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Introduction of Nutrient Solution of Silicon Sulfonated With Elemental Sulfur S8 for the Mini-tuber Production of Potato Cultivars from *in vitro* Micro-tuber

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Abstract

This study with aims to investigate the effect of nutrient solution sulfonated silicon with elemental sulfur S8 in the mini-tuber production of potato cultivars in the greenhouse of Potato Research Station of Ardabil Province, Iran was done during April till August of 2022. This experiment was carried out based on the factorial experimental design in two factors and three repetitions. The first factor with two levels including: 1. foliar spraying with nutrient solution sulfonated silicon with elemental sulfur S8 and 2. Control (without nutrient solution sulfonated silicon with elemental sulfur S8) and the second factor consists of micro-tubers of five cultivars in the name of Agria, Jelli, Anosha, T297 and Sheida. The foliar spraying with S-8 nutrient solution was done in five stages of vegetative growth, plant growth and development, tuberization, flowering and tuber development and tuber bulking. The results of analysis of variance showed that there was a significant difference between the levels of nutrient solution, cultivars and the interaction between nutrient solution and cultivars in terms of mini-tuber number and weight per square meter, mini-tuber number per plant and plant height. Anosha cultivar had the highest values in terms of mini-tuber number and weight per square meter and tuber number per plant traits by using nutrient solution and was placed in the group A. The Agria, Jelli, Sheida and T297 cultivars were placed in the group B and had the highest amount by using nutrient solution in terms of these characteristics. The Agria, Jelli and Anosh cultivars had the highest plant height by using nutrient solution. Based on the results, using sulfonated silicon nutrient solution with elemental sulfur S8 causing an increase mini-tuber number per square meter (515 numbers), mini-tuber number per plant (5 numbers), mini-tuber weight per square meter (47 kg) and plant height (92 cm) became.

Keywords: S8, silicon sulfonated, tuberization, tuber bulking, cluster analysis, tuber, plantlet

1. Introduction

Potato is one of the most important crops in the world. This is the fourth most important product in the world after wheat, rice and corn (Faberio et al., 2001).Based on the latest statistics published by the Ministry of Agriculture-Jahad, Iran, areas under cultivation of potato in 2020 were about 142,000 hectares producing 5.2 million tons with an average of 37 tons per hectare (Ministry of Agriculture-Jahad, Iran, 2022). Iran with 5.2 million tons of potato production, ranks 13th in the world and is the third largest producer in Asia after China and India. The production of potato seed tubers in Iran prevents the import of seed potatoes, saves currency,

