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The Effect of Matrix Nutrition by Sulfonated Silicon With S8 on Tuber Yield and Its Components of Potato Cultivars Under Water Deficit Stress Condition

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Abstract

The goal of this study is to increase the tuber yield of potato cultivars by using of nutrient solution of sulfonated silicon with S8 sulfur element and to choose the most suitable method of using the nutrient solution under water deficit stress and normal conditions. This study was performed based on a split factorial experimental design in three replications in Ardabil Potato Research Station, IRAN in 2022. The main factor includes three levels of irrigation (100, 75, and 50% of plant usable water); the second factor includes foliar spraying with a nutrient solution in four stages of plant growth [(1) Tuber formation; (2) Tuber bulking; (3) Tuber formation and tuber bulking; (4) Control (Without nutritional solution)] and the third factor included three potato varieties (Agria, Rona and Takta). A nutrient solution of Sulfonated silicon with S8sulfur element was used for 5 liters per thousand of water. During the growth period, plant height, main stem number per plant, tuber number and weight per plant, tuber yield and water use efficiency were measured. The results showed that foliar spraying with a nutrient solution of sulfonated silicon with S-8 sulfur element amount 5 liters per thousand of water in the stages of tuber formation and tuber bulking increased tuber yield and water use efficiency under normal conditions (100% of plant usable water) about 14.24 ton per hectare and 2.44 kg/m^3, under mild stress condition (75% of plant usable water) about 7.04 ton per hectare and 1.61 kg/m^3 and under severe stress condition (50% of plant usable water) about 5.50 ton per hectare and 1.89 kg/m^3, respectively. The use of the nutrient solution of sulfonated silicon with S8 sulfur element amount 5liters per thousand of water in the stages of tuber formation and tuber bulking increased tuber yield and its components and water use efficiency under normal, mild and severe conditions.

Keywords: quantitative traits, matrix nutrition, minerals, S8, water use efficiency, cultivar, tuber yield, potato

1. Introduction

Intense competition in the international market of grains and other agricultural products will cause the fluctuation of food prices in the world and ultimately lead to the risk of food shortages and social unrest in low-income countries. One of the strategies that help to reduce this risk is changing food production towards

producing basic nutritious products such as potatoes. In terms of potato production Iran ranks 13th among countries in the world (FAO, 2018). Based on the latest statistics published by the Ministry of Agriculture, Jahad Iran, areas under cultivation of potatoes in 2020 were about 142,000 hectares producing 5.3 million tons with an average of 37 tons per hectare (Ministry of Agriculture, Jahad, Iran, 2022). At present per capita consumption of potatoes for each person is 56 kg which is planned to reach 63 kg in the predicted schedule until 2026 without increasing the area under cultivation (Kazemi et al., 2016). Supplying foodstuff for this population needs more attempts and pursuance in the field of agriculture and its related sciences. Despite significant improvements in the recent 3 decades, world consumption has only increased by about 20%. According to the existing statistics, the food production rate should be 70% more than the current rate by 2030 in developing countries so that can keep up with the increasing population to meet their needs (FAO, 2018).

Water deficit stress is one of the most important factors limiting the growth and yield of plants. To screen genotypes tolerant to drought stress in potatoes, from the distribution of assimilates and total live weight produced under stress conditions (Coleman, 2008), the ability to survive in severe water deficit stress conditions without losing leaves (Coleman, 2008), maximum leaf area index (Deshi et al., 2015), maximum leaf area index (Deshi et al., 2015), later leaf fall in dry conditions (Lahlou et al., 2003), maximum leaf area index and leaf durability period (Al-Mahmud et al., 2014), maximum the leaf surface index and its retention time (Deshi et al., 2015) and the highest relative water content and the chlorophyll index and the lowest electrolyte leakage rate (Nouri et al., 2015) are used. Water deficit stress is a common stress in potato production, leading to decreased tuber quality and yield. Water deficit stress in potatoes causes a decrease in the fresh and dry weight of the plant (Farooq et al., 2009), leaf area and their development (Shao et al., 2008), photosynthesis and dry matter production (Nayyar & Gupta, 2006), root and leaf fresh weight and root number (Donnelly et al., 2003), root dry weight (Sharma et al., 2011), harvest index and tuber dry matter (Schittenhelma et al., 2006), leaf photosynthesis rate, biomass aerial organ, tuber growth (Irna & Mauromicale, 2006), plant height (Donnelly et al., 2003; Schittenhelmaet al., 2006), tuber number per plant (Schittenhelma et al., 2006; Badarau et al., 2013) and reducing tuber yield (Shock & Feibert, 2002; Schittenhelma et al., 2006; Irna & Mauromicale, 2006; Hassanpanah, 2009; Badarau et al., 2013; Sobhani & Hamidi, 2013).

One of the important points for successful production in these systems is supplying the nutrients required by the plant depending on the type of cultivation bed and the period of plant growth (Alifar et al., 2010). Shahabi Far (2006) has announced that Sulfur is known as an essential and necessary element for plant nutrition. The silicon element increases the number and quality of the products (Gerami &Torabipoor, 2021; Kaya et al., 2006), the tolerance to water stress (Wang et al.,2016; Kaya et al., 2006), antioxidant enzymes production (Kaya et al., 2006), antioxidant system improving under drought stress (Slinkard & Singleton, 1997), the activity of SOD and CAT enzymes under drought stress (Guness et al., 2008) and improve the absorption of Potassium and Calcium in the situation of drought stress (Kaplan &Orman, 1998). Kafi et al. (2018) reported that the use of silicon is an effective way to reduce the effects of salinity. Sulfur increases the resistance to drought stress (Tate, 1995), tuber yield (Shahabi Far, 2006; Ansouri et al., 2014; Golmoradi Marani et al., 2017), growth of terminal buds, number and strength of stems (Gerami &Torabipoor, 2021) and decreases the soil pH (Golmoradi Marani et al., 2017). The purpose of this study is to increase the tuber yield and its components and water use efficiency in potato cultivars by using a nutrient solution of sulfonated silicon with S8 sulfur element, to choose the most suitable method of using the nutrient solution prepared and determining the most suitable potato variety under water stress and normal conditions.

