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Response of Vegetative and Reproductive Parameters of Water Stressed Tuberose Plants to Vapor Gard and Kaolin Antitranspirants

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Abstract. Effects of different types of antitranspirants (ATs), Kaolin and Vapor Gard, on vegetative growth, flowering, and chemical composition, of tuberose (*Polianthes tuberosa* L.) cv. "Double" plants, grown under different irrigation regimes were investigated. Results showed that plant biomass, number of leaves, length and weight of marketable inflorescences and bulb yield were significantly reduced by water deficit, particularly at 60% evapo-transpiration (ET). But, the flowering period was markedly shortened under stress conditions. Under water deficit N, P, K, Ca, total carbohydrates and soluble sugars decreased in treated leaves as compared to the control plants. Both types of ATs effectively enhanced plant performance, flower formation, bulb production, nutrient uptake and carbohydrate synthesis at the 80% ET treatment, relative to the irrigation regime of 80% ET. The performance of Kaolin was more effective than that of Vapor Gard (VG). This might be contributed to its mechanism in reducing leaf temperature, transpiration rate, improvement of plant water status and maintaining biomass production of tuberose plants. Due to the superiority of Kaolin particle film in regulating plant performance and chemistry, it is recommended to be used for reducing water loss by plants in Al-Qassim region, Saudi Arabia.

Keywords: Antitranspirants, Flowering, Growth, *Polianthes tuberose*, Water stress.

Introduction

There is a critical balance between water requirement and water consumption of the crops. Thus, conserving water is an important aspect for agricultural expansion particularly in arid and semiarid regions where water deficit and high temperature are the main limiting factors for plant growth and productivity [1]. Water deficit often causes reduction in plant growth by inhibiting leaf and stem elongation [2] and by reducing nutrient uptake by plants [1]. In addition, water deficit affects negatively the process of flowering inflorescence in many plant species by reducing the fertility of newly formed flowers [3, 4]. Under such drought conditions, actively growing plants transpire a weight

of water equal to their leaf fresh weight each hour if water is adequately supplied [5]. Thus, it is necessary to find ways by which available water could be economically utilized. One way to achieve this goal is by reducing the transpiration rate using anti-transpirant materials to minimize the amount of irrigation water.

Anti-transpirants (ATs) are grouped into three categories [6], namely film-forming types (which coat leaf surface with films that are impervious to water vapor), reflecting materials (which reflect back a portion of the incident radiation falling on the upper surface of the leaves) and stomatal closing types (which affect the metabolic processes in leaf tissues). Film forming (Vapor Gard) and reflecting (Kaolin) ATs are not toxic and have longer periods of effectiveness than metabolic types [7]. Moreover, Vapor Gard has not been reported to reduce the photosynthetic rate, and it dries on plants to form a clear, glossy film which retards normal moisture loss without interfering with plant growth or normal respiration. Kaolin spray was found to decrease leaf temperature by increasing leaf reflectance and to reduce the transpiration rate more than photosynthesis in many plant species grown at high solar radiation levels [8]. Early studies demonstrated that Kaolin improved the water status and the growth of water-stressed tomato plants [9].

Tuberose (*Polianthes tuberosa* L.) cv. Double is one of the most popular odorous flowering ornamentals, and it is an excellent summer flowering bulb, suitable for summer marketing. It is commercially grown for its attractive and luring cut flowers and also for the production of bulbs. This species usually blooms during summer and fall months, producing showy conspicuous fragrant yield of cut flowers of high marketable value due to the lack of other flowering bulbs in summer and autumn [10].

The present study was undertaken to compare the effects of Vapor Gard emulsion film and Kaolin particle film on vegetative and reproductive growth, nutrient uptake, soluble sugars and total carbohydrate content of tuberose (*Polianthes tuberosa* L.) cv. Double plants grown under different water regimes.

