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Article

The Possibility of Reducing the Water Requirements of Potatoes by Using Some Materials and Its Effect on Yield and Tuber Quality

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Abstract: In order to investigate the effects of irrigation water quantities (1200, 1600, and 2000 m^3/fad.) and spraying with some materials (Trehalose at 1000 ppm, Potassium silicate at 2000 ppm, and proline amino acid at 500 ppm and their interactions on growth, yield, water use efficiency, and tuber quality of potato plants, a field experiment was conducted in a private farm at Meet Faris village, Dekarns, Dakhlia Governorate, Egypt Spunta cultivar under a clay soil environment in summer plantation. Under clay soil conditions and using drip irrigation system during summer plantation, irrigation potato plants at 1600 m^3/fad. and spraying with trehalose at 1000 ppm increased shoot dry weight / plant, average tuber weight, average tuber number/ plant, yield / plant and total yield /fad., water use efficiency, also the irrigation of the same level and spraying with potassium silicate at 2000 ppm increased tuber quality (specific gravity, dry matter (%) and starch content). In this context, the interaction treatment between irrigation at a rate of 1600 m^3/faddan and foliar spraying with trehalose at a concentration of 1000 ppm recorded a relative increase in the total yield of 22.42% and a saving of 20% of irrigation water compared to the irrigation treatment at a rate of 2000 m^3/fad. only (average of the two seasons).

Key words: Potato, irrigation water quantity, trehalose, potassium silicate, and proline amino acid, yield and quality.

INTRODUCTION

In general, the potato (*Solanum tuberosum* L.) is regarded as one of the most significant vegetable crops in Egypt and is considered a promising crop for domestic use, export to the European market and some Arabian nations, as well as for manufacturing, therefore the total cultivated area of potato in Egypt according **FAO (2021)** was about 549410 feddan during 2021 season, which produced 6768000 tons with average of 12.318 tons/feddan according to varieties, cultural methods, soil type, harvest date, irrigation intervals, water quantity fertilization, etc.

One of the natural resources that are currently receiving significant attention is irrigation water, especially in light of the current water resource constraint. Water use and plant water needs must be balanced carefully. It is evident that a large portion of the irrigation water used is lost through transpiration and leaching. Wherever possible, it is possible to reduce the irrigation water quantity needed and so partially ease the plant's water stress.

Increasing Irrigation water quantity had significant effect on growth of potato plant (**Eid *et al.* 2013 and Dash *et al*., 2018**), water relationship of plant (**El-Ghamriny *et al*. 2005 and Farhad *et al.* 2011**), plant chemical constituents (**Jayramaiah *et al.*, 2005 and Abou El-Khair *et al*. 2011**) and productivity (**Ati *et al.*2013, Abdel-Ati *et al.* 2014, Farrag *et al.*, 2016 and Zahran *et al*., 2020**), and tuber quality (**Abou El-Khair *et al*. 2011, Ati *et al.*, 2013 and Badawy *et al.* 2019**).

Trehalose is thought to provide protective properties against a variety of abiotic adverse stimuli, including desiccation, salt, and temperature extremes. Additionally, it controls how efficiently most plants use water and how their stomata move. For growth to continue under stressful conditions, detectable endogenous trehalose levels are essential. Trehalose given exogenously in small doses reduces abiotic stress-related physiological and biochemical problems (**Kosar *et al*., 2019**). Additionally, in order to adapt to the changing environmental conditions, it is crucial to increase the drought tolerance of commercial cash crops and vegetables. There are numerous physiological, pharmacological, and molecular strategies that plants adopt to cope with water stress (**Ashraf, *et al*. 2011**).

Plant growth, yield and quality of some vegetable crops had affected by spraying with trehalose (**Alam *et al*., 2014, Akram *et al*., 2015 and Shafiq *et al*., 2015** on **and El- Metwaly, 2021** on**, Abou El-Khair and Mandour, 2022 and Al-Rubaie and Al-Jubouri, 2023** on Brassica species, radish**,** sweet potato, strawberry and potato, respectively**).**

As a first physiological response to stress factors like salinity and drought, crops begin to accumulate proline. A measure of how long a crop has been under stress and how well it is tolerant of that stress factor is an increase in proline concentration in the vacuole inside the cell. Studies revealed that proline is produced inside the cell and occurs during protein degradation. Proline is said to play a vital role in strengthening the cell wall, stabilising osmotic effects by balancing ion concentrations such sodium, potassium, magnesium, and calcium and in other enzymatic processes (**Iba, 2002**).

Spraying plants with proline amino acid under water stress reduced the negative effect of drought and significantly increased plant growth (**AL-Hamdany and Mohammed, 2014**), yield and its components (**Gouda *et al.*, 2015, Kumar *et al.*, 2018 and Abdulnabi and Al-Zubaidi, 2021**) and tuber quality (**Yousry *et al.* 2015 and El-Helaly, 2019**).

By regulating physiological, metabolic, and molecular processes, silicon (Si), often thought of as a non-essential element for plants, may help plants cope with environmental challenges (**Zargar *et al*., 2019**). It can improve nutrient uptake and lessen stress through a number of mechanisms, such as functioning as a physical barrier, improving plant water status (by raising root water uptake and regulating leaf transpiration), or controlling biochemical cues like defence enzyme levels, antioxidant defence, osmolyte regulation, and phytohormone biosynthesis (**Ahire *et al.*, 2021**). Additionally, according to Manivannan and Ahn (2017), silicon can alter the expression of genes in plants that are involved in physiological procedures that help the plants cope with stress.

Spraying potato plants with potassium silicate enhanced plant growth, plant chemical constituents , yield and tuber quality (**Adriano *et al*., 2008, Salim *et al*., 2014, Abd El-Gawad *et al*., 2017, Soltani *et al*., 2018, Mahmoud *et al*., 2019, Mostafa *et al.* , 2019, Moussa and Shama 2019, Shaheen *et al.*, 2019, Baddour, and Masoud, 2022, Wadas, 2022 and wadas and Kondraciuk , 2023**).