independence and security. With the optimization of mini-tuber production in Iran, the provision of healthy seedlings of potato varieties, the training of manpower, and the help to equip the laboratory and greenhouses, the private sector became active in this field. The establishment of such companies has created direct and permanent employment for the youth of this country in the laboratory and greenhouse sector (Hassanpanah & Akbarlu, 2013). The seed tuber used for the production of edible potatoes is provided from the certified class A, for the sub-crop area of about 143 thousand hectares of potatoes in the country, it is necessary to provide about 650 thousand tons of seed tubers. To provide this amount of seeds, it is necessary to produce about 10 to 12 million mini-tubers annually. This number of mini-tubers completely satisfies the domestic need for the production of different classes of potato seed tuber in the country, and there is no need to import potatoes from foreign countries. Mini-tubers there are small seed tubers that seedlings propagated under *in vitro* conditions produced and later transferred to the greenhouse. Mini-tubers are produced through seedlings in the greenhouse with high density (Lommen & Struik, 1992c). Each product has an optimal nutritional requirement. Each potato cultivar may have different nutritional needs. This also depends on the chemical quality of the water and nutrients used to prepare the nutrient solution (Otazu, 2010). Balamani et al. (1986) concluded the use of calcium can increase the ability of nutrition in the tips of stolons to start tuber formation. Kang and Han (2005) reported that the use of nitrogen in the nutrient solution increases the growth of potato crops. Also, results that the use of a nutrient solution including total nitrogen, phosphorus, potassium and magnesium increased the tuber yield by 13% per square meter. The presence of continuous nutrients around the plant roots in the hydroponic system leads to higher than expected efficiency in comparison with potato soil cultivation (Brianna, 2006). Hassanpanah (2014a) with investigate potential production of mid-late maturing promising mini-tuber clones and cultivars, resulted the mid-late maturity promising clones of 397081-1 and 397009-3 produced higher mini-tuber number per square meter (2766 and 2141 mini-tubers, respectively), mini-tuber weight per square meter (11400 and 16500 g, respectively) than the remaining types. Mid-late maturity promising clone of 397081-1 also produced higher mean mini-tuber weight per square meter (5.59 g) and plant height (174 cm) as compared with the others. The differences per square meter in the number of mini-tuber of mid-late maturing promising clones of 397081-1 and 397009-3 with Agria cultivar were about 1166 and 541, respectively. Hassanpanah (2014b) by investigation different nutrient solutions effects on Agria potato mini-tubers production under aeroponic system concluded between nutrient solutions were significant on mini- tubers numbers and mini-tubers weight per square meter and plant height. Maximum mini-tubers weight per square meter (11074 g), mini-tuber weight per plant (8.64 g) and plant height (87 cm) were observed in Lommen and Struik nutrient solution. Sulfur and Silicon increases the plants tolerance to drought, cold and heat stresses (Tate, 1995; Kaya et al., 2006; Wang et al., 2016). Silicon and Potash increases the number and strength of stems and the plant's resistance to sucking insects (Grami & Tarabipour, 2021). Silicon increases tuber yield (Kaya et al., 2006; Shahabifar, 2006; Ansuriet al., 2014; Golmoradi Marani et al., 2017; Gerami & Torabipoor, 2021; Hassanpanah et al., 2022). Hassanpanah et al. (2022) by examining the effect of sulphonated silicon nutrient solution with elemental sulfur S8 on potato cultivars, they concluded the use of sulfonated silicon nutrient solution with elemental sulfur S-8 in two forms of foliar spraying at a rate of 3 per thousand and use of 2 kg of solution in 200 liters of water increased tuber yield and water use efficiency.More number of mini-tubers per plant can be produced by repeating one or more harvests during the season (Lommen & Struik, 1992a, 1992b, 1992c; Lommen, 1995), dense planting in a greenhouse bed (Jones, 1988), hydroponic (Muro et al., 1997; Rolot & Seutin, 1999), aeroponics (Rolot & Seutin, 1999; Nugaliyadde et al., 2005; Kang & Han, 2005; Farran & Mingo-Castel, 2006; Hassanpanah, 2014) and nutrient solution (Gunasena & Harris, 1968; Balamani et al., 1986; Kang & Han, 2005; Brianna, 2006; Hassanpanah, 2014a, 2014b). This research aims to increase the mini-tuber number and weight per unit areaby using sulphonated silicon nutrient solution with elemental sulfur S8 in potato cultivars and transferring experience and knowledge and new technologies to potato mini-tubers producers for Ardabil province, Iran was implemented during 2022.