Material and Methods

Tuberose (*Polianthes tuberosa* L.), cv. "Double", bulbs of about 4-5 cm in diameter were planted on 7 April 2002, in 30 cm plastic pots each filled with 10 kg air dried sandy soil (Table 1). Experimental design, anti-transpirant treatments, and irrigation procedure were carried out as in [7]. The following data were obtained:

a) Number of leaves per flowering stalk, number of basal leaves, total leaf area, and shoot dry weight per plant (after drying at 70°C for 3 days until steady weight) were determined.
b) Flowering time, flowering stalk length and diameter, spike length, number of flowers per spike, and fresh weight of flowering stalk were determined.
c) Number, diameter, and dry weight of bulbs per plant (after drying at 70°C until steady weight) were measured.

d) Flower quality rating was based on a scale of 1-10 [10]; 1-3 = poor quality (short stem, slender, small spike and poor appearance), 3-7 = good quality (average specification and appearance), 7-10 = excellent quality (high marketable and superior quality of strong, healthy showy and luring flowering stalk).

e) Ion analysis at the end of the harvest, total N was determined using the Kjeldahl method. Phosphorus concentration was measured using a colorimetric assay, while K, and Ca were measured by atomic absorption spectrophotometry [13].

f) Soluble sugar content was determined following the method described by Buysse and Merckx [14]. Briefly, 50 mg of dry leaf powder were extracted with 20 ml of 80% (v/v) ethanol for three times. The total volume of the combined and filtered extracts was adjusted to 100 ml using deionized water. One milliliter of samples was transferred into a glass tube, and 1 ml 18% (w/v) phenol solution was then added. Immediately afterwards, 5 ml of concentrated sulphuric acid were added, the solution in the tube was mixed using a vortex mixer. The tubes were allowed to stand for 20 min, and cooled to room temperature before absorbance was measured with a spectrophotometer at 490 nm (Genesys, Spectronic Instruments, Inc., Rochester, NY, USA).

g) Total carbohydrate was determined spectrophotometrically using the phenol/sulphuric acid method as described by Buysse and Merckx [14]. All chemical measurements were made in dry ground materials from fully expanded leaves of nine plants per treatment (three plants per block).

Statistical analysis

All data were statistically analyzed according to Snedecor and Cochran [15] with the aid of COSTAT computer program for statistics. Differences among treatments were tested with LSD at 5% level of significance.

Table 1. Chemical and physical analyses of the soil

Chemical properties		**Physical properties**		
pH*:	8.20	Fractions (%):		
ECe (ms)**:	2.06	Sand:	95.30	
Soluble cations (meq L^{-1}):			*Silt:*	*3.60*
		Clay:	1.10	
Na^+	11.00			
Ca^{2+}	4.35			
Mg^{2+}	2.50			
Soluble anions (meq L^{-1}):		Texture:	Sandy Soil	
$CO_3^{2-} + HCO_3^-$	2.99			
SO_4^{2-}	11.70			
Cl^-	7.60			
$CaCO_3$	4.00%			
	O.M. *0.23%*			

* pH of H_2O (soil : water = 2.5 : 1)

** ECe = Electric conductivity of the extract.

Results and Discussion

Growth parameters

Number of leaves, leaf area, and shoot dry weight of tuberose significantly reduced by water deficit treatments, particularly 60% ET regime as compared with the control (Table 2). The decrease in number of basal leaves was about 27% and 54% of control at 80% and 60% ET, respectively, while the number of leaves on the flowering stalk was reduced by 20% and 48%, respectively. The corresponding decrease in area reached 13% and 31%, respectively, compared to the control. Thus, shoot biomass (dry weight) was reduced by about 17% at moderate water deficit, while severe stress (60% ET) caused 39% decrease in shoot dry weight per plant. The results are in agreement with Younis *et al.* [2] who found that the water deficit on plants inhibited leaf expansion, stem and root elongation. Therefore, a small decrease in plant water content and turgor can slow down or fully stop growth [1].