2. Method

This research was carried out based on a split factorial experimental design in three replications in Ardabil Potato Research Station, IRAN in 2022. The main factor includes three levels of irrigation (100, 75, and 50% of plant usable water); the second factor includes foliar spraying with a nutrient solution in four stages of plant growth [(1) Tuber formation; (2) Tuber bulking; (3) Tuber formation and tuber bulking; (4) Control (Without nutritional solution)] and the third factor included three potato varieties (Agria, Rona and Takta). The quantitative and qualitative characteristics of the cultivars are shown in (Table 1).

Table 1. The quantitative and qualitative characteristics of the cultivars

Cultivars	Skin Color	Flesh Color	Potato Uses	Tuber Yield	Texture	Maturity
Agria	Yellow	Yellow	French fries	High	Flour	Medium late
Rona	Light Pink	Dark Yellow	Chips	High	Very floury	Medium late
Takta	Light Pink	Light Yellow	Multipurpose	High	Soft	Medium late

A nutrient solution of sulfonated silicon with S-8 sulfur element was used for 5 liters per thousand of water. S-8 nutrient solution includes 80% sulfur, 2% silicon, 15% Potassium, 2% nitrogen, 2,500 PPM Iron and 200 PPM Zinc. This nutrient solution has a license with registration number 08492 and certificate number 8342/243 dated 15.10.2019 from the Khak-o-Ab {Soil and Water} Institute. The treatments were planted in plots with a length of 5 meters in three rows in the form of a furrow with a density of 75 × 25 cm and a planting depth of 10 cm. The irrigation method was in the form of drip irrigation. After planting and before the potato plants sprouted, Gramaxon (Paraquat) herbicide was used to remove the weeds. The wedding and soiling of the plant were done in two stages. About 250 ml of Confidor (Imidacloprid) insecticide was used to control the Colorado potato beetle pest (*Leptinotarsa decemlineata*). Consumption of urea fertilizers was done in three stages in the amount of 300 kg per hectare (one-third at planting time, one-third at weed wedding and one-third at the time of plant earthling up), Ammonium Phosphate fertilizer at two stages in the amount of 150 kg (50% at planting time and 50% at the time of tuberization stage) and potassium sulfate fertilizer at a time of 150 kg at planting time was used based on the soil test.

The project site has a semi-arid and cold climate and winter temperatures are often below zero. The average rainfall is 310 mm, the climate is slightly humid, the altitude is 1,350 meters above sea level and its longitude and latitude are 48°17′35.88″ E and 38°14′59.28″ N, respectively. The average maximum and minimum annual temperatures and absolute maximum temperatures are 1.98, 15.18 and 21.58 °C, respectively. The soil of these lands is loamy clay and is poor in organic matter (0.7%). The PH of these lands is about 7.7 and the PH of the water is 7.1. The arable soil (B + A) is about 70 cm deep. The land of the area is flat and its condition is suitable in terms of proper drainage and groundwater aquifer in it is very deep and the condition of soil ventilation is also favourable.

The amount of water used was based on different stages of growth and plant needs. To calculate the amount of irrigation water for each time and at each stage of potato growth, the required percentage of field capacity (F.C.), percentage of permanent wilting (P.W.P.), specific bulk density (Bd. D.), available water (A.W.) and raw water (R.A.W.) are needed (Rasoolzade & Raoof, 2013). The test site has a specific bulk density of 1 g per cubic centimetre, the field capacity is 29.1% and the permanent wilting is 14.6%. The maximum allowable shortage for potatoes was considered to be 0.35. The maximum allowable deficiency is a part of the amount of available water that the plant easily absorbs. Usually, after this amount of soil moisture, the plant should make more efforts to provide the required moisture, and this will reduce the yield of the crop. Therefore, the amount of moisture in the soil, which is followed by a decrease in crop yield, is known as the maximum allowable depletion and is expressed as a percentage. The standard value for potatoes is 35%. The amount of available water (A.W.) and raw water (R.A.W.) of the experimental farm are 18.705 and 6.547%, respectively. The percentage of soil moisture was calculated to determine the start time of irrigation by adding the amount of raw water and permanent wilting. The amount of soil moisture was considered 21.147% for the start of irrigation based on the calculations performed at the test site. The percentage of soil moisture at the test site during the potato-growing period was measured using a portable hygrometer device PMS-714 made in Taiwan.

