Middle East Journal of Agriculture Research
ISSN 2077-4605
Volume : 04 | Issue : 04 | Oct.-Dec. | 2015
Pages: 1047-1064

Spraying potassium silicate and sugar beet molasses on tomato plants minimizes transpiration, relieves drought stress and rationalizes water use

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ABSTRACT

Transpiration is a physiological phenomenon in which water is lost from the plants in the form of water vapors. Under the global shortage of water, transpiration reduction is an efficient and a necessary procedure for conserving irrigation water with keeping the plant survival and protecting foliage against drought harms and consequently increasing water productivity. One of the main strategies to reduce the transpiration rate and reduce the deleterious impacts of drought stress is the foliar application of antitranspirants. The impacts of foliar application of five antitranspirants (potassium silicate, sugar beet molasses, kaolin, abscisic acid, or linseed oil) as well as water-sprayed plants on growth, some physiological parameters, yield components and water use efficiency of tomato plants cv. 023 grown under three irrigation levels (100, 80 or 60% of the estimated crop evapotranspiration, ETc) were studied. The field experiment was conducted during 2014 and 2015 seasons at the Experimental Farm of Horticulture Department, Faculty of Agriculture, Ain Shams University, Shoubra El Kheima, Qalyubia Governorate, Egypt. Results revealed that decreasing irrigation level from 100% to 60% of ETc reduced the vegetative growth parameters, SPAD readings, leaf relative water content, leaf osmotic potential, N, P, K and Ca percentages in leaves, yield components, and water use efficiency, while leaf electrolyte leakage was increased in both growing seasons. Foliar applications of antitranspirants exhibited varying responses in relation to alleviating of the negative effects of drought stress. Potassium silicate and sugar beet molasses were the most effective antitranspirants for attenuating the severity of water deficit. On the contrary, both ABA and linseed oil had significant inhibitory effects on some parameters, while kaolin had moderate and neutral effects. In conclusion, potassium silicate or sugar beet molasses can be used as effective antitranspirants and ameliorative substances for alleviating the hazardous effects of water deficit on tomato plants.

Key words: *Solanum lycopersicum*, Potassium silicate, Sugar beet molasses, Kaolin, Abscisic acid, Linseed oil, water use efficiency

Maximizing the productivity of the crops from the available irrigation water, particularly in arid and semi-arid regions, is a sustainable target for several agricultural researches (Singh *et al.*, 2014; Al-Mansor *et al.*, 2015) especially since the agriculture is the main consumer of the freshwater. Meanwhile, the freshwater quantity for human health and enterprise is constant and represents less than 1% of the available freshwater worldwide (FAO, 2011). Hence, growing the global shortage of fresh water quantity requires more rational use of the water in agriculture through adopting new agricultural production forms lead to saving and raising the productivity of the water.

Tomato (*Solanum lycopersicum* L.) is one of the most planted vegetable crops in Egypt, since its production area was 205276 ha with a total production of 8290551 tons and an average yield of 44.52 tons ha^{-1} (FAOSTAT, 2013). It is grown along the year in different conditions of soil types, irrigation water quality and quantity and environmental conditions. Tomatoes consume large quantities of water in semi-arid and arid climate conditions where water availability is an important constraint for plant growth and productivity. Furthermore, tomato plants are sensitive to water stress (Nuruddin *et al.*, 2003) which affects growth and productivity of tomato, since 15 and 30% of irrigation reductions reduced gross revenue by 15 and 22%, respectively (Obreza *et al.*, 1996). Wherever the water constituents about 90% of the plant weight and 97% of the absorbed water is lost in the process of transpiration (Nobel, 2009), therefore, a reduction of transpiration will contribute efficiently for saving water then rising transpiration efficiency which is defined as the quantity of water consumed in transpiration equivalent to the production of dry matter units (Glickman, 2000). To

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cope with the negative effects of water deficit in tomato plants, numerous strategies have been proposed. Among these strategies, foliar applications of antitranspirants are used to reduce the transpiration rate and reduce these deleterious impacts of drought stress (del Amor *et al.*, 2010; Degif and Woltering, 2015).

Based on the mode action, antitranspirants have been classified as (del Amor *et al.*, 2010; Degif and Woltering, 2015): 1) film forming antitranspirants like linseed and silicone oils that hinder the escape of water vapor from the leaves, 2) reflecting types of antitranspirants like calcium carbonate and magnesium carbonate that reduce the absorption of the radiant energy and thereby reduce leaf temperatures and thus transpiration rate, and 3) metabolic inhibitors like abscisic acid and phenyl mercuric acetate that prevent stomata from opening fully decreasing the loss of water vapor from plant leaves.

Therefore, this work is interested in reducing the transpiration rate to alleviate the drought stress *via* evaluation and comparing the efficiency of five antitranspirants, i.e. potassium silicate, sugar beet molasses, kaolin, abscisic acid and linseed oil as well as control (water spraying), in attenuating the unfavorable effect of drought stress on tomato plants.

Materials and Methods

Experimental site and plant material

The field experiment was conducted during 2014 and 2015 seasons at the Experimental Farm of Horticulture Department, Faculty of Agriculture, Ain Shams University, Shoubra El Kheima, Qalyubia Governorate, Egypt (30°06′46″N, 31°14′37″E). According to soil analysis results, soil texture of the experimental site was a sandy loam. Annual precipitation was negligible through the two growing seasons. Nile River (located in the experimental area) is the source of irrigation water with pH about 7.4 and an average EC 0.66 dS m^{-1}.

Tomato (*Solanum lycopersicum* L.) cv. 023 used in this study was produced by Sakata Company, Japan, and imported by Gaara Seeds Company, Egypt. Tomato seedlings at four-leaf stage were transplanted at a distance of 50 cm between plants and 150 cm between rows on the 20^{th} and 22^{nd} March in the first and second season, respectively.

Experimental treatments and design

The experimental design was a split plot with four replications. The treatments included three irrigation levels (100, 80 or 60% of the estimated crop evapotranspiration, ETc) which were randomly distributed in the main plots and five antitranspirant substances (potassium silicate, sugar beet molasses, kaolin, abscisic acid, or linseed oil) as well as water-sprayed plants as control which also were randomly distributed in the sub-plots.