The 20% reduction in available soil water did not adversely affect plant growth when sprayed with ATs, especially Kaolin, which has more pronounced effects on growth parameters than VG (Table 2). The insignificant differences between AT-treated plants and the 80% ET may be attributed to the increased turgor and water use efficiency in the former compared to untreated water-stressed tuberose plants. Since water consumption was less for the AT treated plants, the biomass-to-water ratio was expected to be significantly better in these plants compared to unsprayed ones. This result may indicate also that ATs have the potential to help plants form a well-developed root system for vegetative and reproductive growth just as it was reported by Liang *et al.* [16].

Table 2. Effects of Vapor Gard (VG) and Kaolin sprays on the vegetative growth parameters of tuberose plants grown under different irrigation regimes. Each value represents the mean of three replicates

Water regime (% ET)[1]	AT[2] spray	No. leaves /flowering stalk	No. basal leaves /plant	Total leaf area/plant (cm^2)	Shoot dry wt (g/plant)
Control	00	6.23a*	22.14a	986a	16.22a
80%ET	00	5.00b	16.07b	862b	13.45b
	+ VG	6.06a	19.15a	904b	13.86b
	+ Kaolin	6.14a	20.90a	935a	14.58b
60%ET	00	3.24c	10.13c	674c	9.88d
	+ VG	4.20b	15.03b	687c	10.16c
	+ Kaolin	4.28b	15.04b	714c	10.82c

[1] ET = Evapo-transpiration. [2] AT = Anti-transpirant.
*Similar letters in the same column indicate no significant differences between values at L.S.D. (0.05).

Reproductive parameters

Naturally, when a plant experiences unfavorable conditions, inflorescence and seed production are often accelerated. The present study shows that tuberose plants tended to flower early as they were subjected to water deficit. Thus, 60% ET treated plants had significant shorter flowering period, flowering nearly a week earlier and producing fewer flowers than the control (Table 3). No significant differences in days to flower were recorded between the 80% ET treatment and the control. Vapor Gard spray shortened the flowering period by about 2 to 5 days while Kaolin spray accelerated flowering by about 4 to 5 days at 80% and 60% ET, respectively, as compared to the control.

All elements of the marketable inflorescences were reduced significantly in plants grown under water deficit conditions. Even at mild water deficit (80% ET), flowering stalk length, flowering spike length, and the number of flowers per inflorescence were significantly reduced by about 15, 23 and 29%, respectively, as compared to the control plants. Similarly, the number of bulbs per plant, the dry weight of bulbs per plant, and the daughter bulb diameter were decreased by about 19, 14 and 4%, respectively. The decrease in floral and bulbous variables were more severe at 60% ET with or without AT applications. Such a decrease is not considered economically acceptable (Table 4). These results were in agreement with those of [17] and [18], who found that the water deficit had significant effect on number of aborted flowers, bulb size, inflorescences and floral buds and number of flowers per plant. According to the present study and earlier work by Al-Humaid and Moftah [7], it could be speculated that water deficit and high evapotranspiration rates during dry warm periods, which coincides with the flowering stage in this region significantly reduced both flower production and inflorescence formation. They also lowered leaf water potential that caused stomatal closure which, in turn, reduced the photosynthetic rate and decreased the photosynthates transported to the produced bulbs. Consequently, bulb production and quality were lower than the control. This conclusion is in harmony with that reported by Jaimez *et al.* [17].

Recorded data clearly showed that VG or Kaolin sprays were beneficial only for plants grown under 80% ET irrigation regime, while at 60% ET both ATs did not compensate for the harmful effect on flowering and bulb production resulted from the water deficit. Flowering stalk length and diameter of AT-treated plants grown at 80% ET and the control were comparable, while spike length, number of flowers per plant and flowering stalk weight of the corresponding treatments were significantly different. Although both materials are considered economically acceptable for plants grown under 80% ET water supply, plants showed a better response to Kaolin than to VG treatments as flowering and bulb parameters were substantially improved under the former compared to the latter material (Table 4). The distinct effect of Kaolin might be due to its ability to reflect most of the solar radiation fall on the plant leaves. The reflection causes better cooling for the leaf tissues under water stress conditions and warm climate prevailing in the region. This leads to the enhancement of the photosynthetic rate, the water status, the carbohydrate metabolism and the elemental uptake under water deficit conditions. Such improvement was found to mitigate the detrimental effect of water