The aim of this work was to study the possibility of reducing the water requirements of potatoes by using some materials such as trehalose, proline and potassium silicate as a foliar application, and its effect on growth, productivity, water use efficiency and tuber quality.

MATERIALS AND METHODS

During the two successive summer seasons of 2022 and 2033, a field experiment was conducted on a private farm in the village of meet Faris, Dekarns, Dakhlia Governorate, to examine the effects of irrigation water quantity, material spraying, and their interactions on potato tuber cv. Cara growth, yield, water use efficiency, and tuber quality. The experimental soil physical and chemical analyses are presented in Tables A.

Table A. The experimental soil's chemical and physical characteristics

Soil properties	1st season	2nd season
Physical properties		
Sand (%)	23.25	21.23
Silt (%)	23.14	24.98
Clay (%)	53.61	53.79
O.M (%)	1.88	1.79
Chemical properties		
pH	7.82	7.64
Total N (%)	0.17	0.14
Available P_2O_5 (%)	0.030	0.036
Available K_2O (%)	0.58	0.61

Twelve treatments were included in this experiment, which involved interactions between three irrigation water amounts (1200, 1600 and 2000 m^3/fad.), three materials as foliar application at 1000 ppm ,2000 ppm and 500 ppm for trehalose, potassium silicate, and proline amino acid respectively, in addition to water spraying.

These treatments were arranged in a split plot design with three replicates, irrigation water quantities were distrusted in the main plots and spraying with some materials were randomly distributed in the sub plots.

The allotment measured 16.8 square metres, with four dripper lines measuring 6 metres long and 0.7 metres broad. Three dripper lines were used to test tuber quality, yield and its components, while one dripper line was used to measure plant growth features. Furthermore, a guard area consisting of one row was positioned between every two experimental units to prevent irrigation water and spraying treatments from overlapping.

The potato cultivar's tuber seeds were planted 20 cm apart on January 19 and 23, respectively, during the first and second seasons.

All experimental units during germination stage up to 20 days from planting received 100m^3 water/fad., then the irrigation treatments started on at 8th and 12th Feb. in the 1st and 2nd seasons, respectively and ended 19th and 23rd May (10 days before harvesting) in the 1st and 2nd seasons, respectively. The water was added using water counter and pressure counter. Irrigation was at 3 days intervals.

Drippers commercially with flow rate of 2 l/ hour at one bar pressure were used in design the line system and placed 20 cm apart from each other in the two tested irrigation systems. Laterals lines, 16 mm in diameter. Water counter and pressure gauge at 1 bar were used to add the irrigation water amounts (m^3/fed.), which, using the drippers' 2 L/h water flow rate as a base, were computed and expressed in terms of time. For 1100, 1500, and 1900 m^3 of water/fed, respectively, irrigation times were 42.66, 50.29, and 73.68 minutes, and irrigation number was 33 for each treatment.

Trehalose, Potassium silicate and proline amino acid were produced in China and imported by Technogene Company.

Using a manual atomizer, plants were sprayed five times at 30, 45, 60, 75, and 90 days after planting with a combination of trehalose, potassium silicate, and proline amino acid to ensure complete and even coverage of the foliage. In the meantime, the untreated plants (control) received a single application of water.

Calcium super phosphate (15.5% P_2O_5), potassium sulphate (48–52%), ammonium sulphate (20.6% N), and 80 kg P_2O_5 were administered to each treatment in the following amounts: 120 kg N, 80 kg P_2O_5, and 96 kg K_2O kg/. During soil preparation, one-third of the N, K_2O, and P2O5 were added. One month after planting, the remaining N and K_2O (two thirds) were added as fertigation at six-day intervals. Normal agricultural practises were carried out in the district under inquiry, as is customary.

Data recorded

1. Growth parameters

In both study seasons, five plants were randomly selected at 110 days after planting from each plot to measure the following growth characteristics of potato plants:

1. Height of plant (cm)
2. Leaf number per plant
3. Plant/leaf area (m^2)
4. Shoot/plant dry weight (gm).

2. Plant Water Relations and Proline Amino Acid Content

At 110 days after planting in both growing, random sample of the fourth leaf of potato for every plot to determined total, free and bound water in leaves according to the method described by **Gosev (1960**). Also, **Proline Amino Acid Content** was determined in dry leaves at 110 days after planting in both seasons according to the method described by **Bates (1973**).

3. Yield and its components

Tubers from each plot were measured, weighed, and numbered at harvest, approximately 130 days after planting for the Cara cultivar. The following parameters were computed:

1. Number of tubers/plant,
2. Tuber yield per plant (g),
3. Average tuber weight (g),
4. Total yield (ton/ faddan)

4. Tuber Quality

1. Nitrogen, phosphorus and potassium contents

Total nitrogen, phosphorous and potassium were determined in the dry matter of tubers according to the methods described by **A.O.A.C. (1990).**

2. Specific gravity

It was determined according to the method of **Murphy and Govern (1959**). The tubers were weighed in the air and then in water and specific gravity was calculated by the formula:

$$\text{Specific gravity} = \frac{\text{Tuber weight in air (g)}}{\text{Tuber weight in air (g) - tuber weight in water (g)}}$$

3. **Dry matter (%)** was calculated after 100 grammes of the shredded mixture were dried at 105 0C until their weight remained constant.

Starch content (%): It was determined according to the method reported by **A.O.A.C. (1990).**

Statistical analysis

Snedecor and Cochran (1980) provided the statistical analysis of variance for the recorded data, and **Duncan (1955)** provided the means separation.

