J. King Saud Univ., Vol. 18, *Agric. Sci.,* (1), pp. 35-49, Riyadh (1426H./2005)

Effects of Kaolin and Pinolene Film-forming Polymers on Water Relations and Photosynthetic Rate of Tuberose (*Polianthes tuberosa* L.)

Ansary E. Moftah and Abdulrahman I. Al-Humaid
College of Agriculture and Veterinary Medicine,
University of Al-Qassim, Saudi Arabia
E-mail: ansary80@yahoo.com

(Received 3/4/1425H.; accepted for publication 7/11/1425H.)

Abstract. The effects of pinolene-base Vapor Gard (VG) emulsion type film and Kaolin (Surround WP) particle type film antitranspirants on stomatal behavior, water status, carbon assimilation and transpiration rate of tuberose (*Polianthes tuberosa* L.) cv. double plants grown under the irrigation regimes of 100, 80 and 60% of total evapotranspiration (ET) values were investigated to select the most suitable antitranspirant for conserving irrigation water, less detrimental effects on growth and production of tuberose plants grown in Al-Qassim region. Severe water stress, decreased stomatal frequency and conductance (g_s), leaf water potential (Ψ_w), osmotic potential (Ψ_π), turgor potential (Ψ_p), relative water content (RWC), chlorophyll content (chl), carbon assimilation rate (A) and the transpiration rate (E). Both types of antitranspirants effectively enhanced the performance and physiological activities of water-stressed plants particularly, at the 80% ET, but they did not compensate for the negative effects caused by the 60% ET treatment. However, the particle type (Kaolin) was more effective than the emulsion type (VG) due to its ability to reduce leaf temperature. The increased g_s caused by VG and Kaolin sprays were accompanied by increased A suggesting that g_s might have a limiting effect on A in water-stressed plants. Water use efficiency (WUE) of Kaolin–sprayed leaves was significantly higher than that of VG–sprayed leaves. However, no significant differences between both antitranspirants on E were recorded. Increased WUE, therefore, could be attributed to a higher A by using Kaolin as compared with VG sprays. Thus, particle type antitranspirants are more effective in regulating water status, WUE and the photosynthetic activity of tuberose plants in Al-Qassim regions, Saudi Arabia.

***Keywords*:** Tuberose, Water stress, Antitranspirant, Photosynthesis, Water relations.

Introduction

There is a critical need to balance water availability, water requirements and water consumption in conserving water which has become a decisive consideration for agricultural expansion, particularly in arid and semi-arid regions where water is the main limiting factor for plant growth. Moreover, plants are prodigal in the water use because only roughly 5% of water uptake is used for its growth and development while the remaining 95% is lost for transpiration [1]. Actively growing plants transpire a weight of water equal to their leaf fresh weight each hour under conditions of arid and semi-arid regions if water is supplied adequately [2]. This scare figure makes it necessary to find ways by which available water could be economically utilized. one way to achieve this goal is to reduce the transpiration rate in order to minimize the amount of irrigation water.

Certain chemicals with some biological activities could be used to reduce the transpiration rate and mitigate plant water stress by increasing leaf resistance to diffusion of water vapor. Based on their mechanisms of action, such anti-transpirants (ATs) were grouped into three categories [1], 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 and reflecting ATs were found to be non-toxic and have a longer period of effectiveness than metabolic types [3]. Moreover, in contrast to most film-forming ATs which are impermeable to CO_2 exchange and thus may reduce the rate of photosynthesis [2], the pinolene-base vapor gard (VG) has not been reported to reduce the photosynthetic rate. It dries on plants to form a clear, glossy film which retards normal moisture loss without interfering with plant growth or normal respiration. It is also safe for human use as well as it has been used on various fruit crops. In addition, a reflective Kaolin spray was found to decrease leaf temperature by increasing leaf reflectance and to reduce transpiration rate more than photosynthesis in many plant species grown at high solar radiation levels [4]. Early studies demonstrated that the reflective Kaolin improved water status and yield of water-stressed apple seedlings, while it did not reduce carbon assimilation [5].

Many studies have focused on comparing the effects of ATs on vegetables [1] fruits [5] and field crops [2, 6, 7]. Data concerning the impact of combined ATs and extreme desert climatic conditions on ornamental plants are crucially lacking. Moreover, to our knowledge, there are no studies that have investigated the use of a specific AT on ornamental plants grown under water deficit conditions in warm desert regions such as Saudi Arabia and other similar parts of the world.

Tuberose (*Polianthes tuberosa* L.) cv. double is one of the most popular odorous flowering ornamentals and is an excellent summer blooming flowering bulb well suited to the summer season. It is commercially grown for its attractive and luring cut flowers and also for the production of new bulbs. The plant is used in floral arrangements such as floral bouquets and table decorations because the flowers remain effectively fresh and attractive for relatively long time. Also, tuberose produces a showy, conspicuous, fragrant yield of cut flowers of a high marketable value due to the lack of other flowering bulbs in summer and autumn [8].