The irrigation was performed through drip irrigation system and was regularly undertaken every three days because of the higher water holding capacity of the soil. Irrigation levels were applied during all growth stages starting from the establishing stage (20 days after transplanting date). The ETc values were calculated using the Penman-Monteith equation ($ETc = ET_o \times kc$) as presented by FAO which is recognized as the most reliable method for calculating the ETc all over the world (Smith and Steduto, 2012). The reference evapotranspiration (ET_0) values were calculated by a class-A evaporation pan obtained from the nearest Metrological Station in Bahtim, Shoubra El Kheima, Qalyubia Governorate, Egypt. The kc values were used as proposed by Doorenbos and Kassam (1979) and described in Table 1.

Table 1. The Kc values of tomato during different growth stages.

Items	Growth stages of tomato			
	Initial stage	Developmental stage	Middle growth season	Late stage
No. of days/ stage	25	30	40	25
ET_o (mm/day)	4.9	5.1	5.9	6.8
Crop coefficient (Kc)	0.6	0.88	1.15	0.9

Potassium silicate (11% silicon and 60% K_2O) at 2000 ppm, sugar beet molasses at 5 ml l^{-1}, kaolin (95% kaoline and 5% inter ingredients) at 5%, abscisic acid at 50 ppm, or linseed oil at 10 ml l^{-1} were foliar sprayed. The selection of the concentrations of used antitranspirants was based on the previous studies. The control plants were sprayed with distilled water. All foliar sprayings were carried out to cover completely the whole plant foliage early in the morning. Foliar sprayings were applied four times at 2-week intervals, started after three weeks from transplanting and stopped 60 days afterward.

The experiment involved 18 treatments (three irrigation levels and six antitranspirant substances). The experimental plot consisted of three rows; each was 6 m in long and 1.5 m in wide so the plot area was 27 m^2. All experimental plots were separated by a water barrier sheet to prevent water leakage between them. For two weeks after transplanting, all plots were well irrigated, then irrigation treatments were applied.

All cultural practices (fertilization, weed control, and pest and disease control) were carried out as recommended by the Egyptian Ministry of Agriculture for tomato production during growth season under the experimental site conditions.

Data recorded

Vegetative growth parameters

After 60 days from transplanting date, five plants were randomly selected from each experimental plot and uprooted then immediately transferred to the Lab. for measuring stem length, stem diameter, number of branches and number of leaves per plant. Afterwards, the plants were bagged in paper bags and were dried at 70°C in an aerated oven until weight constancy then the plant dry weight was calculated.

Leaf parameters

After 50 days from transplanting date, five full expanded leaves (the fourth leaves from plant apex) for each parameter for each experimental plot were used to measure the following parameters:

Average leaf area was measured on detached leaves as a relation between area unit and fresh weight of leaves (Koller, 1972) using the following equation:

$$\text{Leaf area} = \frac{\text{Disk area x No. of disks x fresh weight of leaves}}{\text{Fresh weight of disks}}$$

Leaf chlorophyll readings (SPAD) were measured on attached leaves using a portable chlorophyll meter (SPAD–502, Konica Minolta Sensing, Inc., Japan).

Leaf relative water content (RWC) was measured on fully expanded leaves according to the method of Barrs and Weatherley (1962). Fresh weight (FW) was immediately recorded, and then leaves were immediately soaked for 4 hours in distilled water at room temperature under a constant light and saturated humidity to record turgid weight (TW). The samples were then dried for 24 hours at 80 ºC for recording dry weight (DW). Relative water content (RWC) was calculated by the following formula:

$$\text{RWC (\%)} = \frac{FW - DW}{TW - DW} \times 100$$

Leaf electrolytes leakage was measured according to Bajji *et al.* (2002). Fully expanded leaves were taken and then were cut into discs of 1 cm^2. Thirty discs were put into a 100 ml flask then washed slowly three times by deionized distilled water to remove surface adhered electrolytes. The leaf discs were submerged in a 30 ml solution of polyethylene glycol (PEG 600) for a certain period at 10°C in the dark to minimize secondary effects. The concentration of the PEG solution, as well as the duration, were adjusted to reach the severity of desiccation desired. After that, the leaf discs were quickly washed for three times with deionized distilled water. Thirty ml of deionized distilled water were then added and kept for 24 hours at 10°C in the dark. Then the flask was warmed to 25°C, shaken well and the electrical conductivity (ECi) was measured. After measuring the electrical conductivity, the leaf tissues were killed *via* electrical conductivity (ECt) was re-measured. The value of electrical leakage (EL) is calculated using the following equation:

EL = (ECi/ECt-Ci/Ct) X 100
Where ECi is the initial electrical conductivity, ECt is the total electrical conductivity, Ci is the initial electrical conductivity of non-desiccated control, and Ct is the total electrical conductivity of the control.

Osmotic potential of the leaf press sap was determined according to Hussin (2007). The osmotic potential was measured relaying on the freeze-point depression method using an Osmometer (Osmomat 030, Genotec GMBH, Berlin). A 300 mOsmol NaCl solution was used as a standard, and the calibration was checked after every ten readings. The readings were then converted to pressure units according to a conversion table as described by Koyro (2003).

Leaf nitrogen, phosphorus, potassium and calcium contents

After 50 days from transplanting date, samples of fully expanded leaves were taken to analyze some macronutrients in tomato leaves. Samples were dried at 70 °C until a constant weight and then milled to a fine powder. A sample of 0.1 g of the dry samples was taken and digested using a mixture of sulphuric acid (H_2SO_4 98 %) and hydrogen peroxide (H_2O_2 30 %) as described by Allen (1974). All the measured nutrients were assayed in the digest of the concerned plant samples. Total nitrogen was determined using the Kjeldahl method as described by Piper (1950). Phosphorus content was spectrophotometrically measured according to Watanabe and Olsen (1965). Potassium and calcium contents were determined as described by Chapman and Pratt (1961).

Yield components

The fruits were harvested four times during three weeks. Average fruit weight, number of fruits/plant and fruit yield/plant were calculated.

Water use efficiency

Water use efficiency (WUE) was expressed as kg fruits per cubic meter of irrigation water (Howell, 2001).

Statistical analysis

All data were subjected to an analysis of variance using the CoStat package program (version 6.303; CoHort Software, USA). The differences among main effects were compared by Duncan's Multiple Range Test, while the differences among interactions effects were separated using least significance difference (LSD). All statistical determinations were made at $p \leq 0.05$.

Results

Vegetative growth parameters

Reducing irrigation level from 100% to 60% of ETc decreased the vegetative growth parameters, i.e. stem length, stem diameter, number of branches/plant, number of leaves/plant, and plant dry weight of tomato plants in both growing seasons (Table 2).