RESULTS AND DISCUSSION

Plant growth

Effect of irrigation water quantity

Data in Table 1 indicate that height of plant, leaves number / plant, leaf area/ plant significantly enhanced with increasing irrigation water quantity up to highest level 1200 m^3/fad. without any significant differences with irrigation water quantity at 1600 m^3/fad. with respect to number of leaves / plant and leaf area/ plant. As for shoot dry weight, irrigation at 1600 m^3/fad. increased dry weight of shoot/ plant in the two seasons. This means that irrigation of potato plants grown in clay soil at 1600 m^3/fad. increased number of leaves/ plant, leaf area/ plant and dry weight of shoot/ plant, whereas irrigation at 2000 m^3/fad. increased height of plant. The increases in shoot dry weight were about 7.33 and 7.20 g/ plant for irrigation at 1600 m^3/fad. and 4.58 and 4.38 g / plant for irrigation at 2000m^3/fad. over the irrigation at 1200 m^3/fad. in the 1st and 2nd seasons, respectively.

It is possible to hypothesise that giving potato plants more water helped to maintain a higher soil moisture content, which in turn may have benefited plant metabolism and increased the production of dry matter and other aspects of plant growth. However, water stress resulted in a decrease in the absorption of nutrients, which could disrupt the physiological processes necessary for plant growth (**Salter and Goode, 1967**).

However, Marschner (1995) found that healthy growth was indicated by a rise in CYT, GA, and IAA and a decrease in ABA when there was adequate water.

Obtained results are in harmony with those reported by **Eid *et al.* (2013) and Dash *et al*. (2018).** They found that increasing water quantity levels increased plant growth characters of potato.

Effect of foliar spray treatments

There were significant differences among foliar spray treatments in plant growth of potato and spraying with Trehalose (Treh) at 1000 ppm, proline amino acid (PAA) at 500 ppm and potassium silicate (KSil) at 2000 ppm increased plant growth parameters compared to spraying with water (control) at 110 days after planting in both seasons (Table 1). Spraying with Treh at 1000 ppm increased plant height, number of leaves/ plant and leaf area/ plant and shoot dry weight/ plant compared to other treatments. The increases in shoot dry weight were about 10.78 and 10.80 g/ plant for Treh at 1000 ppm 2.67 and 2.53 g / plant for PPA at 500 ppm and 5.67 and 6.15 g/plant for KSil at 2000 ppm over the control (spraying with water) in the 1st and 2nd seasons, respectively.

Trehalose spraying improves photosynthesis, particularly in water-stressed environments, which raises the production of sugar, enhances metabolism, and ultimately boosts vegetative growth (**Feng *et al*., 2019**). Furthermore, silicon is present in potassium silicate, which helps plants withstand biological and non-biological stresses by preserving their ability to absorb light, retain water, maintain stomatal conductance, and produce leaves even at high transpiration rates (**Das *et al*., 2017**).

These results are harmony with those obtained with **Al-Rubaie and Al-Jubouri (2023)**. They indicated that spraying potato plants with trehalose at 30 mmol L significantly increased leaf area and dry weight of shoot as compared to unsprayed plants. As for the response of potato plants to spraying with proline, **Gouda *et al.* (2015)** and **El-Helaly, (2019**) showed that potato plants treated by proline at 0.15g/l as foliar application recorded the highest plant height as compared to unsprayed plants. In this regard, **Adriano *et al*., (2008) and Salim *et al.* (2014)** showed that spraying potato plants with potassium silicate produced the best growth of plant than unsprayed plants.

Table (1). Effect of irrigation water quantity and foliar spray treatments on plant growth at 110 days after planting of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments	Plant height (cm)		Number of leaves/ plant		Leaf area/ plant (m^2)		Dry weight of shoots (g/ plant	
	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season
	Effect of irrigation water quantity (m^3/fad.)							
1200	55.41 c	55.75 c	23.41 b	23.50 b	0.293 b	0.303 b	26.83 c	27.86 c
1600	63.91 b	64.25 b	25.99 a	26.00 a	0.345 a	0.355 a	34.16 a	35.06 a
2000	66.41 a	66.25 a	25.49 a	25.75 a	0.344 a	0.349 a	31.41 b	32.24 b
	effect of foliar spray treatments							
Unsprayed	57.88 d	59.00 d	21.99 d	21.66 d	0.261 d	0.269 d	25.99 d	26.85 d
Treh.	65.33 a	65.66 a	27.77 a	27.66 a	0.367 a	0.384 a	36.77 a	37.65 a
PAA	61.00 c	60.66 c	23.66 c	24.66 c	0.331 c	0.336 c	28.66 c	29.38 c
KSil	63.44 b	63.00 b	26.44 b	26.33 b	0.351 b	0.354 b	31.77 b	33.00 b

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

Effect of the interaction

The interaction between irrigation at 2000 m^3/fad. and foliar spray with Treh at 1000 ppm increased plant height, whereas, the interaction between irrigation at 1600 m^3/fad. and foliar spray with Treh at 1000 ppm increased number of leaves/plant and leaf area/ plant and shoot dry weight/ plant in both seasons (table 2).

Under irrigation at 1200, 1600 and 2000 m^3/fad. and spraying with Treh, PPA and KSil increased plant growth of potato compared to spraying with water (control) under the same treatments.

The increases in shoot dry weight were about 17.33 and 17.83 g/ plant for the interaction between irrigation at 1600 m^3/fad. and spraying with Treh at 1000 ppm over the irrigation at 1200 m^3/fad. and spraying with water (control) in the 1st and 2nd seasons, respectively.

Trehalose likely improves drought tolerance in plants by two mechanisms: by regulating carbohydrate levels during stress conditions, possibly via the SnRK1 kinase and by altering ABA signaling and stomatal conductance and then increased plant growth (**Paul *et al.* 2018**).

Our results were in agreement with **Demelash (2013)** who indicated that the spraying with trehalose with good water management, which causes an increase in plant growth. Also, A**lam *et al*. (2014**) who found that drought stress on Brassica decreased fresh and dry weight, whereas combination of trehalose with drought stress enhanced seedlings fresh and dry weight.