Table 3. Effects of Vapor Gard (VG) and Kaolin sprays on the flowering and inflorescence characteristics of tuberose plants grown under different irrigation regimes. Each value represents the mean of three replicates

Water regime (% ET)		Flowering AT[2] rating spray	Quality days to flowering	Flowering stalk length (cm)	Flowering stalk diam. (cm)	Spike length (cm)	No. of flowers /spike	stalk wt (g)
Control		00	135.9a*	58.54a	0.78a	23.50a	14.22a	52.41a
		8.1a						
80%ET		00	133.2a	49.66b	0.75a	18.12b	10.12c	42.17c
		6.5b						
		+VG	134.3a	52.12a	0.75a	19.66b	12.34b	47.20b
		6.9b						
	+	Kaolin	131.6b	56.14a	0.73a	22.11a	12.85b	50.66a
		7.8a						
60%ET		00	128.4c	35.15d	0.64c	12.10c	7.06d	30.42e
		2.1c						
	+	VG	131.3b	42.10c	0.68b	19.74b	10.62c	39.11d
		2.5c						
	+	Kaolin	130.5b	40.22c	0.69b	18.85b	9.33d	38.72d
		2.8c						

Table 4. Effects of Vapor Gard (VG) and Kaolin sprays on bulb yields and bulb characteristics of tuberose plants grown under different irrigation regimes. Each value represents the mean of three replicates

Water regime daughter (% ET)[1]	AT[2] spray	No. of bulbs /plant	Dry wt of bulbs (g/plant)	Diameter of bulb (cm)
Control	00	22.24a*	6.82a	3.11a
80%ET	00	18.12b	5.85b	3.00b
	+ VG	20.40a	6.72a	3.10a
	+ Kaolin	21.05a	6.77a	3.19a
60%ET	00	10.03d	5.41c	2.08c
	+ VG	14.30c	5.65b	2.86b
	+ Kaolin	14.90c	5.73b	2.97b

[1] ET = Evapo-transpiration. [2] AT = Anti-transpirant.
*Similar letters in the same column indicate no significant differences between values at L.S.D. (0.05).

Table 5. Effects of Vapor Gard (VG) and Kaolin sprays on nutrient element concentration in leaves of tuberose plants grown under different irrigation regimes. Each value represents the mean of three replicates

Water regime (% ET)[1]	AT[2] spray Ca%	N%	P%	K%	
Control	00 2.15b	2.45a*	0.35a	2.65a	
80%ET	00 2.02c	2.12b	0.28b	2.04b	
+	VG 2.11b	2.24b	0.29b	2.10b	
+	Kaolin	2.35a	0.30b	2.48a	3.08a
60%ET	00 1.74d	1.86c	0.18c	1.56c	
+	VG 1.92c	1.99c	0.21b	1.98c	
+	Kaolin 2.01c	2.00c	0.23b	2.02b	

[1] ET = Evapo-transpiration. [2] AT = Anti-transpirant.
*Similar letters in the same column indicate no significant differences between values at L.S.D. (0.05).

deficit on the partitioning of assimilates during the period of flowering bud initiation. Thus, this mitigation improved flower formation and bulb production [17]. Data showed that Kaolin, also, increased leaf area per plant as compared with 80% ET (Table 2). That increase has been positively and significantly correlated with improvement of the reproductive organs [19].