Results also revealed that the above-mentioned vegetative growth parameters appeared to be affected by foliar application of antitranspirants. Potassium silicate or sugar beet molasses sprayings significantly increased all measured growth parameters compared with the control plants in both growing seasons. Potassium silicate spraying was more effective than sugar beet molasses as an antitranspirant. On the other hand, Kaolin, abscisic acid, or linseed oil sprayings did not show any significant differences for the vegetative growth parameters compared with the control plants in both seasons.

Concerning the interaction effect, data in Table 2 demonstrated a clear interactive effect between irrigation levels and foliar spraying with antitranspirant substances. Under full irrigation

(100% of ETc) and both irrigation deficit conditions (80 and 60% of ETc), potassium silicate sprayings surpassed the rest of antitranspirants in improving all vegetative growth characteristics as compared with the control plants in both seasons. Compared with the water-sprayed plants grown under full irrigation, sprayings with different types of antitranspirant, except for linseed oil for number of leaves/plant and ABA for plant dry weight, combated the negative effects of reducing irrigation to 80%. On the other hand, spraying with potassium silicate, sugar beet molasses, or kaolin ameliorated the adverse effects of irrigation reduction to 60% ETc. These obtained results indicated that potassium silicate, sugar beet molasses, or kaolin seemed to be the most effective antitranspirants for attenuating the severity of water deficit. On the contrary, both ABA and linseed oil had significant inhibitory effects on stem length, stem diameter, number of leaves/plant and plant dry weight with reducing water deficit to 60% ETc.

Leaf area

Data in Table 3 obviously revealed that decreasing irrigation level reduced leaf area of tomato plants in both growing seasons. Leaf area reduction was increased with increasing drought severity.

As for the effect of antitranspirant spraying, potassium silicate or sugar beet molasses sprayings significantly increased leaf area compared with the other treatments in both seasons.

Concerning the interaction effect, the data demonstrated that potassium silicate or sugar beet molasses sprayings on plants grown under full irrigation or water deficit significantly increased leaf area as compared with the respective control plants. Compared with the water-sprayed plants grown under full irrigation, potassium silicate, sugar beet molasses, or kaolin sprayings attenuated the negative effects of 80% ETc, while potassium silicate or sugar beet molasses sprayings alleviated the negative effects of 60% ETc.

Leaf SPAD readings

As shown in Table 3, SPAD readings were not influenced by reducing irrigation from 100% to 80%, while reducing irrigation level to 60% reduced leaf SPAD readings in both seasons.

Concerning the foliar application of antitranspirants, potassium silicate or sugar beet molasses sprayings significantly improved leaf SPAD readings compared with the other treatments.

As for the interaction effects, the results indicated that spraying tomato plants with potassium silicate significantly increased SPAD readings compared with the respective control under 100 or 80% of ETc, while plants grown under 60% of ETc exhibited increased readings of SPAD when sprayed with potassium silicate or sugar beet molasses compared with the respective control in both growing seasons.

Leaf relative content

Results in Table 3 clearly revealed that decreasing irrigation level reduced leaf relative water content of tomato plants in both growing seasons.

As for the effect of antitranspirant potassium silicate, sugar beet molasses or kaolin sprayings significantly improved the water relative content compared with the water-sprayed plants, while ABA or linseed oil sprayings significantly diminished the relative water content of tomato leaves.

Concerning the interaction effects, potassium silicate or sugar beet molasses applications significantly improved leaf relative water contents of tomato plants grown under full and mild irrigation conditions (100 and 80% of ETc), while spraying of potassium silicate, sugar beet molasses or kaolin improved relative water content of tomato leaves under 60% of ETc as comparison with the respective control. Moreover, it is noted that ABA and linseed oil treatments had depressed effects under water deficit conditions.

Leaf electrolyte leakage

Data in Table 3 evidently demonstrated that increasing the severity of water deficit led to increases in leaf electrolyte leakage.

Table 2. Effect of foliar spraying of some antitranspirants on stem length, stem diameter, number of branches/plant and number of leaves/plant of tomato plants grown under different irrigation levels in 2014 and 2015 seasons.

Treatments		Stem length (cm)		Stem diameter (cm)		Number of branches/plant		Number of leaves/plant		Plant dry weight (g)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation levels[a]											
100% ETc		66.15a	69.77a	1.36a	1.45a	4.75a	5.89a	48.24a	59.58a	26.13a	26.43a
80% ETc		63.28b	66.99b	1.30b	1.39b	4.06b	5.21b	44.16b	55.12b	25.17b	25.41b
60% ETc		58.40c	62.27c	1.20c	1.27c	3.84b	4.99b	37.98c	48.33c	23.55c	24.03c
Antitransparents[a]											
Potassium silicate (K_2SiO_3)		68.30a	71.84a	1.41a	1.50a	4.91a	6.05a	47.29a	58.54a	26.99a	27.24a
Sugar beet molasses		64.28b	67.96b	1.35ab	1.44ab	4.45ab	5.59ab	45.29ab	56.34ab	26.10a	26.42a
Kaolin		62.96bc	66.68bc	1.30bc	1.38bc	4.26b	5.40b	43.29bc	54.17bc	24.63b	25.03b
Abscisic acid (ABA)		61.26cd	65.04cd	1.24cd	1.32cd	3.88b	5.03b	41.67c	52.38c	23.60c	24.07c
Linseed oil		58.64d	62.51d	1.17d	1.25d	3.96b	5.11b	41.51c	52.20c	24.03bc	24.49bc
Water-sprayed (Control)		60.22cd	64.03cd	1.25cd	1.33cd	3.84b	4.99b	41.71c	52.43c	24.04bc	24.49bc
Irrigation level X Antitransparents[b]											
100% ETc	**K_2SiO_3**	72.01	75.44	1.49	1.58	5.44	6.58	51.43	63.10	28.60	28.73
	Sugar beet molasses	67.30	70.88	1.41	1.50	5.11	6.25	50.00	61.50	27.23	27.47
	Kaolin	66.17	69.78	1.34	1.43	4.87	6.01	47.77	59.07	25.67	26.00
	ABA	64.89	68.55	1.33	1.41	4.31	5.45	47.57	58.83	24.83	25.23
	Linseed oil	62.21	65.96	1.28	1.36	4.56	5.70	46.77	57.97	24.73	25.13
	Control	64.33	68.01	1.32	1.40	4.22	5.37	45.90	57.00	25.73	26.03
80% ETc	**K_2SiO_3**	69.40	72.91	1.40	1.49	4.93	6.07	48.00	59.30	27.17	27.43
	Sugar beet molasses	64.07	67.75	1.37	1.46	4.10	5.25	46.43	57.60	26.20	26.53
	Kaolin	62.67	66.40	1.31	1.40	4.00	5.15	44.77	55.80	24.57	24.97
	ABA	62.68	66.41	1.29	1.38	3.67	4.82	43.10	53.97	23.73	24.20
	Linseed oil	59.86	63.68	1.18	1.26	3.78	4.93	41.00	51.63	24.50	24.93
	Control	60.99	64.78	1.26	1.34	3.87	5.02	41.67	52.43	23.93	24.40
60% ETc	**K_2SiO_3**	63.48	67.18	1.34	1.43	4.34	5.49	42.43	53.23	25.20	25.57
	Sugar beet molasses	61.47	65.24	1.26	1.34	4.14	5.29	39.43	49.93	24.87	25.27
	Kaolin	60.03	63.85	1.23	1.32	3.90	5.05	37.33	47.63	23.67	24.13
	ABA	56.22	60.17	1.11	1.18	3.67	4.82	34.33	44.33	22.23	22.77
	Linseed oil	53.86	57.88	1.07	1.14	3.56	4.71	36.77	47.00	22.87	23.40
	Control	55.33	59.31	1.17	1.24	3.44	4.60	37.57	47.87	22.47	23.03
$LSD_{0.05}$[b]		**4.68**	**4.53**	**0.13**	**0.14**	**1.03**	**1.02**	**4.75**	**5.21**	**1.63**	**1.53**