- A.W. = $[(\theta_{.FC} - \theta_{.PWP})/100] \times$ Bd. D = $[(29.1 - 14.6)/100] \times 1.29 = 18.705\%$
- R.A.W. = A.W. × M.A.D. = 18.705 × 0.35 = 6.547%
- Moisture percentage of the soil = R.A.W. + P.W.P. = 6.547 + 14.6 = 21.147%

The amount of water needed for the treatment of the normal condition (100% of plant usable water):

A: In the Planting Stage

- The first stage: Farm capacity × Rooting development in the planting stage × The area of one hectare = 29.1 percent × 0.2 meter × 10,000 square meters = 582 cubic meters per hectare
- The second stage: Soil moisture at the beginning of irritation × Rooting development in the planting stage × The area of one hectare = 21.147 per cent × 0.2 meters × 10,000 square meters = 423 cubic meters per hectare
- The first stage − the second stage = 582 − 423 = 159 cubic meters per hectare

B: In the Planting Stage Until the Tuber Formation

- The first stage: Farm capacity × Rooting development in the planting stage × The area of one hectare = 29.1 percent × 0.3 meter × 10,000 square meters = 873 cubic meters per hectare
- The second stage: Soil moisture at the beginning of irritation × Rooting development in the planting stage ×The area of one hectare = 21.147 per cent × 0.3 meters × 10,000 square meters = 634 cubic meters per hectare
- The first stage − The second stage = 873 − 634 = 239 cubic meters per hectare

C: In the Starting Stage of Tuber Formation Until the Harvesting of Tubers

- The first stage: Farm capacity × Rooting development in the planting stage × The area of one hectare = 29.1 percent × 0.5 meter × 10,000 square meters = 1,455 cubic meters per hectare
- The second stage: Soil moisture at the beginning of irritation × Rooting development in the planting stage × The area of one hectare = 21.147 per cent × 0.5 meters × 10,000 square meters = 740 cubic meters per hectare
- The first stage − The second stage = 1,455 − 740 = 740 cubic meters per hectare

Table 2. The amount of water used for the treatment studied

Stages	100% of usable water(m^3/ha)	75% of usable water(m^3/ha)	50% of usable water(m^3/ha)
In the planting stage	160	120	80
In the planting stage until tuber formation	240	180	120
In the starting stage of tuber formation until the harvesting of tubers	740	555	370

During the growth period, plant height, number of main stems per plant, tuber number and weight per plant, tuber yield and water use efficiency were measured. For data analysis, the normality test of data distribution was performed by the Kolmogorov-Smirnov test. Analysis of variance was performed using SAS 9.1 statistical software. Comparison of mean traits was compared using the LSD test at a 5% probability level. Minitab16 software was used to calculate factor analysis and cluster analysis by the Ward method.

3. Results and Discussion

The results of the analysis of variance showed that there was a significant difference between the different levels of plant usable water, nutrient solution and cultivars in terms of tuber weight per plant, tuber number per plant, tuber yield, plant height and water use efficiency; between the different levels of plant usable water and nutrient solution interaction in terms of tuber number and weight per plant, tuber yield, main stem number per plant and water use efficiency; between the different levels of plant usable water and cultivars interaction in terms of tuber number per plant and water use efficiency; between the different levels of nutrient solution and cultivars interaction in terms of tuber number per plant and main stem number per plant and between the different levels of plant usable water, nutrient solution and cultivars interaction in terms of tuber number per plant at the level of 1% and 5% probability (Table 3).

Table 3. Variance analysis of evaluated traits in levels of plant usable water, nutrient solution and potato cultivars

S.O.V.	D.F.	Mean of squares					
		Tuber weight per plant	Tuber number per plant	Tuber yield	Plant height	Main stem number per plant	Water use efficiency
Replication	2	26507.91	0.250	74.75	97.44	0.704	2.97
Usable water levels (A)	2	754127.74**	19.75**	2118.43**	667.56**	0.009	87.62**
Error	4	9399.32	0.33	26.41	24.03	0.176	0.574
Nutrient levels (B)	3	136594.09**	8.31**	383.65**	994.85**	3.959**	19.12**
Cultivars (C)	2	260798.71**	3.25**	732.62**	368.64**	8.065**	40.46**
A × B	6	24701.84**	2.315**	69.37**	52.44	0.625**	1.690**
A × C	4	9200.10	1.25**	25.86	10.06	0.204	0.927**
B × C	6	1951.24	1.47**	5.48	43.18	0.978**	0.175
A × B× C	12	5628.23	0.472*	15.81	27.80	0.228	0.782
Error	66	6070.99	0.25	17.05	33.34	0.140	0.522
C.V. (%)		11.40	9.53	10.49	8.72	10.48	7.75

Note. * and **: Significant at the 5 and 1%, probability levels, respectively.

Tuber number and weight per plant, tuber yield, plant height, main stem number per plant and water use efficiency in foliar application treatment with nutrient solution at a dose of 5 per thousand in the stage of tuber formation and tuber bulking under 100% of plant usable water had the highest value and was placed in group A and AB (Table 4). Tuber weight per plant, tuber yield and main stem number per plant in foliar application

treatment with nutrient solution at a dose of 5 per thousand in the stage of tuber bulking and plant height, tuber number per plant and water use efficiency in foliar application treatment with nutrient solution at a dose of 5 per thousand in the two treatments of (1) tuber bulking, and (2) tuber formation and tuber bulking under 75% of plant usable water had the highest value (Table 4). Tuber number and weight per plant, tuber yield, plant height and water use efficiency in foliar application treatment with nutrient solution at a dose of 5 per thousand in the stage of tuber formation and tuber bulking under 50% of plant usable water had the highest value (Table 4).