Leaf mineral concentration

The concentrations of N, P, K and Ca in tuberose leaves were substantially decreased by severe water deficit conditions (60% ET treatment). However, there were significant differences between 80% ET stressed plants and the control for their nutrient contents (Table 5). While Kaolin significantly increased nutrient contents (N, K and Ca) at 80% ET relative to 80% ET treatment, Kaolin had a pronounced effect on ion content compared to VG. Since long distance movement from roots to the above ground parts occurs in the transpiration stream, a reduction in the rate of ion transport might occur in severely stressed plants to reduce transpiration. Moreover, efficiency of nutrient absorption and transport within the plant may be reduced because the movement of minerals is slow in drying soil. Also, root extension was decreased, and suberization reduced root permeability [20].

Phosphorus values were significantly decreased in AT-treated plants due to low transpiration rate [5]. On the other side, K and Ca levels were improved in sprayed plants (by Kaolin) under 80% ET regime, because the availability of soil water that was developed by ATs might enhance the active transport of these elements. Nitrate reductase in tuberose roots may also be enhanced by the improved water level in the soil, leading to an increase in N uptake and content in plant leaves. The positive effect of AT (Kaolin) on nutrient uptake was also reported by Martinez *et al.* [11]. The increased K and Ca concentrations in plant tissues suggests that these ions may play a fundamental role in facilitating high turgor maintenance under water deficit conditions. This conclusion is in agreement with De-Pascale *et al.* [21] in pepper plants grown under drought stress.

Soluble sugars and total carbohydrates

Water deficit decreased both soluble sugars and total carbohydrate contents in tuberose leaves (Table 6). The decrease in soluble sugars were almost 19% and 21% at 80% and 60% ET treatments, respectively, while the corresponding values for total carbohydrates were 16% and 37%, respectively. This means that total carbohydrates were more sensitive to water deficit and thus decreased more than soluble sugars. Interestingly, the ratio of soluble sugars to total carbohydrates increased as water deficit became more severe. This ratio was about 51% at 80% ET, while at 60% ET the ratio was almost 65%, as compared with 52% for control (Table 6). The increase in soluble sugars with Kaolin treatments was observed at 80% or 60% ET regime, as compared with 80 or 60% ET alone.

Soluble sugars and total carbohydrates were significantly lower in 80 and 60% ET-treated plants, either with or without AT treatments, than in the control. However, soluble and total sugars were significantly higher in Kaolin than in VG-treated plants. Barathi *et al.* [22] found that soluble sugar content affected by water stress, and this effect accompanied by a decrease in starch content, indicating drought injury signs. In the present study, decreases in soluble sugar content occurred after soil water was nearly depleted. This was coincident with the decrease in vegetative growth and flowering quality, indicating that the reduction in soluble sugars could be associated with cell damage and leaf senescence. These findings are in harmony with Wang *et al.* [23]. The superior effect of Kaolin over VG on enhancing formation of soluble sugars and total carbohydrates in water-stressed tuberose leaves may reflect the role of Kaolin in reducing leaf temperature during the warm period of tuberose production. Therefore, photosynthesis and water status were improved in Kaolin-treated plants under water deficit conditions.

It could be concluded that water deficit, in arid and semiarid regions, negatively affected vegetative growth and flowering parameters, the quality of the marketable inflorescences, and the bulb production of tuberose plants. Applications of emulsion film type "Vapor Gard" and particle film type "Kaolin" were found to enhance most parameters in plants subjected to mild water stress, while at severe water stress, plants were not able to reach the economical level even when they were sprayed with the antitranspirants. Under these conditions of water deficit and heat stress, with high evaporative demands, such as that prevailing in most arid and semi-arid regions, Kaolin-sprayed plants performed better than VG-sprayed plants due to Kaolin's ability to reflect most of the solar radiations falling on leaves and thus reduce leaf temperature, improve plant functions, increase nutrient content, carbohydrate formation, and, therefore, to enhance growth and productivity of tuberose plants.