2. Material and Methods

This study with aims to investigate the effect of nutrient solution sulfonated silicon with elemental sulfur S8 in the mini-tuber production in potato cultivars in the greenhouse of Potato Research Station of Ardabil Province, Iran was done during April till August of 2022. This experiment was carried out based on the factorial experimental design in two factors and three repetitions. The first factor with two levels including: 1. foliar spraying with nutrient solution sulfonated silicon with elemental sulfur S8 and 2. Control (without nutrient solution sulfonated silicon with elemental sulfur S8) and the second factor consists of micro-tubers of five cultivars in the name of Agria, Jelli, Anosha, T297 and Sheida. The foliar spraying with S-8 nutrient solution was done in five stages of vegetative growth, plant growth and development, tuberization, flowering and tuber development and tuber bulking. In each time in the amount 7.5 ml of nutrient solution per one liter of water sprayed on the plants. 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 micro-tubers obtained from the *in vitro* of potato cultivars were produced in the tissue culture laboratory, then transferred to the greenhouse and cultivated in the planting bed. In each square meter, 100 micro-tubers were planted at a distance of 10 × 10 cm. The water required by plants was done based on the plant's needs and by the method of tape irrigation. The pH of the nutrient solution was set at 5.8.Gramaxon (Paraquat) poison was used at the rate of 0.3 mm per square meter to remove weeds a few days before planting potato micro-tubes. Confidor (Imidacloprid) poison was used in the amount of 2.5 mm per square meter on three occasions to fight against the carriers of viral diseases. Soiling of the plant was done at the height of the plant between 10 till 20 cm with a suitable amount of soil. At the time of planting, in both nutrient solution treatments, were used ammonium nitrate and ammonium phosphate fertilizers of 7.5 grams per square meter each as basic fertilizers. NPK fertilizer (20-20-20) in four times (1-plant growth; 2-plant development; 3-during tuber formation; 4-flowering and tuber development) in both nutrient solution treatments, in each time in the amount of 2 grams per liter was sprayed on the plants. During the growth period, mini-tuber number per square meter, mini-tuber number per plant, mini-tuber weight per square meter and plant height were measured. For data analysis, the normality test of data distribution was performed by Kolmogorov-Smirnov test. Analysis of variance was performed using SAS 9.1 statistical software. Comparison of mean traits was compared using LSD test at 5% probability level. Minitab16 software was used to calculate factor analysis and cluster analysis by Ward method.

3. Results and Discussion

The results of analysis of variance showed that there was a significant difference between the different levels of nutrient solution, cultivars and the interaction between nutrient solution and cultivars in terms of mini-tuber number per square meter, mini-tuber number per plant, mini-tuber weight per square meter and plant height at the level of 1% probability (Table 1).

Anosha cultivar had the highest values in terms of mini-tuber number per square meter, tuber number per plant and mini-tuber weight per square meter traits by using nutrient solution and was placed in the group A (Table 2). The Agria, Jelli, Sheida and T297 cultivars were placed in the group B and had the highest amount by using nutrient solution in terms of these characteristics (Table 2). The Agria, Jelli and Anosh cultivars had the highest plant height by using nutrient solution and were placed in group A (Table 2).

Traits of mini-tuber number per square meter, tuber number per plant, mini-tuber weight per square meter and plant height had the most value in treatments of foliar spraying on the plants with nutrient solution amount 7.5 ml per liter in five stages (Table 2).

Table 1. Variance analysis of evaluated traits in cultivars and nutrient solution levels

S.O.V.	D.F.	Mean of squares			
		Mini-tuber No. per square meter	Mini-tuber No. per plant	Mini-tuber weight per square meter	Plant height
Nutrient solution (A)	1	1989187.5**	198.92**	16619.71**	63756.30**
Cultivars (B)	1	40662.45**	4.066**	4.30**	4400.70**
A × B	1	45710.25**	4.57**	147.01**	3609.80**
Error	22	9000	0.887	32.40	1000.0
C.V. (%)		13.19	13.99	16.22	22.74

Note. ns: non-significant; * and **: significant at the 5 and 1%, probability levels, respectively.

Table 2. Mean of quantitative traits in cultivars and nutrient solution levels

Nutrient solution	Cultivars	Mini-tuber No. per square meter	Mini-tuber No. per plant	Mini-tuber weight per square meter (kg)	Plant height (cm)
With nutrient solution	Agria	900 b	9.00 b	54.00 b	178 a
	Jelli	978 b	9.78 b	58.68 b	175 a
	Anosha	1256 a	12.56a	75.36 a	160 a
	Sheida	880 b	8.80 b	52.80 b	88 bc
	T297	872 b	8.72 b	52.32 b	98 b
No nutrient solution (Control)	Agria	490 c	4.90 c	12.25 c	54 bcd
	Jelli	540 c	5.40 c	13.50 c	59 bcd
	Anosha	431 c	4.31 c	10.78 c	53 bcd
	Sheida	411 c	4.11 c	10.28 c	34 d
	T297	439 c	4.39 c	10.98 c	38 cd