Table 4. The mean of quantitative traits in plant usable water levels and stage of nutrient solution interaction

Plant usable water levels	Stage of nutrient solution	Tuber weight per plant (gr)	Tuber yield (ton/ha)	Tuber number per plant	Plant height (cm)	Main stem number per plant	Water use efficiency (kg /m^3)
Normal condition (100% of plant usable water)	Tuber formation	803.51 bc	42.59 bc	6.00 b	67.22 bcd	3.78 abcd	7.32 ef
	Tuber bulking	870.36 b	46.13 b	6.67 a	71.22 b	3.44 d	7.93 de
	Tuber formation and tuber bulking	1047.87 a	55.54 a	7.00 a	80.33 a	4.00 ab	9.54 b
	Control (Without nutritional solution)	779.12 cd	41.29 cd	4.67 d	63.67 de	3.00 e	7.10 f
Mild stress condition (75% of plant usable water)	Tuber formation	728.43 de	38.61 de	4.67 d	64.33 d	3.44 d	8.85 c
	Tuber bulking	833.40 bc	44.17 bc	5.33 c	66.56 bcd	4.11 a	10.12 b
	Tuber formation and tuber bulking	796.06 cd	42.19 cd	5.33 c	70.22 bc	3.67 bcd	9.66 b
	Control (Without nutritional solution)	700.50 ef	37.13 ef	4.67 d	58.67 e	3.00 e	8.51 cd
Severe stress condition (50% of plant usable water)	Tuber formation	560.22 h	29.69 h	4.00 e	63.22 de	3.89 abc	10.21 b
	Tuber bulking	609.38 gh	32.30 gh	5.00 cd	65.67 cd	3.56 cd	11.10 a
	Tuber formation and tuber bulking	643.62 fg	34.11 fg	5.00 cd	67.56 bcd	3.89 abc	11.72 a
	Control (Without nutritional solution)	539.75 h	28.61 h	4.67 d	52.20 f	3.00 e	9.83 b

Note. * Means followed with the same letters in each column are not significantly different at a 5% probability level using the LSD test.

The water use efficiency had the highest value under normal, mild and severe stress conditions (100%, 75% and 50% of plant usable water) in the Takta cultivar (Table 5).

Table 5. Mean of water use efficiency trait in plant usable water levels and potato cultivars interaction

Usable water levels	Cultivars	Water use efficiency (kg /m^3)
Normal condition (100% of plant usable water)	Agria	7.05 f
	Rona	8.25 de
	Takta	8.61 d
Mild stress condition (75% of plant usable water)	Agria	7.90 e
	Rona	9.42 c
	Takta	10.53 b
Severe stress condition (50% of plant usable water)	Agria	9.56 c
	Rona	10.96 b
	Takta	11.62 a

Note. * Means followed with the same letters in each column are not significantly different at a 5% probability level using the LSD test.

The tuber number per plant had the highest value under normal conditions (100% of plant usable water) in the tuber formation stage in Rona and Takta cultivars and in the two treatments of (1) tuber bulking, and (2) tuber formation and tuber bulking, under mild stress condition (75% of plant usable water) in the tuber formation stage in Rona and Takta cultivars, in tuber bulking stage in Takta cultivar and stages of tuber formation and tuber

bulking in Agria cultivar and under severe stress condition (50% of plant usable water) in Agria, Rona and Takta cultivars in (1) tuber bulking, and (2) tuber formation and tuber bulking stages (Table 6).

Table 6. Mean of tuber number per plant in usable water levels, stage of nutrient solution and cultivars interaction

Plant usable water levels	Stage of nutrient solution	Cultivars	Tuber number per plant
Normal condition (100% of plant usable water)	Tuber formation	Agria	5 b
		Rona	7 a
		Takta	6 ab
	Tuber bulking	Agria	6 ab
		Rona	7 a
		Takta	7 a
	Tuber formation and tuber bulking	Agria	7 a
		Rona	8 a
		Takta	6 ab
	Control	Agria	4 c
		Rona	5 b
		Takta	5 b
Mild stress condition (75% of plant usable water)	Tuber formation	Agria	4 c
		Rona	5 b
		Takta	5 b
	Tuber bulking	Agria	5 b
		Rona	5 b
		Takta	6 ab
	Tuber formation and tuber bulking	Agria	6 ab
		Rona	5 b
		Takta	5 b
	Control	Agria	4 c
		Rona	5 b
		Takta	5 b
Severe stress condition (50% of plant usable water)	Tuber formation	Agria	4 c
		Rona	4 c
		Takta	4 c
	Tuber bulking	Agria	5 b
		Rona	5 b
		Takta	5 b
	Tuber formation and tuber bulking	Agria	5 b
		Rona	5 b
		Takta	5 b
	Control	Agria	4 c
		Rona	5 b
		Takta	5 b

Note. * Means followed with the same letters in each column are not significantly different at a 5% probability level using the LSD test.

Under normal conditions (100% of plant usable water), based on the results of factor analysis, the Takta cultivar in terms of tuber yield, tuber number and weight per plant, plant height, main stem number per plant and water use efficiency in foliar spraying with a nutrient solution of sulfonated silicon with S8 sulfur element amount 5 liters per thousand of water in the stage of tuber formation and tuber bulking had the highest amount (Figure 1).