As for potassium silicate effect, **Abd El-Gawad *et al*. (2017)** they showed that the highest values of all plant growth traits of potato were recorded with the interaction between the high moisture content and spraying with potassium silicate at 2000 ppm.

Plant water relationship and proline amino acid

Effect of water quantity

Total water (%) and free water (%) in leaves increased with increasing irrigation water quantity until the highest levels, whereas bound water (%) and proline amino acid decreased with increasing irrigation water quantity at 110 days after planting in both seasons (Table 3).

Table (2). Effect of interaction between irrigation water quantity and foliar spray treatments on plant growth at 110 days after planting of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments		Plant height (cm)		Number of leaves/ plant		Leaf area (m^2)		Dry weight of shoots (g/ plant)	
Irrigation water quantity (m^3/fad.)	Foliar spray treatments	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season
1200	Unsprayed	52.00 j	54.00 h	20.00 g	21.00 g	0.250 h	0.252 f	23.00 i	24.21 h
	Treh	59.00 g	58.00 f	26.66 c	25.00 cd	0.326 e	0.341 cd	32.33 d	31.52 e
	PAA	54.00 i	55.00 gh	22.00 f	23.00 ef	0.283 f	0.293 e	24.66 h	26.14 g
	KSil	56.66 h	56.00 g	25.00 d	25.00 cd	0.316 e	0.327 d	27.33 fg	29.57 f
1600	Unsprayed	60.33 f	61.00 e	23.66 e	22.00 fg	0.260 gh	0.272 ef	28.66 e	29.18 f
	Treh	66.66 c	68.00 b	28.66 a	30.00 a	0.393 a	0.415 a	40.33 a	42.06 a
	PAA	63.00 e	62.00 e	24.00 de	25.00 de	0.366 c	0.361 bc	33.00 d	33.00 d
	KSil	65.66 d	66.00 cd	27.66 bc	27.00 bc	0.363 c	0.373 b	34.66 c	36.00 c
2000	Unsprayed	61.33 f	62.00 e	22.33 f	22.00 fg	0.273 fg	0.284 e	26.33 g	27.17 g
	Treh	70.33 a	71.00 a	28.00 ab	28.00 ab	0.383 ab	0.396 a	37.66 b	39.38 b
	PAA	66.00 cd	65.00 d	25.00 d	26.00 cd	0.346 d	0.355 bc	28.33 ef	29.00 f
	KSil	68.00 b	67.00 bc	26.66 c	27.00 bcd	0.376 bc	0.362 bc	33.33 d	33.44 d

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

Irrigation at 2000 m^3/fad. increased total water (88.95%) and free water (62.52%) in leaves, whereas irrigation at 1200 m3/fad. increased bound water (35.22%) and proline amino acid (150.66 mg /100 g DW) as average of the two seasons. This means that high irrigation water quantity (high soil moisture) increased total and free water in leaf tissues, whereas low irrigation water (low soil moisture) increased bound water and proline amino acid in leaf tissues of potato . There was positive correlation between irrigation water quantity and total and free water, whereas there was negative correlation between irrigation water quantity and bound water and proline amino acid in leaf tissues .

In general, the irrigation at 2000 m^3/fad. increased total and free water percentages in leaf tissues and decreased bound water (%) and proline amino acid content in leaves.

Proline accumulation was discovered to be produced by high salt, drought, and selenium in tubers (**Teixeira and Pereira, 2007**). Proline accumulation was reported to be a response activated by stress in the leaves of diverse plant species (**Obata and Fernie, 2012**). In addition to being involved in the regulation of proline levels in plants, glutamine synthetase is essential for nitrogen metabolism (**Brugiere *et al*., 1999**). Furthermore, the conversion of starch into soluble carbohydrates was the primary cause of the rise in bound water and the decrease in free water during water stress (**Lancher, 1993**). These changes also increased the concentration of cell sap and its osmotic pressure.

These results agree with those reported by **El-Ghamriny *et al*. (2005) and Farhad *et al.(* 2011)** they found that the highest the free and total water content, and the lowest the bound water and proline content in leaf tissues were produced from the highest level of water quantity to the plants, , and vice versa under water stress. Also, **Mansour and Abu El-Fotoh (2018)** found that increasing irrigation water levels up to the highest levels significantly enhanced total and free water in leaf tissues of potato. On the other hand ,the percentage of bound water in the leaf tissues was the highest with the lowest level of irrigation water.

Effect of foliar spray treatments

Data in table 3 indicate that spraying with Treh at 1000 ppm , PPA at 500 ppm and KSil at 2000 ppm had significant effect on plant water relations (total , free and bound water percentages) as well as proline amino acid content in leaf tissues of potato at 110 days after planting in both seasons .

Spraying with PAA at 500 ppm increased total (87.54 %) and free water (59.68%), whereas spraying with water (control) increased bound water (34.93%) and proline amino acid content (138.48 mg /100g DW) as the average of the two seasons in leaf tissues.

In general, spraying with PAA increased total and free water (%) in leaf tissues and decreased bound water (%) and proline amino acid in leaves. In the same line, **Akram *et al*. (2015)** showed that spraying Radish plants with trehalose at 25 or 50 mM enhanced growth and reduced relative membrane permeability .

Results are harmony with those obtained with **Rashid (2016) and Al-Khafaji and Oliwi** (2020) they showed that spraying potato plants with Proline at 300ppm significantly increased proline leaf content as compared to unsprayed plants. Also, **Al-Rubaie and Al-Jubouri (2023)** they showed that spraying potato plants with trehalose with a 30 mmol/ L showed a significant superiority in relative water content of leaf than unsprayed plants.