[a]*Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.*
[b]*LSD applied to a comparison of the interactions between irrigation levels and antitranspirants.*

Table 3. Effect of foliar spraying of some antitranspirants on leaf area, SPAD readings, relative water content, electrolyte leakage and osmotic potential in the leaves of tomato plants grown under different irrigation levels in 2014 and 2015 seasons.

Treatments		**leaf area (cm^2)**		**Leaf SPAD readings**		**Leaf relative water content (%)**		**Leaf electrolyte leakage (%)**		**Osmotic potential (MPa)**	
		1st season	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**	**1st season**	**2nd season**
Irrigation levels[a]											
100% ETc		44.21a	41.01a	56.77a	49.71a	80.58a	77.06a	10.32c	11.32c	-0.71a	-0.69a
80% ETc		39.99b	37.49b	57.10a	50.02a	70.68b	68.24b	11.04b	11.93b	-0.76b	-0.72b
60% ETc		35.99c	34.15c	53.84b	46.90b	65.51c	63.64c	12.39a	13.08a	-0.82c	-0.76c
Antitransparents[a]											
Potassium silicate (K_2SiO_3)		44.89a	41.58a	59.31a	52.16a	77.20a	74.04a	10.52c	11.49c	-0.68a	-0.67a
Sugar beet molasses		44.03a	40.84a	58.11ab	51.00ab	76.71a	73.62a	10.67c	11.62c	-0.69a	-0.67a
Kaolin		39.90b	37.40b	55.74bc	48.72bc	73.33b	70.61b	11.11b	11.99b	-0.77b	-0.73b
Abscisic acid (ABA)		37.39bc	35.33bc	53.39c	46.45c	68.06d	65.90d	11.76a	12.55a	-0.82cd	-0.76cd
Linseed oil		36.50c	34.58c	54.37c	47.40c	67.71d	65.61d	12.04a	12.79a	-0.84d	-0.77d
Water-sprayed (Control)		37.67bc	35.56bc	54.49c	47.52c	70.52c	68.11c	11.39b	12.23b	-0.79bc	-0.74bc
Irrigation level X Antitransparents[b]											
100% ETc	**K_2SiO_3**	49.00	45.00	59.73	52.57	86.37	82.20	9.72	10.81	-0.68	-0.67
	Sugar beet molasses	47.30	43.57	58.27	51.17	84.50	80.57	9.81	10.89	-0.79	-0.74
	Kaolin	43.50	40.40	56.83	49.77	80.77	77.23	10.09	11.12	-0.85	-0.78
	ABA	41.67	38.90	54.93	47.93	77.37	74.20	10.76	11.70	-0.88	-0.81
	Linseed oil	41.37	38.63	55.40	48.40	76.20	73.16	11.38	12.22	-0.89	-0.81
	Control	42.43	39.53	55.43	48.43	78.27	75.00	10.16	11.19	-0.83	-0.77
80% ETc	**K_2SiO_3**	45.70	42.27	60.97	53.73	77.10	74.17	10.28	11.28	-0.69	-0.67
	Sugar beet molasses	44.50	41.23	59.57	52.40	76.23	73.34	10.43	11.42	-0.68	-0.66
	Kaolin	40.07	37.53	55.83	48.80	73.37	70.63	11.05	11.94	-0.77	-0.73
	ABA	37.23	35.20	54.67	47.67	65.70	63.80	11.29	12.15	-0.82	-0.76
	Linseed oil	35.63	33.87	55.70	48.67	65.63	63.77	11.47	12.30	-0.86	-0.78
	Control	36.80	34.83	55.87	48.83	69.03	66.80	11.70	12.50	-0.76	-0.72
60% ETc	**K_2SiO_3**	39.97	37.47	57.23	50.17	70.13	67.77	11.57	12.39	-0.68	-0.67
	Sugar beet molasses	40.30	37.73	56.50	49.43	70.40	68.00	11.75	12.54	-0.61	-0.62
	Kaolin	36.13	34.27	54.57	47.60	65.87	63.97	12.20	12.92	-0.68	-0.67
	ABA	33.27	31.90	50.57	43.77	61.10	59.70	13.24	13.80	-0.74	-0.71
	Linseed oil	32.50	31.23	52.00	45.13	61.30	59.90	13.28	13.84	-0.76	-0.72
	Control	33.77	32.30	52.17	45.30	64.27	62.53	12.30	13.00	-0.77	-0.73
$LSD_{0.05}$[b]		**4.40**	**3.66**	**4.17**	**4.01**	**2.55**	**2.26**	**0.54**	**0.46**	**0.07**	**0.05**

[a]*Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.*
[b]*LSD applied to a comparison of the interactions between irrigation levels and antitranspirants.*

Regarding the spraying of antitranspirants, the results revealed that potassium silicate or sugar beet molasses spraying significantly reduced leaf electrolyte leakage, while spraying of ABA or linseed oil significantly increased electrolyte leakage of leaves compared with the water-sprayed plants in both growing seasons.

