 tons. hectare^{-1}) respectively.

Whereas the interaction between treatments had a significant effect on marketable yield, the interaction between Zn (100 mg. L^{-1})+ Ca (1 g. L$^{-1)}$ and Zn (100 mg. L^{-1})+ sorbitol (10 g. L^{-1}) and Ca (1 g. L^{-1})+ sorbitol (10 g. L^{-1}) gave the highest value, reaching (56.37, 55.75, and 56.94 tons. hectare^{-1}) respectively compared to the control treatment, reaching (34.27, 33.62, and 40.35 tons. hectare^{-1}) respectively.

As for the triple interaction between the treatments, the sorbitol (10 g. L^{-1}) + Zn (100 mg. L^{-1}) + Ca (1 g. L^{-1}) gave the highest value in marketable yield, reaching 68.20 tons. hectare^{-1}, while the control treatment gave the lowest value, reaching 22.98 tons. hectare^{-1}.

Table 6. Effect of spraying with zinc, calcium, and sorbitol on marketable yield (ton. hectare^{-1}(

Ca (g. L^{-1})	Sorbitol (g. L^{-1})	Zn (mg. L^{-1})			Ca+ Sorbitol
		0	100	200	
0	0	22.98 h	51.35 c d	46.72 d e f	40.35 c
	10	45.56 d e f	44.57 d e f	40.36 f g	43.50 b c
0.5	0	36.30 g	48.47 c d e	41.63 e f g	42.13 b c
	10	41.45 e f g	54.47 b c	40.84 f g	45.59 b
1	0	41.58 e f g	44.54 d e f	43.15 e f g	43.09 b c
	10	43.79 e f	68.20 a	58.83 b	56.94 a
					Ca
Ca+Zn	0	34.27 e	47.96 b c	43.54 c d	41.92 B
	0.5	38.87 d	51.47 b	41.24 d	43.86 B
	1	42.68 d	56.37 a	50.99 b	50.01 A
					Sorbitol
Sorbitol+ Zn	0	33.62 d	48.12 b	43.83 c	41.86 B
	10	43.60 c	55.75 a	46.68 b c	48.67 A
Zn		38.61 C	51.93 A	45.25 B	

DISCUSSION

The results in tables 2–6 showed the positive effect of the treatments on the yield and its components, where spraying plants with zinc individually led to an increase in yield indicators, and this increase may be attributed to the role of zinc in improving many physiological and biochemical activities during the growth process of the plant [18], including cell division and elongation, which led to an increase in the characteristics of vegetative growth, and consequently an increase in yield indicators [5]. Zinc also has an important role in the pollination process through its influence on the formation of the pollen tube [16], and its participation in the photosynthesis of proteins, carbohydrates and hormones [11], and zinc has great importance in the formation of chlorophyll, which is necessary to complete the processes of division and elongation of plant cells, which leads to an increase in the rate of vegetative growth and thus increases the manufactured food inside the plant, this in turn leads to an increase in yield characteristics [21], and zinc works to increase the fertility rates in flowers and stimulate the seeds to germinate [15].

As for an increase in the yield characteristics by spraying calcium individually on the plant, it may be due to its role in increasing the characteristics of vegetative growth and also an increase in the plant's absorption of nutrients that activate enzymes that decompose organic compounds and encourage the process of respiration and photosynthesis and contribute to the construction of proteins, protoplasmic structures, and nucleic acids DNA and RNA , which are important for cell division and increase their activity, and it provides these materials that are stored in the form of starch, carbohydrates in the tubers, which increases their size and quality [1].

An increase in yield indicators and its components by spraying sorbitol individually may be attributed to the role of sorbitol sugar, which works to transfer nutrients from the places of manufacture to the places of storage, where it forms a complex with these elements and thus facilitates their transportation, especially the slow-moving nutrient elements inside the plant [19,7].

The significant increase in the yield traits indicators caused by the interaction between zinc, calcium, and sorbitol sugar may be attributed to the role of zinc, calcium, and sorbitol in all stages of growth, as they are involved in building proteins, activating many enzymes, and regulating vital, metabolic, and physiological processes that increase the division and elongation of cells and their number, thus it is reflected on the number of aerial stems in the plant, thus increasing the number of tubers and increasing their reception of manufactured carbohydrates and storing them in the tubers, which leads to an increase in the overall yield and marketable yield [11,21,18].

CONCLUSION

Spraying potato plants with zinc, calcium, and sorbitol individually or together led to increasing the yield and its components, such as total number of tubers per plant, plant yield, tuber weight, total yield, and marketable yield.

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