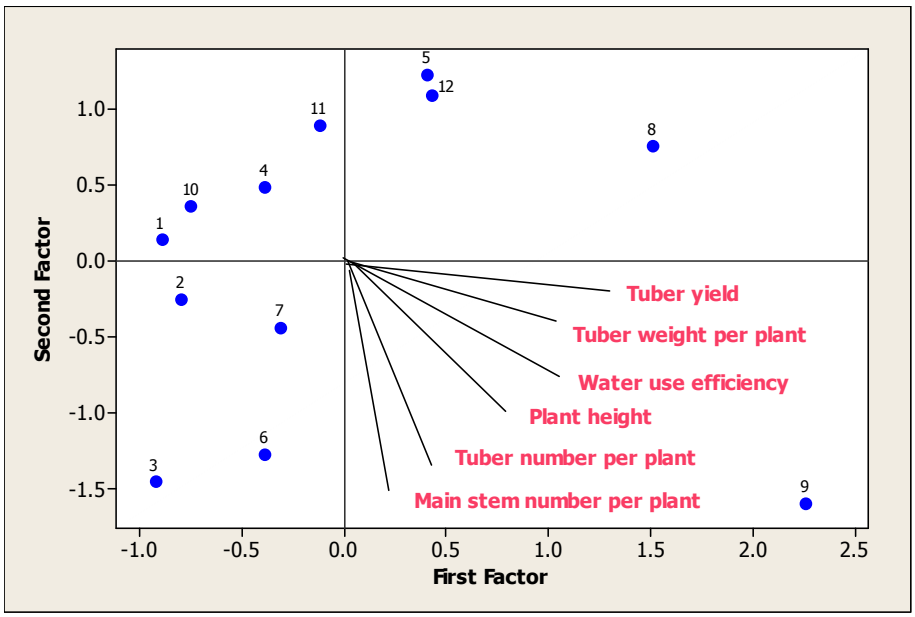
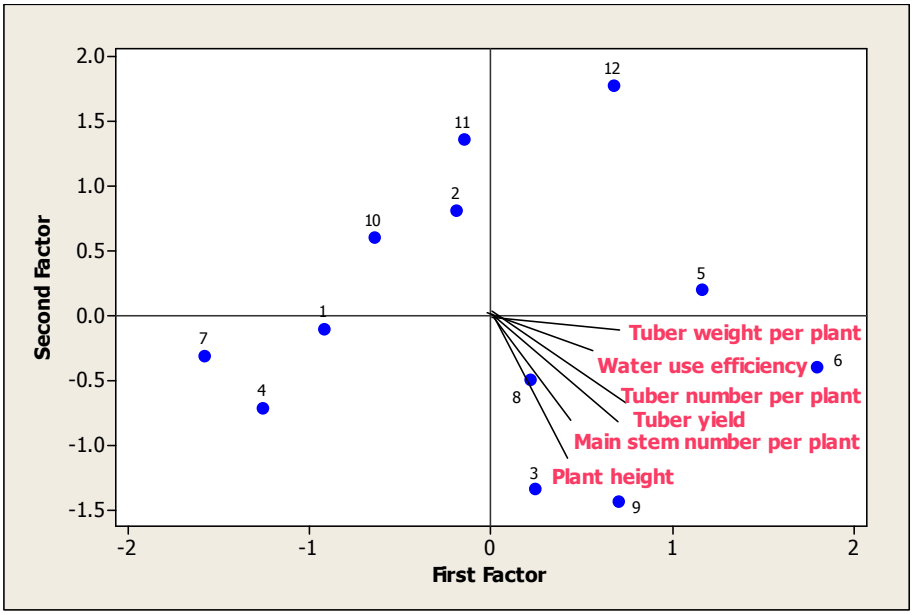


Figure 1. Bi-plot of factor analysis in potato cultivars and stage of the nutrient solution under 100% plant usable water based on all studied traits

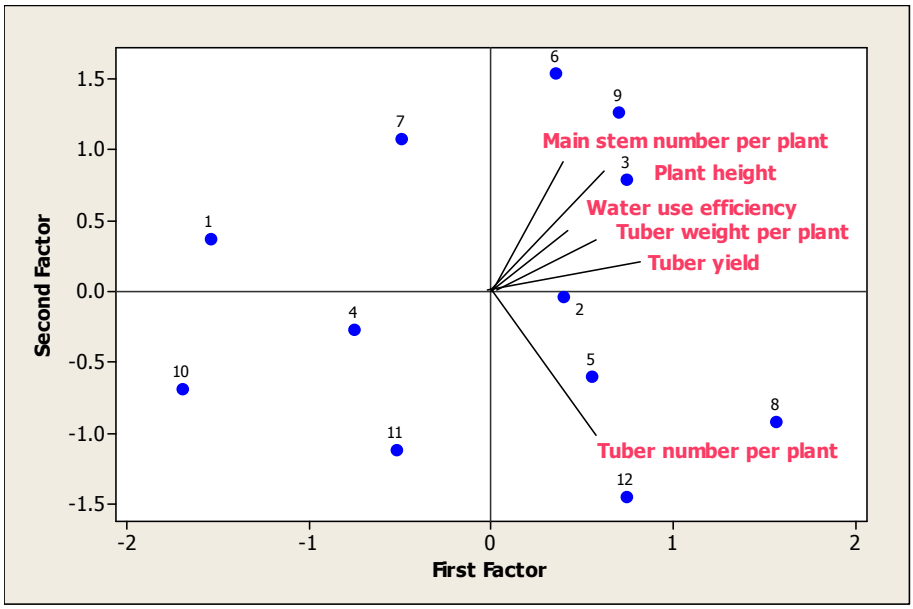
Under mild stress conditions (75% of plant usable water), based on the results of factor analysis, the Takta cultivar in terms of tuber yield, tuber number and weight per plant, plant height, main stem number per plant and water use efficiency in foliar spraying with a nutrient solution of sulfonated silicon with S-8 sulfur element amount 5 liters per thousand of water in the stages of (1) Tuber formation, (2) Tuber bulking and (3) Tuber formation and tuber bulking had the highest amount (Figure 2).