Table (3). Effect of irrigation water quantity and foliar spray treatments on plant water relationship proline amino acid in leaves at 110 days after planting of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments	Total water (%)		Free water (%)		Bound water (%)		Proline amino acid (mg/100 g DW)	
	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season
	Effect of irrigation water quantity (m^3/fad.)							
1200	84.16 c	84.31 c	50.49 c	47.72 c	33.67 a	36.78 a	150.32 a	150.93 a
1600	86.69 b	86.77 b	56.19 b	54.69 b	30.49 b	32.07 b	127.70 b	127.72 b
2000	89.04 a	88.87 a	63.10 a	61.94 a	25.94 c	26.92 c	88.73 c	86.48 c
	Effect of foliar spray treatments							
Unsprayed	85.19 c	85.61 c	51.34 d	49.85 d	33.84 a	36.03 a	134.57 a	130.29 a
Treh	86.81 b	86.98 ab	58.20 b	56.54 b	28.60 c	30.44 c	119.96 c	122.30 b
PAA	87.42 a	87.49 a	60.29 a	59.07 a	27.13 d	28.42 d	108.43 d	110.58 c
KSil	87.10 ab	86.50 bc	56.54 c	53.69 c	30.56 b	32.81 b	126.04 b	123.67 b

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

Effect of the interaction

The combination between irrigation at the highest levels (2000 m^3/fad.) and spraying with PAA at 500 ppm increased total and free water percentages in leaf tissues with no significant differences between the combination between irrigation at the highest levels and spraying with Treh at 1000 ppm and the combination between irrigation at the highest levels and spraying with KSil at 2000 ppm in both seasons with respect to total water and in the 1st season with respect to free water percentage (Table 4). As for bound water and proline amino acid, the combination between irrigation at 1200 m^3/fad. and spraying with water increased bound water and proline amino acid in leaves in both seasons.

In general, the irrigation at 2000 m^3/fad. (highest levels) and spraying with Treh, PPA and KSil increased total and free water in leaf tissues, and decreased bound water and proline amino acid content in leaves.

In this respect, using trehalose to increase the use efficiency of water, prolific deep root system, suppression in transpiration loss, maintenance of cell turgor potential, better leaf pigments at decrease of leaf water potential, stomatal regulation, up regulation of antioxidants, synthesis of osmolytes, and osmotic adjustment/osmoregulation may all play a positive role in helping plants resist drought stress (**Shafiq *et al*., 2015**).

Table (4). Effect of the interaction between irrigation water quantity and foliar spray treatments on plant water relationship and proline amino acid in leaves at 110 days after planting of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments		Total water (%)		Free water (%)		Bound water (%)		Proline amino acid (mg/100 g DW)	
Irrigation water quantity (m^3/fad.)	Foliar spray treatments	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season
1200	**Unsprayed**	82.07 e	83.27 g	45.01 g	43.20 i	37.06 a	40.87 a	165.92 a	161.19 a
	Treh	84.35 d	84.80 efg	52.16 ef	49.50 g	32.19 c	35.30 c	148.59 c	148.18 b
	PAA	84.59 d	85.17 def	53.82 de	52.50 f	30.77 de	32.67 d	131.17 e	145.21 b
	KSil	85.64 c	84.00 fg	50.98 f	45.69 h	34.66 b	38.31 b	155.61 b	149.13 b
1600	**Unsprayed**	85.96 c	86.49 cde	51.20 ef	49.50 g	34.76 b	36.99 bc	139.42 d	136.40 c
	Treh	86.74 bc	86.78 cd	57.87 c	56.42 e	28.87 f	30.36 e	123.63 f	127.79 d
	PAA	87.53 b	87.35 bc	60.84 b	59.31 d	26.69 g	28.04 fg	118.98 g	115.14 e
	KSil	86.54 bc	86.46 cde	54.87 d	53.56 f	31.67 cd	32.90 d	128.78 e	131.57 cd
2000	**Unsprayed**	87.54 b	87.08 c	57.82 c	56.85 e	29.72 ef	30.23 ef	98.37 h	93.27 f
	Treh	89.34 a	89.38 a	64.59 a	63.71 b	24.75 hi	25.67 hi	87.67 j	90.94 f
	PAA	90.16 a	89.97 a	66.22 a	65.40 a	23.94 i	24.57 i	75.13 k	71.40 g
	KSil	89.14 a	89.05 ab	63.77 a	61.83 c	25.37 h	27.22 gh	93.74 i	90.31 f

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

Yield and its components

Effect of irrigation water quantity

Average tuber weight, tuber number/ plant, yield / plant and total yield /fad. increased with increasing irrigation water quantity up to the highest level (2000 m^3/fad.) with no significant differences between the moderate and highest irrigation levels in both seasons (Table 5). This means that the moderate irrigation levels (1600 m^3/fad.) increased average tuber weight, average tuber number / plant, yield / plant and total yield /fad. The increases in total yield /fad (ton) were about 6.20 and 6.09 ton for the moderate irrigation levels and 6.33 and 6.34 ton for the highest irrigation level (2000 m3/fad.) over the lowest irrigation level (1200 m^3/fad.) in the 1st and 2nd seasons, respectively.

As for water use efficiency (WUE), using the moderate levels of irrigation water quantity (1600 m^3/fad.) significantly increased WUE (8.945 and 8.995 kg tuber/m^3 water) followed by the highest irrigation level of water (7.228 and 7.320 kg tuber/m^3 water) in the 1st and 2nd seasons, respectively.

The increase in total tuber yield was clearly achieved owing to the increases in weight of tubers / plant and average tuber weight rather than number of tubers/plant. In addition, the results obtained with yield and its components reflected similar trend to that obtained with plant growth.

It is possible that increasing the amount of water that is applied to the soil results in a higher soil moisture content, which increases the availability of nutrients to the plant. This could then favour the physiological processes that are directly related to yield and its constituent parts, as well as the physiological characteristics of the plant. Additionally, more water was supplied to the plants, which kept more water in the tissues of the plants, resulting in tubers that were heavier than those under water stress.