As for the interactions, spraying of antitranspirants did not affect leaf electrolyte leakage under full irrigation conditions in both growing seasons. On the contrary, potassium silicate, sugar beet molasses or kaolin sprayings significantly lowered leaf electrolyte leakage compared with the respective control under water-deficit conditions in both seasons.

Leaf osmotic potential

As shown in Table 3, decreasing irrigation level significantly lowered leaf osmotic potential in both growing seasons.

Concerning the spraying of antitranspirants, the results revealed that potassium silicate or sugar beet molasses spraying significantly attenuated the osmotic potential reductions. On the other hand, linseed oil significantly lowered leaf osmotic potential compared with the water-sprayed plants in both growing seasons.

As for the interactions, spraying of antitranspirants did not affect leaf osmotic potential under full irrigation conditions in both growing seasons. On the contrary, potassium silicate or sugar beet molasses under 80% of ETc, and potassium silicate, sugar beet molasses or kaolin sprayings significantly alleviated the osmotic potential reductions compared with the respective control in both seasons.

Leaf nitrogen, phosphorus, potassium and calcium percentages

Data in Table 4 obviously indicated that reducing irrigation level reduced nitrogen, phosphorus, potassium and calcium percentages in tomato leaves in both seasons. However, there was no significant difference between 100 and 80% of ETc for phosphorus percentages.

Regarding the spraying of antitranspirants, spraying of potassium silicate or sugar beet molasses significantly improved leaf nitrogen, potassium and calcium percentages compared with the water-sprayed plants in both seasons. Leaf phosphorus was not affected by antitranspirant spraying. On the other hand, linseed oil depressed nitrogen and potassium accumulation in leaves in comparison with the control plants in both seasons.

Under full irrigation conditions, potassium silicate spraying significantly increased nitrogen percentages, while spraying of potassium silicate or sugar beet molasses significantly improved leaf potassium and calcium percentages compared with the water-sprayed plants in both seasons. Similarly, plants grown under 80% of ETc and sprayed with potassium silicate or sugar beet molasses significantly accumulated more nitrogen, potassium and calcium than the control plants. Under severe irrigation deficit (60% of ETc), percentages of nutrients were not affected by antitranspirant spraying compared with the respective control. Moreover, phosphorus percentages were not influenced by spraying of different antitranspirants in all irrigation levels in both seasons.

Yield components

Results in Table 5 apparently revealed that decreasing irrigation level reduced tomato yield components, i.e. fruit weight, number of fruits/plant and fruit yield/plant in both growing seasons.

Except for linseed oil for fruit weight and ABA or linseed oil for fruit number and fruit yield, spraying with the rest of antitranspirants significantly increased yield components of tomato plants as compared with the water-sprayed plants. Potassium silicate and sugar beet molasses applications were the significant effective treatments. On the contrary, both ABA and linseed oil exhibited inhibitory effects on yield components.

Under full irrigation, fruit weight was not affected by antitranspirant spraying except for linseed oil, while potassium silicate and sugar beet molasses applications significantly improved fruit number and fruit yield per plant in both growing seasons. Under water deficit conditions (80 and 60% of ETc), potassium silicate and sugar beet molasses applications significantly increased all yield

Table 4. Effect of foliar spraying of some antitranspirants on nitrogen, phosphorus, potassium and calcium percentages of leaves of tomato plants grown under different irrigation levels in 2014 and 2015 growing seasons.

Treatments		N (%)		P (%)		K (%)		Ca (%)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation levels[a]									
100% ETc		1.72a	1.88a	0.85a	0.86a	1.18a	1.09a	0.97a	0.96a
80% ETc		1.60b	1.78b	0.80a	0.82a	1.06b	1.01b	0.87b	0.86b
60% ETc		1.37c	1.59c	0.70b	0.73b	0.93c	0.91c	0.76c	0.76c
Antitransparents[a]									
Potassium silicate (K_2SiO_3)		1.71a	1.87a	0.85a	0.86a	1.22a	1.13a	1.03a	1.01a
Sugar beet molasses		1.67ab	1.83ab	0.83ab	0.84ab	1.15a	1.07a	0.96a	0.95a
Kaolin		1.59bc	1.77bc	0.80ab	0.81ab	1.04b	0.99b	0.86b	0.85b
Abscisic acid (ABA)		1.48de	1.68de	0.74ab	0.77ab	0.96bc	0.93bc	0.78bc	0.78bc
Linseed oil		1.41e	1.63e	0.72b	0.75b	0.93c	0.91c	0.75c	0.75c
Water-sprayed (Control)		1.53cd	1.72cd	0.77ab	0.79ab	1.02b	0.98b	0.83bc	0.83bc
Irrigation level X Antitransparents[b]									
100% ETc	**K_2SiO_3**	1.86	1.99	0.92	0.91	1.34	1.21	1.20	1.17
	Sugar beet molasses	1.80	1.95	0.89	0.89	1.28	1.17	1.11	1.08
	Kaolin	1.73	1.89	0.86	0.86	1.15	1.08	0.97	0.96
	ABA	1.64	1.81	0.82	0.83	1.11	1.05	0.82	0.82
	Linseed oil	1.58	1.77	0.79	0.81	1.04	0.99	0.79	0.79
	Control	1.69	1.86	0.84	0.85	1.13	1.06	0.95	0.94
80% ETc	**K_2SiO_3**	1.76	1.91	0.87	0.88	1.25	1.15	1.01	0.99
	Sugar beet molasses	1.72	1.88	0.86	0.86	1.19	1.10	0.97	0.95
	Kaolin	1.66	1.83	0.84	0.85	1.07	1.01	0.84	0.84
	ABA	1.50	1.70	0.75	0.77	0.93	0.91	0.82	0.82
	Linseed oil	1.42	1.64	0.72	0.75	0.89	0.88	0.77	0.77
	Control	1.55	1.74	0.78	0.80	1.03	0.98	0.78	0.79
60% ETc	**K_2SiO_3**	1.50	1.70	0.75	0.78	1.08	0.98	0.87	0.87
	Sugar beet molasses	1.47	1.68	0.74	0.77	0.98	0.95	0.81	0.81
	Kaolin	1.37	1.60	0.69	0.73	0.92	0.90	0.75	0.76
	ABA	1.29	1.53	0.66	0.70	0.85	0.85	0.70	0.70
	Linseed oil	1.24	1.49	0.64	0.68	0.85	0.85	0.68	0.69
	Control	1.34	1.57	0.68	0.71	0.90	0.89	0.75	0.76
LSD $_{0.05}$[b]		**0.17**	**0.13**	**0.19**	**0.16**	**0.14**	**0.10**	**0.15**	**0.14**

[a]*Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \le 0.05$) according to Duncan's multiple range test.*
[b]*LSD applied to a comparison of the interactions between irrigation levels and antitranspirants.*

Table 5. Effect of foliar spraying of some antitranspirants on average fruit weight, number of fruits/plant, fruit yield/plant and water use efficiency of tomato plants grown under different irrigation levels in 2014 and 2015 growing seasons.