1	Tuber formation	Agria	4	Tuber bulking	Agria	7	Tuber formation and tuber bulking	Agria	10	Control	Agria
2		Rona	5		Rona	8		Rona	11		Rona
3		Takta	6		Takta	9		Takta	12		Takta

Figure 2. Bi-plot of factor analysis in potato cultivars and stage of a nutrient solution under 75% plant usable water based on all studied traits

Under severe stress conditions (50% of plant usable water), based on the results of factor analysis, the Takta cultivar in terms of tuber yield, tuber weight per plant, plant height, main stem number per plant and water use efficiency in foliar spraying with a nutrient solution of sulfonated silicon with S8 sulfur element amount 5 liters per thousand of water in the stages of tuber formation and tuber bulking had the highest amount (Figure 3).



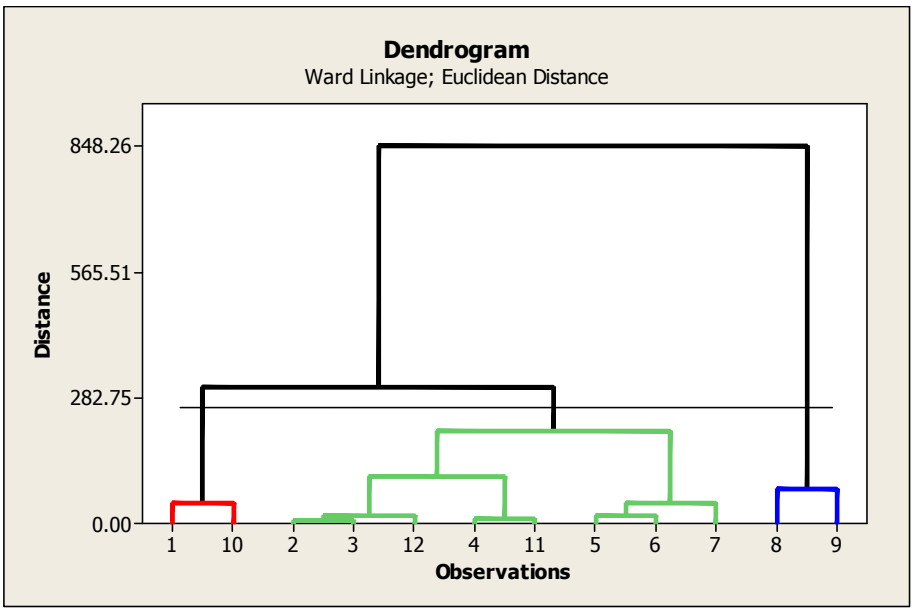
1	Tuber formation	Agria	4	Tuber bulking	Agria	7	Tuber formation and tuber bulking	Agria	10	Control	Agria
2		Rona	5		Rona	8		Rona	11		Rona
3		Takta	6		Takta	9		Takta	12		Takta

Figure 3. Bi-plot of factor analysis in potato cultivars and stage of a nutrient solution under 50% plant usable water based on all studied traits

In normal condition (100% of plant usable water), based on the results of cluster analysis by the Ward method, the grouping was placed as follow: in the first group of Agria cultivar in foliar spraying with a nutrient solution of sulfonated silicon with S8 sulfur element amount 5 liters per thousand of water in the stage of tuber formation and control.

The second group was placed as follows: Rona and Takta cultivars in foliar spraying with a nutrient solution of sulfonated silicon with S8 sulfur element amount 5 liters per thousand of water in the stages of (1) Tuber formation, (2) Tuber bulking and (3) control, and Agria cultivar in the stages of (1) Tuber bulking and (2) Tuber formation and tuber bulking.

In the third group, Rona and Takta cultivars were placed in foliar spraying with a nutrient solution of sulfonated silicon with S-8 sulfur element amount of 5 liters per thousand of water in the stages of tuber formation and tuber bulking under normal conditions (Figure 4).



1	Tuber formation	Agria	4	Tuber bulking	Agria	7	Tuber formation and tuber bulking	Agria	10	Control	Agria
2		Rona	5		Rona	8		Rona	11		Rona
3		Takta	6		Takta	9		Takta	12		Takta

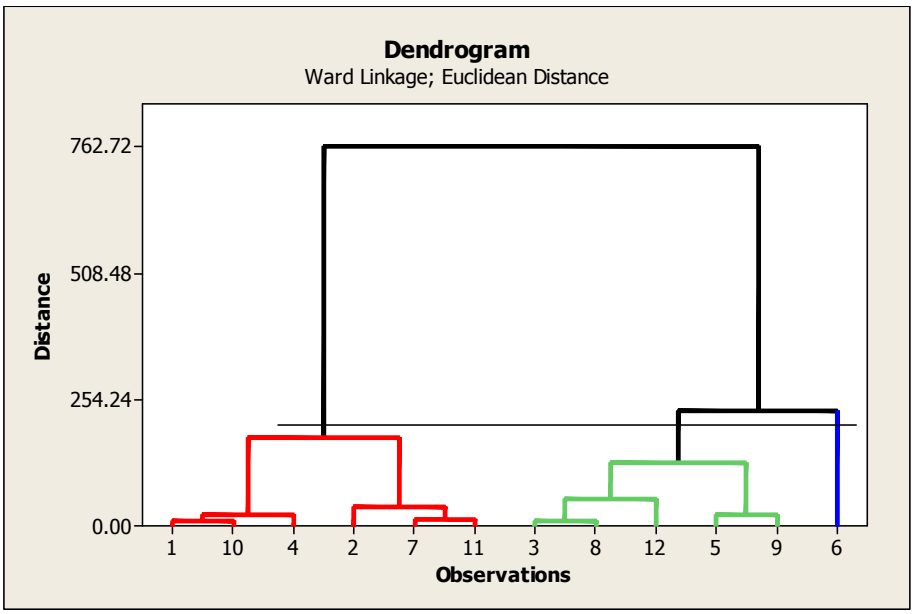
Figure 4. Grouping of potato cultivars and stage of a nutrient solution under 100% plant usable water based on all studied traits using the Ward method