Table (5). Effect of irrigation water quantity and foliar spray treatments on yield and its components and water use efficiency of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments	Average tuber weight (g)		Avege tuber number / plant		Yield / plant (g)		Total Yield (ton/fed.)		WUE (kg tubers/m^{3}water)	
	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season
Effect of irrigation water quantity (m^3/fad.)										
1200	112.89b	114.42b	2.58 b	2.62 b	292.24b	300.12 c	8.125 b	8.300 b	6.770 c	6.916 c
1600	155.63 a	154.76a	3.31 a	3.36 a	516.93 a	520.85b	14.327 a	14.393 a	8.945 a	8.995 a
2000	156.01 a	156.44 a	3.32 a	3.37 a	519.99 a	528.79 a	14.456 a	14.641 a	7.228 b	7.320 b
Effect of foliar spray treatments										
Unsprayed	133.35 c	132.30 c	2.91 c	2.97 b	392.85 c	397.79 c	10.905 c	10.985 c	6.828 c	6.895 c
Treh.	145.41a	146.72 a	3.16 a	3.18 a	468.72 a	474.77a	13.024 a	13.159 a	8.079 a	8.168 a
PAA	142.90b	142.55b	3.09 b	3.14 a	449.87b	455.57b	12.495b	12.597 b	7.731 b	7.818 b
KSil	144.39ab	145.93 a	3.14 a	3.17 a	460.77 a	471.55 a	12.786ab	13.038 a	7.954 ab	8.095 ab

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm and **WUE= water use efficiency**

Similar results were reported by **Ati *et al.* (2013) Abdel-Ati *et al.* (2014), Farrag *et al.* (2016) and Zahran *et al.* (2020).**

Effect of foliar spray treatments

Spraying with Treh, PPA and KSil increased yield and its components of potato compared to spraying with water (control) as shown in Table 5. Foliar spray with Treh at 1000 ppm or with KSil at 2000 ppm increased average tuber weight, tuber number/ plant, yield / plant and total yield /fad. as well as water use efficiency in the two seasons .

The increases in total yield /fad. (ton) were about 2.11 and 2.17 ton for spraying with Treh at 1000 ppm , 1.55 and 1.61 ton for spraying with PAA at 500 ppm and 1.88 and 2.05 ton for spraying with KSil at 2000 ppm over the control (spraying with water) in the 1st and 2nd seasons, respectively.

Spraying potato plants with Treh at 1000 ppm was the best treatment for increasing total yield and water use efficiency may be due to that spraying with Treh at 1000 ppm increased shoot dry weight (Table 1) and total and free water (Table 3) as well as average tuber weight and average tuber number / plant (Table 5).

In the same line, **Al-Rubaie and Al-Jubouri (2023)** showed that the highest values of number of tubers/ plant, average tuber weight , yield of tuber per plant and per ha. were obtained with potato plants which sprayed with trehalose with a 30 mmol/ L as compared to unsprayed plants. As for the effect of proline amino acid , **Kumar *et al.* (2018) and Abdulnabi and Al-Zubaidi (2021)** showed that spraying of proline at 250 ppm was significantly produced the highest values of number of tubers / plant, while the concentration 200 ppm significantly excelled and gave the highest value of the fresh weight of tubers.

Regarding the effect of potassium silicate on yield and its components (**Shaheen *et al*., 2019, Baddour and Masoud, 2022 and Wadas and Kondraciuk, 2023**). They found that the highest yield and its components were produced by potato plants which sprayed with potassium silicate than unsprayed.

Effect of the interaction

The combination between irrigation water quantity and spraying with Treh, PAA and KSil had significant effect on yield and its components of potato (Table 6).

The combination between high irrigation level and spraying with Treh at 1000 ppm and the combination between moderate level of irrigation and spraying with Treh at 1000 ppm or KSil at 2000 ppm increased average tuber weight, tuber number/ plant, yield / plant and total yield /fad. and water use efficiency compared to other interaction treatments in both seasons.

This means that the combination between moderate irrigation level (1600 m^3/fad.) and spraying with Treh at 1000 ppm or with KSil at 2000 ppm gave the highest values of average tuber weight, tuber number/ plant, yield / plant and total yield /fad. as well as water use efficiency, for all combination treatments, average tuber weight was ranged from 110.65 to 160.67 g and total yield /fad. was ranged from 7.83 to 15.47 ton (as average of the two seasons).

From the foregoing results, it could be concluded that irrigation of potato plants at the moderate level (1600 m^3/fad.) and spraying with Treh at 1000 ppm or KSil at 2000 ppm increased average tuber weight, average tuber number / plant, yield / plant and total yield /fad as well as water use efficiency .

These results are in harmony with those reported with **Mahmoud *et al*. (2019)** they indicated that the combination between high water content and potassium silicate as foliar spray at 3ml/l produced the highest yield and its components of potato as compared to the low irrigation water quantity and unsprayed plants.