Treatments		Average fruit weight (g)		Number of fruits/plant		Fruit yield/plant (kg)		Water use efficiency (kg m^3)	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Irrigation levels[a]									
100% ETc		169.24a	155.40a	36.31a	36.76a	6.17a	5.73a	17.01a	16.80a
80% ETc		154.59b	143.68b	32.23b	33.13b	5.03b	4.79b	17.77b	17.56b
60% ETc		136.49c	129.19c	26.80c	28.30c	3.69c	3.68c	15.89c	16.87c
Antitransparents[a]									
Potassium silicate (K_2SiO_3)		163.72a	150.97a	36.19a	36.66a	5.98a	5.57a	20.61a	20.42a
Sugar beet molasses		163.50a	150.80a	35.63a	36.16a	5.88a	5.50a	20.26a	20.16a
Kaolin		155.70b	144.56b	31.87b	32.82b	5.03b	4.79b	17.33b	17.56b
Abscisic acid (ABA)		147.92c	138.34c	28.25c	29.59c	4.24c	4.14c	14.61c	15.17c
Linseed oil		138.18d	130.54d	27.61c	29.03c	3.86c	3.82c	13.30c	14.00c
Water-sprayed (Control)		151.63bc	141.31bc	31.10b	32.13b	4.77b	4.58b	16.44b	16.79b
Irrigation level X Antitransparents[b]									
100% ETc	**K_2SiO_3**	178.04	162.43	39.63	39.72	7.05	6.45	19.43	18.91
	Sugar beet molasses	177.67	162.13	40.67	40.64	7.23	6.59	19.93	19.33
	Kaolin	173.45	158.76	36.69	37.10	6.36	5.89	17.53	17.27
	ABA	163.65	150.92	33.73	34.47	5.52	5.20	15.21	15.25
	Linseed oil	153.33	142.67	30.93	31.98	4.74	4.56	13.07	13.37
	Control	169.33	155.47	36.20	36.67	6.13	5.70	16.90	16.72
80% ETc	**K_2SiO_3**	165.81	152.65	39.50	39.60	6.55	6.05	22.57	22.18
	Sugar beet molasses	165.50	152.41	36.77	37.18	6.09	5.67	20.99	20.78
	Kaolin	156.65	145.32	33.20	33.99	5.20	4.94	17.92	18.11
	ABA	150.90	140.72	26.51	28.05	4.20	3.95	14.47	14.48
	Linseed oil	136.78	129.43	27.02	28.50	3.70	3.69	12.75	13.53
	Control	151.90	141.52	30.38	31.49	4.62	4.46	15.92	16.35
60% ETc	**K_2SiO_3**	147.30	137.84	29.46	30.67	4.34	4.23	18.69	19.39
	Sugar beet molasses	147.33	137.87	29.47	30.67	4.34	4.23	18.69	19.39
	Kaolin	137.00	129.60	25.73	27.35	3.52	3.54	15.16	16.22
	ABA	129.22	123.37	24.51	26.27	3.19	3.26	13.74	14.94
	Linseed oil	124.42	119.53	24.89	26.27	3.14	3.22	13.52	14.76
	Control	133.67	126.93	26.73	28.24	3.57	3.59	15.37	16.45
LSD $_{0.05}$[b]		**12.59**	**10.07**	**3.39**	**3.02**	**0.73**	**0.61**	**2.50**	**2.01**

[a]*Means into every group within a column for the same factor followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.*
[b]*LSD applied to a comparison of the interactions between irrigation levels and antitranspirants.*

components except for fruit number/plant under 60% ETc which was no affected by antitranspirant sprayings. However, linseed oil exhibited the depressed effects on all yield components under 100 and 80% ETc. Moreover, it is worth mentioning that yield components of plants grown under 80% of ETc and sprayed with potassium silicate or sugar beet molasses were similarly as those of water-sprayed plants grown under full irrigation.

Water use efficiency

Data in Table 5 clearly demonstrated that water use efficiency was significantly reduced with increasing water-deficit level in both growing seasons.

As for the spraying of antitranspirants, results in Table 5 revealed that spraying of potassium silicate or sugar beet molasses significantly increased the efficiency of water use compared with the water-sprayed plants in both seasons. On the contrary, ABA or linseed oil sprayings significantly reduced the efficiency of water use.

Concerning the interaction effects, potassium silicate or sugar beet molasses applications significantly improved the efficiency of water use compared with the water-sprayed plants under every individual level of irrigation in both seasons. On the other hand, linseed oil diminished the efficiency of water use under 100 and 80% of ETc. Furthermore, it is noted that spraying of stressed plants with potassium silicate, sugar beet molasses, or kaolin gave significant similar efficiencies of water use by the water-sprayed plants grown under full irrigation.