According to (Table 7), in the third group, in terms of tuber yield, tuber number and weight per plant, plant height, main stem number per plant and water use efficiency traits have a deviation of the mean of each trait from the total positive average and are selected as a suitable group in terms of yield traits and yield components (Table 7).

Table 7. Deviation of the mean of each group from the total mean in the evaluated traits of potato cultivars and studied treatments

Traits	Cluster 1	Cluster 2	Cluster 3
Tuber number per plant	-1.58	0.17	**0.92**
Tuber yield	-8.33	-1.36	**13.75**
Tuber weight per plant	-157.24	-25.56	**259.49**
Plant height	-7.44	-1.11	**11.89**
Main stem number per plant	-0.39	-0.06	**0.61**
Water use efficiency	-1.43	-0.23	**2.36**

In mild stress condition (75% of plant usable water), based on the results of cluster analysis by the Ward method, the grouping was placed as follow: in the first group of Agria cultivars in foliar spraying in the stages of (1) Tuber formation, (2) Tuber bulking, (3) Tuber formation and tuber bulking and (4) Control, and Rona cultivar in the stages of (1) Tuber formation and (2) Control. The second group was placed as follows: Takta cultivar in foliar spraying in stages (1) Tuber bulking, (2) Tuber formation and tuber bulking and (3) Control, and Rona cultivar in the stages of (1) tuber bulking and (2) tuber formation and tuber bulking. In the third group, the Takta cultivar was placed in foliar spraying in the stages of tuber bulking (Figure 5).



1	Tuber formation	Agria	4	Tuber bulking	Agria	7	Tuber formation and tuber bulking	Agria	10	Control	Agria
2		Rona	5		Rona	8		Rona	11		Rona
3		Takta	6		Takta	9		Takta	12		Takta

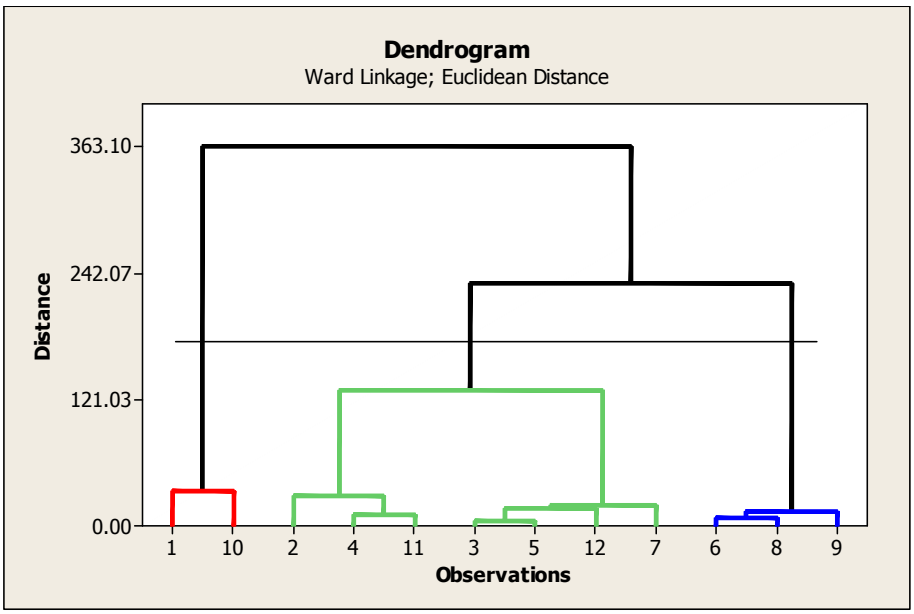
Figure 5. Grouping of potato cultivars and stage of a nutrient solution under 75% plant usable water based on all studied traits using the Ward method

According to (Table 8), in the third group, in terms of tuber yield, tuber number and weight per plant, plant height, main stem number per plant and water use efficiency traits have a deviation of the mean of each trait from the total positive average and are selected as a suitable group in terms of yield traits and yield components (Table 8).

Table 8. Deviation of the mean of each group from the total mean in the evaluated traits of potato cultivars and studied treatments

Traits	Cluster 1	Cluster 2	Cluster 3
Tuber number per plant	-0.17	0.00	**1.00**
Tuber yield	-4.92	3.50	**11.98**
Tuber weight per plant	-92.72	66.06	**226.04**
Plant height	-2.78	1.99	**6.72**
Main stem number per plant	-0.45	0.31	**1.11**
Water use efficiency	-1.13	0.80	**2.75**

In severe stress condition (50% of plant usable water), based on the results of cluster analysis by the Ward method, the grouping was placed as follow: in the first group of Agria cultivar in foliar spraying in the stages of (1) Tuber formation and (2) Control. The second group was placed as follows: Takta cultivars in foliar spraying in stages (1) Tuber formation and (2) Control, Rona cultivar in foliar spraying in the stages of (1) Tuber formation, (2) Tuber bulking and (3) Control, and Agria cultivar in the stages of (1) Tuber bulking and (2) Tuber formation and tuber bulking. In the third group, the Takta cultivar was placed in foliar spraying in stage (1) Tuber bulking and (2) Tuber formation and tuber bulking, and the Rona cultivar were in foliar spraying in the stages of tuber formation and tuber bulking (Figure 6).