Table 6. Effects of Vapor Gard (VG) and Kaolin sprays on soluble sugars and total carbohydrate content in leaves of tuberose plants grown under different irrigation regimes. Each value represents the mean of three replicates

Water regime (% ET)[1]	AT[2] spray	Soluble sugars (%)	Carbohydrates (total %)	SS/TC** ratio
Control	00	12.62a*	24.14a	0.52
80%ET	00	10.20c	20.16b	0.51
+	VG	10.32c	21.45b	0.48
+	Kaolin	11.20b	23.65a	0.47
60%ET	00	10.00c	15.29d	0.65
+	VG	9.13d	18.18c	0.50
+	Kaolin	11.14b	20.20b	0.55

[1] ET = Evapo-transpiration. [2] AT = Anti-transpirant.
*Similar letters in the same column indicate no significant differences between values at L.S.D. (0.05).
**SS = Soluble sugars, TC = Total carbohydrates

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استجابة مقاييس النمـــو الخضري والتكاثري لنباتات التوبروز النامية تحت ظروف الإجهـــاد المائي للمعاملة بمضادات النتح "فابور جارد" و"الكاولين"

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(قدم للنشر في ١٤٢٥/١٢/٢٥هـ؛ قبل للنشر في ١٤٢٦/١٠/١٨هـ)

كلمات مفتاحية: الإجهاد المائي، الإزهار، التوبروز، النمو، مضادات النتح.

ملخص البحث. أجريت هذه الدراسة بمحطة البحوث والتجارب الزراعية التابعة لكلية الزراعة والطب البيطري بالقصيم، وذلك بهدف دراسة تأثير رش كل من مضادات النتح الاستحلابية المكونة لطبقة من المستحلب مثل "فابور جارد"، ومضادات النتح المكونة لطبقة من دقائق وجسيمات المادة مثل "الكاولين" على أسطح الأوراق على كل من النمو الخضري والزهري وجودة النورات القابلة للتسويق والمحتوى الكيماوي للنباتات. قيس عدد الأوراق ومساحتها، ووزن النبات، وطول النورة، وعدد الأزهار في النورة، وإنتاج النبات من الأبصال الجديدة، وتركيز العناصر المعدنية والسكريات الذائبة والكربوهيدرات الكلية في نباتات التوبروز النامية تحت معدلات ري ١٠٠٪ و ٨٠٪ و٦٠٪ من كمية الماء المفقود بواسطة البخر-نتح، كما استهدفت الدراسة معرفة أي أنواع مضادات النتح أكثر ملائمة للاستخدام تحت ظروف نقص الماء السائدة في منطقة القصيم بالمملكة العربية السعودية وذلك في محاولة لتوفير مياه الري عن طريق تقليل الماء المفقود خلال عملية النتح. وقد دلت نتائج هذه الدراسة على أن تعرض النباتات للإجهاد المائي أدى إلى انخفاض الوزن الجاف وعدد الأوراق القاعدية على الساق ومساحة الأوراق الكلية/نبات، وعدد الأوراق على المحور الزهري، وقطر المحور الزهري، وطول النورة، وعدد الأزهار في النورة الواحدة، ووزن النورة، كما انخفضت درجة جودة النورات القابلة للتسويق حيث قصر طولها وتناقص عدد الأزهار بها وذلك تحت معدلات ري ٨٠٪ و ٦٠٪، وكان لمعدل الري الأخير تأثيرا أكثر ضررا على جودة الأزهار إلا أنه دفع النباتات للتزهير المبكر بالمقارنة بنباتات الشاهد. انخفض معنويا تركيز العناصر المعدنية، والسكريات الذائبة، والكربوهيدرات الكلية في النباتات النامية تحت معدل ري ٨٠٪ أو ٦٠٪ مقارنة بنباتات

الشاهد. أدى رش النباتات النامية تحت ظروف الإجهاد المائي بمضادات النتح إلى تحسن حالة النباتات الفسيولوجية وانعكس ذلك على نموها الخضري والزهري وكان الرش بمادة الكاولين أكثر معنوية من الفابور جارد في تحسين جميع الصفات التي تم دراستها، لذا توصي هذه الدراسة باستخدام الكاولين لتحسين نمو وإنتاجية نباتات التوبروز النامية تحت أجواء منطقة القصيم بالمملكة العربية السعودية.