Discussion

Drought is considered the most destructive environmental stress, which severely impairs the growth and productivity of many crops more than any other environmental stress (Taiz *et al.*, 2014). Ongoing global climate change will increase drought severity (Walter *et al.*, 2011). In our study, drought severely diminished the vegetative growth parameters and biomass accumulation of tomato plants, i.e. stem length, stem diameter, number of branches and leaves, dry plant weight (Table 2) and leaf area (Table 3). These reductions may be principally attributed to the reduced cell division, enlargement and differentiation owing to impaired enzyme activities, loss of turgor, and decreased energy supply (Farooq *et al.*, 2009; Taiz *et al.*, 2014). In this respect, similar reductions in vegetative traits of tomato plants were recorded as deficit irrigation levels increased (Wahb-Allah and Al-Omran, 2012; Sibomana *et al.*, 2013; Shalaby *et al.*, 2014; Khan *et al.*, 2015**).**

The obtained results also revealed that severe water deficit caused reductions in SPAD readings (Table 3) which are indicators for chlorophyll content that is one of the major chloroplast components for photosynthesis, resulting decreases in plant growth and biomass accumulation. In this concern, the reductions of SPAD readings under water deficit (Table 3) are in good accordance with the reductions of plant growth parameters and biomass accumulation (Table 2). The reductions in SPAD readings under severe water deficit may be the result of pigment photo-oxidation and chlorophyll degradation. Similar diminutions in chlorophyll content were reported for tomato plants grown under drought stress **(**Sibomana *et al.*, 2013**)**

Leaf relative water content is considered as meaningful index for plant water status and maintains cell turgor, reflecting the metabolic activity in tissues. Relative water content is related to water uptake by the roots as well as water loss by transpiration. In this study, decreasing irrigation level reduced leaf relative water content and leaf water potential (Table 3). Similar decreases in leaf relative water content were previously reported for tomato plants grown under water deficit **(**Sibomana *et al.*, 2013; Sivakumar, 2014; Khan *et al.*, 2015). The reduction rates depend on the interaction of severity, duration of the drought event and species (Yang and Miao, 2010).

Plant membranes are damaged by drought stress and often associated with the increases in permeability and loss of integrity. Therefore, the electrolyte leakage is used as a meaningful index to assess the damages in cell membrane stability induced by water deficit. The obtained data indicated that as deficit irrigation levels increased, the electrolyte leakage of leaves increased (Table 4).

Osmotic adjustment, i.e., a net increase in solutes leading to a lowering of osmotic potential is one of the main mechanisms whereby crops can adapt to limited water availability (Morgan, 1984). The solutes that accumulate during osmotic adjustment include sugars, amino acids, organic acids, proline and glycine betaine (Hanson and Hitz, 1982). Moreover, the reductions in leaf osmotic potential may be also attributed to the leaf dehydration resulting from water deficit (Morgan, 1984). The obtained results demonstrated that increasing the severity of water deficit reduced leaf osmotic potential (more negative values). Moreover, the decreases in leaf osmotic potential are well related to the reductions in leaf relative water content (Table 4). Decreases in leaf osmotic potential were reported in tomato plants subjected to water-deficit conditions **(**Zgallaï *et al.*, 2005**)**.

As nutrient uptake and water requirements are closely related, water deficit lowers absorption of nutrients and their concentrations in crop plants as a result of inhibition of transpiration rate by drought (Farooq *et al.*, 2009; Taiz *et al.*, 2014). The obtained results indicated that reducing irrigation level diminished nitrogen, phosphorus, potassium and calcium percentages in the leaves (Table 4). Similarly, Samarah *et al.* (2004) reported that water deficit affected nutrient uptake by decreasing nutrient transport from soil to root surface as well as by reducing root growth and extension. Farooq *et al.* (2009) indicated that drought-induced reduction in the absorption of essential nutrients might be attributed to drought interference in nutrient uptake and unloading mechanism as well as reduced transpirational flow.

Yield is determined by many of physiological and biochemical processes in a complex way and these yield-determining processes are influenced by water deficit, limiting the productivity of plants. Our results demonstrated that decreasing irrigation level reduced tomato yield components (Table 5). Reductions in yield components were previously reported in water-stressed tomato plants (Nuruddin *et al.*, 2003; Wahb-Allah and Al-Omran, 2012; Sibomana *et al.*, 2013; Shalaby *et al.*, 2014), which depend upon the severity and duration of the stress. These decreases in yield may attributed to the reductions in assimilate translocation and dry matter portioning (Farooq *et al.*, 2009) through the impairments of physiological and biochemical processes. In this concern, the reductions of yield components under water deficit (Table 5) are in good accordance with the reductions in leaf nutrient concentrations (Table 4), SPAD readings and water relations (Table 3) and plant growth parameters and biomass accumulation (Table 2).

Water use efficiency also is an important characteristic, which provides information on the adaptation potential of a plant to water stress conditions. In the present study, water use efficiency was decreased with decreasing the availability of water. These results coincide with those obtained by Zgallaï *et al.* (2005**)**.

To cope with the aforementioned deleterious effects of water deficit in crop plants, numerous strategies have been proposed. Among these strategies, foliar applications of antitranspirants are used to reduce the transpiration rate and reduce these adverse impacts of drought stress. Based on the mode action, antitranspirants have been classified as: 1) film forming antitranspirants that hinder the escape of water vapor from the leaves, 2) reflecting types of antitranspirants that reduce the absorption of the radiant energy and thereby reduce leaf temperatures and thus transpiration rate, and 3) metabolic inhibitors that prevent stomata from opening fully decreasing the loss of water vapor from plant leaves. The obtained results demonstrated that potassium silicate, sugar beet molasses, or kaolin seemed to be the most effective antitranspirants than ABA and linseed oil for attenuating the severity of water deficit. Moreover, both ABA and linseed oil had significant inhibitory effects on some recorded parameters under the two water-deficit levels.

Potassium silicate which contained 11% silicon and 60% K_2O significantly attenuated the deleterious effects of water deficit on tomato plants. The attenuating effects of potassium silicate may be due to the alleviating roles of both potassium and silicon for drought stress. In this connection, increased application of potassium has been shown to enhance plant growth, yield and drought resistance in tomato under water stress conditions (Çolpan *et al.*, 2013). Potassium plays important roles in alleviating the damaging effects of drought stress through its substantial effects on enzyme activation, protein synthesis, photosynthesis, stomatal movement and water-relation (turgor regulation and osmotic adjustment) in plants (Marschner, 2011). Moreover, the beneficial roles of silicon in combating various biotic and abiotic stresses have been widely reported (Zhu and Gong, 2014). The alleviative effects of silicon under drought/water stress conditions have been observed in some vegetable crops, such as tomato (Romero-Aranda *et al.*, 2006; Marodin *et al.*, 2014), cucumber (Hattori *et al.*, 2008), pepper (Lobato *et al.*, 2009), and potato (Pilon *et al.*, 2013; 2014) by improving growth parameters, leaf relative water content and chlorophyll content, uptake and accumulation of nutrients, and yield components. Previous studies have explored the mechanisms for silicon-mediated drought tolerance. It has been proposed that silicon can decrease the transpiration *via* cuticle (Gong *et al.*, 2003) or *via* stomata (Gao *et al.*, 2006), reduce electrolyte leakage and stabilize the membrane structure and integrity (Cakmak, 2005), enhance antioxidant defense and thus decrease the oxidative stress (Gong *et al.*, 2005, 2008), improve the plant water status (Gong *et al.*, 2005; Hattori *et al.*, 2005), improve calcium concentration in plant tissues which could help to maintain membrane stability and permeability (Gao *et al.*, 2006), keep the mineral balance in plants (Kaya *et al.*, 2006; Gunes *et al.*, 2008), increase the photosynthesis and relevant carboxylase activities (Gong and Chen, 2012), increase the root hydraulic conductance (Liu *et al.*, 2014), and increase proline concentration which plays a substantive role in osmotic adjustment (Pilon *et al.*, 2014).