1	Tuber formation	Agria	4	Tuber bulking	Agria	7	Tuber formation and tuber bulking	Agria	10	Control	Agria
2		Rona	5		Rona	8		Rona	11		Rona
3		Takta	6		Takta	9		Takta	12		Takta

Figure 6. Grouping of potato cultivars and stage of a nutrient solution under 50% plant usable water based on all studied traits using the Ward method

According to Table 9), in the third group, in terms of tuber yield, tuber number and weight per plant, plant height, main stem number per plant and water use efficiency traits have a deviation of the mean of each trait from the total positive average and are selected as a suitable group in terms of yield traits and yield components (Table 9).

Table 9. Deviation of the mean of each group from the total mean in the evaluated traits of potato cultivars and studied treatments

Traits	Cluster 1	Cluster 2	Cluster 3
Tuber number per plant	-0.67	0.05	**0.33**
Tuber yield	-6.16	0.08	**3.93**
Tuber weight per plant	-116.31	1.43	**74.21**
Plant height	-6.59	-0.71	**6.06**
Main stem number per plant	-0.25	-0.15	**0.53**
Water use efficiency	-2.12	0.03	**1.35**

In this experiment, in the conditions of normal (100% of plant usable water), mild stress (75% of plant usable water) and severe stress (50% of plant usable water), foliar spraying with a nutrient solution in the stages of tuber formation and tuber bulking increased tuber weight per plant, tuber yield and plant height.

The foliar spraying with a nutrient solution of sulfonated silicon with S-8 sulfur element amount 5liters per thousand of water in the stages of tuber formation and tuber bulking increased tuber yield and water use efficiency under normal conditions (100% of plant usable water) by about 14.24 ton per hectare and 2.44 kg/m^3, under mild stress condition (75% of plant usable water) about 7.04 ton per hectare and 1.61 kg/m^3 and under severe stress condition (50% of plant usable water) about 5.50 ton per hectare and 1.89 kg/m^3, respectively.

The water use efficiency had the highest value under normal, mild and severe stress conditions (100%, 75% and 50% of plant usable water) in the Takta cultivar.

The tuber number per plant had the highest value under normal, mild and severe stress conditions (100%, 75% and 50% of plant usable water) in Rona and Takta cultivars in stages of tuber formation and tuber bulking. Foliar

spraying with a nutrient solution in tuber formation and tuber bulking stages increased tuber number per plant. It can be concluded that foliar spraying in the stage of tuber formation increases its number.

The use of a nutrient solution of sulfonated silicon with S-8 sulfur element amount 5 liters per thousand of water in the stages of tuber formation and tuber bulking increased tuber yield and its components under normal, mild and severe stress conditions.

In this study, based on the results of factor analysis, foliar spraying with a nutrient solution of sulfonated silicon with S-8 sulfur element amount to 5 liters per thousand of water in the stages of (1) Tuber formation, (2) Tuber bulking and (3) Tuber formation and tuber bulking in Takta cultivar under normal, mild and severe stress conditions increase tuber yield and its components.

Hassanpanah et al. (2008) and Hassanpanah (2009) concluded that the beginning stages of tuber formation and tuber bulking are the most sensitive stage of potato growth. So, the use of this nutrient solution is recommended to reduce the stress of deficit water in the critical stage of potato growth.

The increase in yield and its components by using silicon element by Gerami and Torabipoor (2021); Kaya et al. (2006) and sulfur element by Shahabi Far (2006); Ansouri et al. (2014); and GolmoradiMarani et al. (2017), has been reported. The increase in plant tolerance to water stress by using silicon elements has been reported by Slinkard and Singleton (1997); Kaya et al. (2006); Wang et al. (2016); and Gerami and Torabipoor (2021) and sulfur element by Tate (1995); and Kafi et al. (2018). Decreased yield and its components by water deficit stress in potatoes have been reported by some researchers including Donnelly et al. (2003) and Schittenhelma et al. (2006) in plant height, Schittenhelma et al. (2006); and Badarau et al. (2013) in tuber number per plant, Shock and Feibert (2002); Schittenhelma et al. (2006); Irna and Mauromicale (2006); Hassanpanah (2009); Badarau et al. (2013); and Sobhani and Hamidi (2013) in tuber yield. Hassanpanah et al. (2022) result in the use of a nutrient solution of sulfonated silicon with S-8 sulfur element in two forms of foliar spraying at a rate of 3 per thousand and the use of 2 kg of solution in 200 liters of water increased tuber yield and its components and water use efficiency.

In conclusion, the use of a nutrient solution of sulfonated silicon with S-8 sulfur element amount 5liters per thousand of water in the stages of tuber formation and tuber bulking in the Takta cultivar increased tuber yield and its components and water use efficiency under normal (100% of plant usable water), mild stress (75% of plant usable water) and severe stress (50% of plant usable water) conditions.

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