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

Based on the results of factor analysis, Anosha and Jelli cultivars by foliar spraying with nutrient solution had the highest values in terms of mini-tuber number per square meter, tuber number per plant, mini-tuber weight per square meter and plant height (Figure 1). In the next group, Agria cultivar and T297 and Sheida cultivars by using nutrient solution were (Figure 1). According to Table 3, mini-tuber number per square meter, tuber number per plant and mini-tuber weight per square meter with the first factor and61.3% variance and plant height with the second factor and38.4% variance was justified (Table 3).

Based on the results of cluster analysis by Ward method, the grouping was placed as follow: in the first group Agria, Jelli, Anosha, T297 and Sheida cultivars by using nutrient solution. The second group was placed as follow: Agria, Jelli, Anosha, T297 and Sheida cultivars in control (without using nutrient solution) (Figure 2). The treatments of by using nutrient solution in Agria, Jelli, Anosha, T297 and Sheida cultivars had the highest amountin the first group, in terms of mini-tuber number per square meter, tuber number per plant, mini-tuber weight per square meter and plant height 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 of mini-tubers (Table 4).

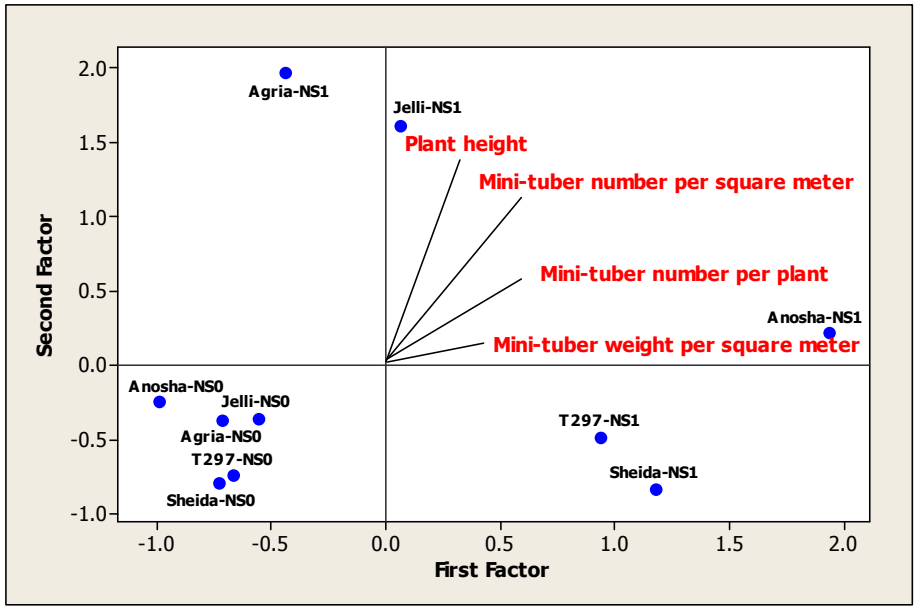

Figure 1. Biplot of factor analysis in cultivars and nutrient solution levels

Table 3. Factors values in evaluated traits in cultivars and nutrient solution levels

Traits	Factor 1	Factor 2
Mini-tuber No. per square meter	**0.859**	0.512
Mini-tuber No. per plant	**0.859**	0.512
Mini-tuber weight per square meter	**0.845**	0.523
Plant height	0.513	**0.859**
Eigen value	2.4501	1.5343
Variance (%)	61.3	38.4