The obtained data in the current study also demonstrated that sugar beet molasses significantly mitigated the adverse effects of water stress. The ameliorative effects of sugar beet molasses may be principally attributed to the alleviative effects of its main constituent; betaine (3-4%) (Šárka *et al.*, 2013). Glycine betaine is the most well-known quaternary ammonium compounds in higher plants that induced and endogenously synthesized and exogenously applied glycine betaine acts as osmoprotectant and improves the growth and development of plants exposed to a variety of abiotic stresses including drought (Farooq *et al.*, 2010; Dawood and Sadak, 2014) in many vegetable crops such as eggplant (Abbas *et al.*, 2010), common bean (Abou El-Yazied, 2011), and tomato (Rezaei *et al.*, 2012; Ragab *et al.*, 2015). Generally, glycine betaine protected the plant cells against the harmful effects of stress by preserving the osmotic balance (Mahouachi *et al.*, 2012), stabilizing the structure of macromolecules and maintaining membrane permeability (Ashraf and Foolad, 2007), protecting the photosynthetic apparatus and promoting the photosynthetic capacity (Allakhverdiev *et al.*, 2003), and enhancing antioxidant enzyme activities, and acting as radical oxygen scavengers (Wang *et al.*, 2010; Kaya *et al.*, 2013). Moreover, it is worthy to mention that sugarbeet extract proved to be better than the glycine betaine in improving growth, photosynthetic rate, transpiration, stomatal conductance and yield under abiotic stresses. Since, sugarbeet extract contains a substantial amount of glycine betaine along with a variety of other important nutrients (Abbas *et al.*, 2010).

Kaolin is a non-toxic reflective antitranspirant material which the main constituent is kaolinite ($Al_2Si_2O_5(OH)_4$). Kaolin spraying decreased leaf temperature by increasing leaf reflectance and reduced transpiration rate, which in turn maintained a higher water content in plant tissues, possibly favoring plant metabolism, physiological processes, photosynthetic rate, carbohydrate metabolism and many other important functions that directly affect plant growth (Bafeel and Moftah, 2008; Cantore *et al.*, 2009; Ibrahim and Selim, 2010). On the contrary, kaolin helped to reduce the heat load on leaves and increased the penetration of solar radiation into the canopy, increasing photosynthesis (Ouda *et al*, 2007; Glenn, 2012). Kaolin spraying alleviated the negative effects of water stress in some vegetable crops such as summer squash (Ibrahim and Selim, 2010), tomato (Aggag *et al.*, 2015), and sweet pepper (Ćosića *et al.*, 2015).

Abscisic acid (ABA) is a plant stress hormone that is observed to accumulate under drought stress and mediates many stress responses. Earlier studies proved that abscisic acid showed a clear improvement of tomato plant growth, especially under abiotic stress mainly drought (Astacio and van Iersel, 2011). However, exogenous abscisic acid treatment showed adverse effects such as leaf chlorosis and abscission of older leaves (Waterland *et al.*, 2010; Kim and van Iersel, 2011). Moreover, Sharma *et al.* (2006) stated that treating the plants with abscisic acid may show a negative effect depending on its usage rate and the period in which the abscisic acid is still effective, where some synthetic forms of the abscisic acid still effective for a long time so leading to closing the stomata and consequently declining rate of the photosynthesis process. This may explain the unfavorable effect of spraying tomato plants with abscisic acid under our study which decreased the measured parameters, i.e. stem length, stem diameter, number of branches and leaves, plant dry weight, relative water content and SPAD of leaves, leaf mineral composition, and yield components.

Usage of oils of various types as antitranspirants began in the early 20^{th} century. As for the oils favorable, Aggag and El-Sabagh (2006) found that spraying linus seed oil on grape vine improved the yield and quality of berries as well as increased water use efficiency under drought stress. Similarly, improving the water status of the water-stressed wheat plants without alteration of the photosynthetic rate due to the foliar spraying of linseed oil (Ouerghi *et al.*, 2010). However, unfavorable effects of oil spraying were reported. In this connection, oil spraying caused leaf senescence and drop (Neumann, 1974), and led to deleterious effects on the growth and fruit quality

(Baudoin *et al.*, 2006). These deleterious effects may be attributed to the covering the aerial plant parts with a layer of the oil interferes in gas exchange and diminishes both photosynthesis and transpiration (Baudoin *et al.*, 2006). This is confirmed by Mokhtari *et al.* (2006) who proved that spraying linseed oil on wheat plants totally closed the stomata and consequently limiting the transpiration rate and reduced the photosynthesis activity immediately after the treatment while the long-term effect was appeared in the form of curled and small leaves. Accordingly, to utilize linseed oil as an antiperspirant, spraying should cover the plant surface partially to allow the activity of photosynthesis to continue. Therefore, in our investigation on tomato, well-spraying of linseed oil several times led to significant reductions of all measured parameters of the plant growth compared with the water-sprayed plants. Also, the recent leaves harmed after each spraying time of the linseed oil (data not shown). Moreover, the negative impacts of spraying linseed oil on photosynthesis activity and the net assimilates resulted in reductions in physiological parameters, yield components and finally water use efficiency.

Conclusion

While increased water stress severity tends to reduce all parameters of tomato growth and productivity, the foliar application of different antitranspirants is considered as a necessary procedure to reduce the deleterious impacts of drought stress. In the current study, sprayings of potassium silicate at 2000 ppm or sugar beet molasses at 5 ml l^{-1} for four times were the most effective antitranspirants for ameliorating the severity of water deficit on tomato plants. On the contrary, both ABA at 50 ppm and linseed oil at 10 ml l^{-1} had significant inhibitory effects on some growth parameters and productivity especially under severe water stress, while kaolin had neutral and moderate effects.

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