Therefore, the present study was conducted to determine and compare the effects of Vapor Gard emulsion film (polyterpene material) and Kaolin particle film (a reflecting material) on the stomatal frequency, water status, photosynthesis and transpiration of tuberose cv. double plants grown in sandy soil under different water regimes. It was also undertaken to select the most suitable one for conserving irrigation water in Al-Qassim region, Saudi Arabia.

Materials and Methods

Tuberose (*Polianthes tuberosa* L.), cv. double, bulbs about 4-5 cm in diameter were planted April 2002, in 30 cm diameter plastic pots each filled with 10 kg of air-dried, sandy soil. Physical and chemical properties of the experimental soil are shown in Table 1. Pots were placed in a greenhouse and plants were allowed to grow at 30/20^{o}C day/night temperatures, 400 µmol m^{-2} s^{-1} photosynthetic active radiation (PAR) enhanced by a high pressure sodium-lamp supplement from 5:00 am to 9:00 pm. Before planting, the first of three equal doses of Sangral compound fertilizer plus micronutrients (William Sinclair Horticulture Ltd., England), was applied to the soil (600 kg ha^{-1}, 9 g pot^{-1}). Sangral fertilizer composition are: 20% N, 20% P (P_2O_5), 20% K, (K_2O), 0.40% S, 0.02% Mg (MgO), 70 ppm Fe, 14 ppm Zn, 16 ppm Cu, 42 ppm Mn, 22 ppm B and 14 ppm Mo. Pots were irrigated to the field capacity. The field capacity of the soil used was 11.50% $\pm$ 0.3 (mean of six replications $\pm$ SE), measured with the pressure-plate apparatus.

After 4 weeks, pots were transferred to open air under field conditions at day/night average temperature of 35/22^{o}C, and plants were irrigated to field capacity for another 4 weeks to prevent water stress, ensure the establishment of seedlings, and allow adaptation to the field conditions before drought treatments were imposed. The remaining two doses of fertilizer were applied at 70 and 84 days after planting, (DAP). Eight weeks after planting, water stress was imposed by withholding irrigation for a period of 3 days, during which ATs were applied. Watering, as assigned to the required water stress levels, was resumed on the 4th day of water deprivation.

Table 1. Chemical and physical analyses of used soil

a) Chemical properties:	**b) Physical properties:**
pH[1]: 8.20	Sand: 95.30
ECe[2]: 2.06	Silt: 3.60
Soluble cations (meq L^{-1}):	Clay: 1.10
Na^{+}: 11.00	Texture: Sandy soil
Ca^{2+}: 4.35	
Mg^{2+}: 2.50	
Soluble anions (meq L^{-1}):	
CO_3^{2-} + HCO^{3-}: 2.99	
SO_4^{2-}: 11.70	
Cl^{-}: 7.60	
CaCO3: 4.00	
O.M.: 0.23%	

[1] pH of water (soil : water = 2.5 : 1).
[2] ECe: electrical conductivity of the soil extract.

Antitranspirant treatments

Based on a preliminary experiment and recommendations of earlier studies on different crop species [2-4, 9], Vapor Gard (Miller Chemical & Fertilizer Corp., Hannover, PA, USA) was applied at 2% (v/v) and Surround WP (Engelhard Corp., Iselin, NJ, USA), a hydrophilic Kaolin particle film, with wetting and sticking agent, was applied at 3% (w/v). The treatments of both ATs were prepared using water only [5, 7]. Thus, AT treatments were: i) 0 (control), ii) 2% VG emulsion film, and iii) 3% Kaolin particle film. Tuberose plants were sprayed three times in a two-week intervals with fine mist of the AT solutions, starting 59 DAP, using a hand pressure-sprayer (Agrimex A15, 2L hand held pressure sprayer with adjustable spray jet). Water was sprayed as a control treatment.

Irrigation procedures

At the beginning of water stress treatments, the evapotranspiration (ET) was determined gravimetrically (weighing pots with plants). The amount of water lost during the 3 days, through which water was withheld, was recovered completely, by irrigation, for control pots only. Other pots received either 80% or 60% of the water added to control plants. Thus, throughout the course of experiment, the amount of water applied at each irrigation event was equal to the net ET between each two successive irrigations.

In order to determine the amount of water evaporated from soil surface, three pots filled with the same amount of soil but without planting were watered to 100, 80 and 60% of the field capacity. The loss in pot weights represented the amount of water lost by evaporation.