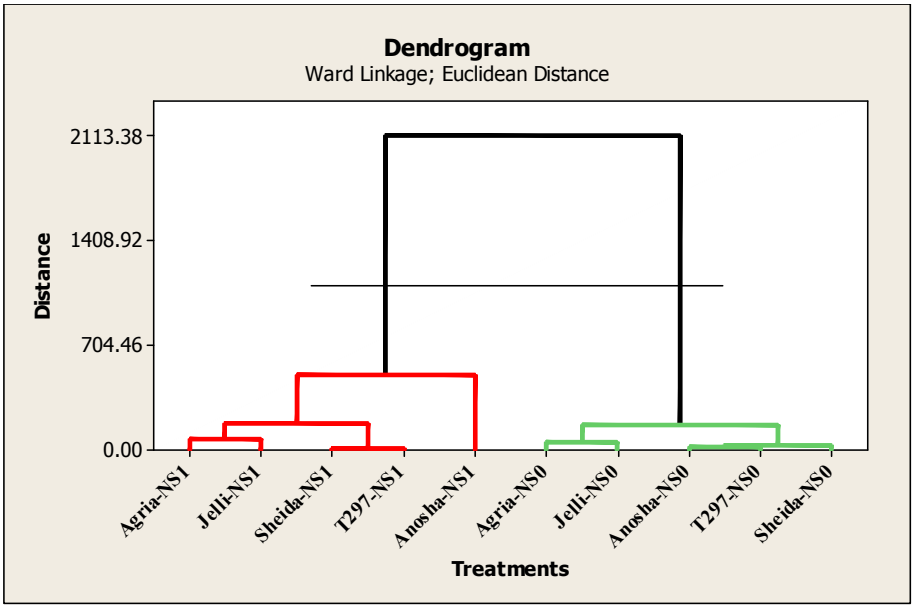

Figure 2. Grouping of treatments based on all studied traits using Ward method

Table 4. Deviation of the mean of each group from the total mean in the evaluated traits and studied treatments

Traits	**Cluster 1**	**Cluster 2**
Mini-tuber No. per square meter	**257.5**	-257.5
Mini-tuber No. per plant	**2.575**	-2.575
Mini-tuber weight per square meter	**23.539**	-23.538
Plant height	**46.1**	-46.1

Based on the results, using sulfonated silicon nutrient solution with elemental sulfur S8with a dose of 7.5 ml per liter of water per in square metersin the form of foliar spraying infive stages of vegetative growth, plant growth and development, tuberization, flowering and tuber development and tuber bulking causing an increase mini-tuber number per square meter (515 number), mini-tuber number per plant (5 number), mini-tuber weight per square meter (47 kg) and plant height (92 cm) became (Table 5). Otazu (2010) reported each potato cultivar may have different nutritional needs. Silicon increases potato yield (Kaya et al., 2006; Shahabifar, 2006; Ansuri et al., 2014; Golmoradi Marani et al., 2017; Gerami & Torabipoor, 2021; Hassanpanah et al., 2022). Hassanpanah et al. (2022) results use of sulphonated silicon nutrient solution with elemental sulfur S8 on potato cultivars, increases tuber yield and water use efficiency. More number of mini-tuber using suitable nutrient solution was also reported by Gunasena and Harris (1968), Balamani et al. (1986), Kang and Han (2005), Brianna (2006), Hassanpanah (2014a, 2014b, 2022).

Table 5. Increasing quantitative traits in treatments of cultivars and nutrient solution levels

Cultivars	Mini-tuber No. per square meter	Mini-tuber No. per plant	Mini-tuber weight per square meter (kg)	Plant height (cm)
Agria	410	4.10	41.75	124
Jelli	438	4.38	45.18	116
Anosha	825	8.25	64.58	107
Sheida	469	4.69	42.52	54
T297	433	4.33	41.34	60
Mean	515	5.00	47.00	92

4. Conclusion

The using sulfonated silicon nutrient solution with elemental sulfur S8 with a dose of 7.5 ml per liter of water per in square meters in the form of foliar spraying in five stages of vegetative growth, plant growth and development, tuberization, flowering and tuber development and tuber bulking increased mini-tuber number and weight per square meter.

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