Table (6). Effect of the interaction between irrigation water quantity and foliar spray treatments on yield and its components and water use efficiency of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments		Average tuber weight (g)		Average tuber no/ plant		Yield / plant (kg)		Total Yield (ton/fed.)		WUE (kg tubers/m^3water)	
Irrigation water quantity (m^3/fad.)	Foliar spray treatments	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season
1200	**Unsprayed**	109.90 e	111.48 d	2.50 f	2.59 d	274.75 e	288.73 f	7.664 e	8.000 d	6.387 f	6.667 ef
	Treh.	114.50 d	116.24 d	2.63 e	2.64 d	301.14 d	306.87 e	8.378 d	8.507 d	6.982 de	7.089 de
	PAA	112.71 de	114.36 d	2.54 f	2.61 d	286.28 e	298.48 ef	7.943 de	8.212 d	6.619 ef	6.843 ef
	KSil	114.47 d	115.62 d	2.68 e	2.65 d	306.78 d	306.39 e	8.513 d	8.482 d	7.094 cde	7.068 de
1600	**Unsprayed**	146.09 c	140.06 c	3.12 d	3.20 c	455.80 c	448.19 d	12.591 c	12.330 c	7.869 b	7.706 c
	Treh.	159.12 ab	160.64 ab	3.46 a	3.48 a	550.56 a	559.03 a	15.256 ab	15.451 a	9.535 a	9.657 a
	PAA	157.24 b	157.07 b	3.36 bc	3.34 b	528.33 b	524.61 c	14.696 b	14.573 b	9.151 a	9.108 b
	KSil	160.07 ab	161.28 ab	3.33 c	3.42 a	533.03 b	551.58 ab	14.764 ab	15.218 ab	9.228 a	9.511ab
2000	**Unsprayed**	144.05 c	145.37 c	3.11 d	3.14 c	448.00 c	456.46 d	12.459 c	12.624 c	6.230 f	6.312 f
	Treh.	162.60 a	163.28 a	3.41 ab	3.42 a	554.47 a	558.42 a	15.439 a	15.519 a	7.720 bc	7.760 c
	PAA	158.75 ab	156.21 b	3.37 bc	3.48 a	534.99 b	543.61 b	14.845 ab	15.005 ab	7.423 bcd	7.503 cd
	KSil	158.63 ab	160.89 ab	3.42 ab	3.46 a	542.51 ab	556.68 a	15.081 ab	15.415 a	7.541 bcd	7.708 c

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm and **WUE= water use efficiency**

Nitrogen, phosphorus and potassium contents in tubers

Effect of irrigation water quantity

Data in Table 7 indicate that the irrigation at 2000 m^3/fad. significantly increased N and P contents in tubers in both seasons and K contents in the 1st season.

The decreased of nitrogen and phosphorus under water stress conditions are related with decreasing of water potential in rhizosphere and cells of the plant (**Mamnabi *et al.* 2020**). In addition, **Bista *et al.* (2018**) stated that drought decreases the concentration of N and P in plants consequently decreasing productivity.

These results are in the same trend with those reported by **Zahran *et al.* (2020)** they found that nitrogen, phosphorus and potassium contents in tuber were higher when potato plants irrigated with 100% ETc as compared to 60 or 80 % Etc.

Effect of foliar spray treatments

In general, spraying with KSil at 2000 ppm significantly increased N, P and K contents in tubers except P content in the 1st season and there were significant differences with Treh at 1000 ppm with respect to P content (Table 7). This means that spraying with Treh at 1000 ppm increased P content in tuber, whereas spraying with KSil at 2000 ppm increased N and K contents in tubers.

These results are harmony with **Soltani *et al*. (2018) and Wadas (2022**) they showed that spraying potato plants with potassium silicate increased mineral contents in tuber as compared to untreated plants.

Table (7). Effect of irrigation water quantity and foliar spray treatments on N, P and K contents in tuber at harvesting time of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments	N (%)		P (%)		K (%)	
	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season
	Effect of irrigation water quantity (m^3/fad.)					
1200	1.23 c	1.23 c	0.247 c	0.243 c	1.96 b	1.96 a
1600	1.46 b	1.50 b	0.308 b	0.317 b	2.11 a	2.07 a
2000	1.53 a	1.56 a	0.342 a	0.345 a	2.09 a	2.10 a
	Effect of foliar spray treatments					
Unsprayed	1.37 c	1.34 d	0.264 c	0.267 c	1.81 d	1.74 d
Treh	1.39 b	1.40 c	0.321 a	0.320 a	2.16 b	2.17 b
PAA	1.41 b	1.46 b	0.300 b	0.303 b	1.99 c	1.99 c
KSil	1.48 a	1.53 a	0.309 b	0.316 a	2.27 a	2.27 a

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

Effect of the interaction

In general, the combination between high irrigation level (2000 m^3/fad.) and spraying with KSil at 2000 ppm increased N, P and K contents in tubers in both seasons (Table 8).

Table (8). Effect of the interaction between irrigation water quantity and foliar spray treatments on N, P and K contents in tuber at harvesting time of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments		N (%)		P (%)		K (%)	
Irrigation water quantity (m³/fad.)	Foliar spray treatments	2021/22 season	2021/23 season	2021/22 season	2022/23 season	2021/22 season	2022/23 season
1200	Unsprayed	1.17 e	1.16 f	0.213 j	0.211 j	1.77 ef	1.76 f
	Treh.	1.37 d	1.20 f	0.282 f	0.272 g	2.00 cd	2.00 d
	PAA	1.20 e	1.23 f	0.243 i	0.230 i	1.88 de	1.90 de
	KSil	1.44 cd	1.35 e	0.250 h	0.260 h	2.22 b	2.20 bc
1600	Unsprayed	1.46 bc	1.35 e	0.266 g	0.280 g	1.97 cd	1.78 ef
	Treh.	1.51 bc	1.46 d	0.330 c	0.340 c	2.24 ab	2.25 abc
	PAA	1.54 b	1.62 ab	0.313 e	0.320 e	2.04 c	2.01 d
	KSil	1.35 d	1.59 abc	0.323 d	0.330 d	2.22 b	2.24 abc
2000	Unsprayed	1.48 bc	1.52 cd	0.313 e	0.310 f	1.69 f	1.68 f
	Treh.	1.22 e	1.54 bcd	0.353 a	0.350 b	2.26 ab	2.28 ab
	PAA	1.54 b	1.55 bc	0.346 b	0.360 a	2.06 c	2.07 cd
	KSil	1.66 a	1.66 a	0.356 a	0.360 a	2.38 a	2.39 a

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

Tuber quality

Effect of irrigation water quantity

Specific gravity, dry matter (%) and starch content significantly increased with increasing irrigation water quantity up to the highest level (2000 m^3/fad.), except specific gravity in the 2nd season and there were no significant differences with the moderate level, i.e., 1600 m^3/fad. (Table 9). This means that the irrigation at 1600 m3/fad. increased specific gravity (1.044 g/cm^3) DM% (18.73%) and starch (13.49%) content as the average of the two seasons.

Water deficiency affects a variety of biochemical and physiological processes, including photosynthesis and the metabolism of amino acids, protein, carbohydrates, and other organic substances (**Pagter *et al*., 2005**).

This outcome is consistent with that of **Abou El-Khair *et al*. (2011),** who found that tuber tissues had higher levels of carbohydrates, starch, and dry matter at the highest irrigation rate (4167 m^3/ha) than at the lowest irrigation rate (1786 m^3/ha). Similar findings were made by **Farrag *et al*. (2016**), who discovered that 100% irrigation produced the highest tuber dry matter values, followed by 75% irrigation.

Effect of foliar spray treatments

Spraying potato plants with Treh, PAA and KSil increased specific gravity, dry matter (%) and starch content compared to control (spraying with water) as shown in Table 9. Foliar spray with KSil at 2000 ppm significantly increased specific gravity (1.056 g/cm^3), dry matter (19.6%) and starch content (14.105%) as the average of the two seasons.

Potassium silicate is the source of potassium's high solubility, and silicon is utilised to provide lower doses of potassium to help improve the value of tuber quality (**Tarabih *et al*., 2014**).

Table (9). Effect of irrigation water quantity and foliar spray treatments on tuber quality and its components of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments	Specific gravity (g/cm^3)		Dry matter (%)		Starch content (%)	
	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season
Effect of irrigation water quantity (m^3/fad.)						
1200	0.990 b	0.989 c	17.68 b	17.75 b	12.29 b	12.28 b
1600	1.039 a	1.040 a	18.79 a	18.67 a	13.48 a	13.51 a
2000	1.024 a	1.019 b	18.97 a	18.90 a	13.08 a	13.06 a
Effect of foliar spray treatments						
Unsprayed	0.946 d	0.942 c	16.78 d	16.81 c	11.61 c	11.55 d
Treh	1.019 c	1.028 b	18.55 c	18.84 b	12.90 b	12.79 c
PAA	1.048 b	1.041 ab	18.89 b	18.60 b	13.21 b	13.35 b
KSil	1.059 a	1.053 a	19.69 a	19.51 a	14.10 a	14.11 a

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

The present results are in harmony with those obtained with Abd **El- Gawad *et al*. (2017)** they found that the potato plants are sprayed with potassium silicate at 2000 ppm recorded the best tuber quality as compared to unsprayed plants. Also, (**Yousry *et al*., 2015**) showed that spraying potato plants with proline at 300 ppm significantly enhanced dry matter content and reducing total sugars in tuber as compared to unsprayed plants.

Effect of the interaction

Data in Table 10 indicate that the combination between the irrigation at 1600 m^3/fad. (moderate level) and spraying with KSil at 2000 ppm recorded the best values of specific gravity (1.09 g/cm^3), dry matter (20.10%) and starch content (14.56%) as the average of the two seasons. for all interaction treatments specific gravity was ranged from 0.917 to 1.09 g/cm^3), DM % was ranged from 16.21 to 20.10 % and starch % was ranged from 11.23 to 14.56 % as the average of the two seasons.

In this concern, **Mahmoud *et al*. (2019**) They found that the interaction between high moisture content and spraying with potassium silicate at 3ml/l recorded the best results for enchanting the quality of potato tuber.

Conclusion

Under the conditions of clay soil and during summer plantation, irrigation potato plants at 1600 m^3/fad. and spraying with trehalose at 1000 ppm increased dry weight of shoot / plant, average tuber weight, average tuber number/ plant, yield / plant and total yield /fad. also the irrigation of the same level and spraying with potassium silicate at 2000 ppm increased tuber quality (specific gravity, dry matter (%) and starch content).

Table (10). Effect of the interaction between irrigation water quantity and foliar spray treatments on tuber quality and its components of potato plants during summer plantation of 2021/2022 and 2022/2023 seasons

Treatments		Specific gravity (g/cm^3)		Dry matter (%)		Starch content (%)	
Irrigation water quantity (m^3/fad.)	Foliar spray treatments	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season	2021/2022 season	2022/2023 season
1200	Unsprayed	0.924 f	0.910 g	16.16 j	16.25 e	11.33 f	11.12 h
	Treh.	0.991 de	0.998 e	17.69 gh	17.83 c	11.69 ef	11.76 fgh
	PAA	1.008 cd	1.008 de	18.00 fg	18.00 c	12.35 e	12.47 ef
	KSil	1.038 b	1.041 bc	18.90 de	18.95 b	13.81 bcd	13.79 abc
1600	Unsprayed	0.940 f	0.958 f	16.79 i	17.10 d	11.56 f	11.60 gh
	Treh.	1.035 b	1.058 b	18.49 ef	18.90 b	13.68 bcd	13.66 bcd
	PAA	1.091 a	1.058 b	19.49 bc	18.90 b	14.15 ab	14.23 ab
	KSil	1.092 a	1.089 a	20.39a	19.80a	14.55 a	14.56 a
2000	Unsprayed	0.974 e	0.958 f	17.40 h	17.10 d	11.94 ef	11.94 fg
	Treh.	1.031 bc	1.029 cd	19.49 bc	19.80a	13.33 cd	12.96 de
	PAA	1.045 b	1.058 b	19.20 cd	18.90 b	13.13 d	13.37 cd
	KSil	1.049 b	1.031 cd	19.80 b	19.80a	13.95 abc	13.99 abc

Treh. Trehalose at 1000 ppm, PAA. = proline amino acid at 500 ppm and KSil= potassium silicate at 2000 ppm

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