Experimental design and analysis

The experimental layout was a randomized complete block design replicated three times. Beside the 3 pots of the evaporation measurements, each block included seven treatments: 100% ET watering, 80% ET watering, 60% ET watering, 80% ET + VG, 60% ET +VG, 80% ET + Surround WP, and 60% ET + Surround WP. Data were statistically analyzed according to Snedecor and Cochran [10] with the aid of COSTAT computer program for statistics. Differences among treatments were tested with LSD 5% significance.

Data obtained

At the three stages of plant growth, vegetative, flowering, and maturity, including:

a) Leaf temperatures were measured using a steady-state porometer (LI-1600; LI-COR, Lincoln, USA). Air temperatures were measured close to plants using radiation-shielded thermocouples. Measurements of leaf and air temperatures were taken simultaneously every 2 hours during the vegetative (June) and flowering (July) stages, and the average temperatures were recorded.
b) Mean values of stomatal frequency in the abaxial and adaxial leaf surfaces were determined microscopically as a number of stomata per mm^2 of leaf surface. The method used involved spreading clear nail polish on the leaf surface,

allowing it to dry, then removing the polish strip using a piece of clear cellophane tape, and taping it to a microscope slide for viewing [11].

c) Leaf water potential (Ψ_w) was measured using a pressure chamber (PMS Instrument Co., Corvallis, USA) as described by Scholander *et al.* [12]. Leaf osmotic potential (Ψ_π) was measured with a vapor pressure osmometer (Wescor 5500, Precision System Inc., Natick, USA). Leaf pressure potentials (Ψ_p) were calculated by subtracting Ψ_π from Ψ_w. Relative water content (RWC) was calculated according to the equation: RWC = 100 x (FW – DW)/(TW –DW) as described by De Pascale *et al.* [13]. Turgid weight (TW) was determined in the uppermost fully expanded leaves that were detached and weighed (FW), floated on distilled water at 22°C in a dark chamber for 24 hours and dry weight (DW) was determined after oven drying at 75°C for 48 hours Water consumption was determined as the total amount of water applied to replace that absorbed or transpired by plants during the period from the beginning of treatments to harvest (110 DAP).

d) Leaves were detached and immediately chlorophyll was extracted by placing discs of known area in liquid N and crushing with a mortar and pestle. Chlorophyll was extracted in acetone (80%) and chlorophyll a, chlorophyll b and total chlorophyll content was spectrophotometrically determined as described by Wettestein [14].

e) The net CO_2 assimilation rate (A), the stomatal conductance (g_s), and the transpiration rate (E) were measured on the first, uppermost, expanded leaves (suitable for cuvette measurements) of three plants per treatment using a portable photosynthesis system (LI-6200; LI-Cor, Inc., Lincoln, USA). Water use efficiency (WUE) was calculated as the ratio A/E. Measurements were taken at 11:00 am and 1:00 pm. The cuvette conditions (air temperature, relative humidity and CO_2 concentration) were set to ambient, and measurements were performed at photosynthetic photon flux density (PPFD) of 1400 µmol m^{-2} s^{-1}. All measurements were taken in three replicates.

Results and Discussion

Leaf temperature

In arid regions such as the central part of Saudi Arabia, sun irradiance and air temperature are often high, particularly in the summer season. Leaf temperature can readily rise 4 to 5°C above ambient air temperature in bright sunlight near midday, when the soil-water deficit causes partial stomatal closure and reduces the evaporative cooling. Thus, as Taiz and Zeiger [15] have indicated, plants in such regions can experience some degree of heat stress, which may negatively affect both photosynthesis and respiration, consequently reducing plant growth and hindering physiological processes.

The present study shows that Kaolin sprays were accompanied by a significant reduction in leaf temperature, particularly at mid-day (1:00 pm – 3:00 pm) when air temperatures and incident radiations were high (Fig. 1). Increased reflection of incident radiation from the white-colored Kaolin-sprayed leaves was probably responsible for the temperature reduction. Glenn *et al*. [5] found more than 3°C reduction in Kaolin-treated-apple-leaf temperatures. In the present study, Kaolin sprays also reduced tuberose leaf temperature of the 80% ET treated plants by about 6 and 7°C in June (vegetative stage) and in July (flowering stage), respectively, at 3:00 pm. The reduction in leaf temperature of the 60% ET treated plants was less pronounced than 80% ET. Vapor Gard, however, did not show significant reductions in leaf temperature, while control plants showed slight reduction in leaf temperature, particularly at 1:00 pm – 5:00 pm. By the end of the day, VG, Kaolin and control plants had similar temperatures implying that long-wave emittance was unaffected by Kaolin sprays. These results are in accordance with those reported by Jifon and Syvertsen [16]. The higher variability in leaf to air temperature difference of control and VG-sprayed leaves compared to Kaolin sprayed leaves suggests that the Kaolin coating may have insulated leaves from changes in air temperature. While VG film may coat stomata, decrease conductance (discussed later) and, consequently, retard transpiration-cooling process.

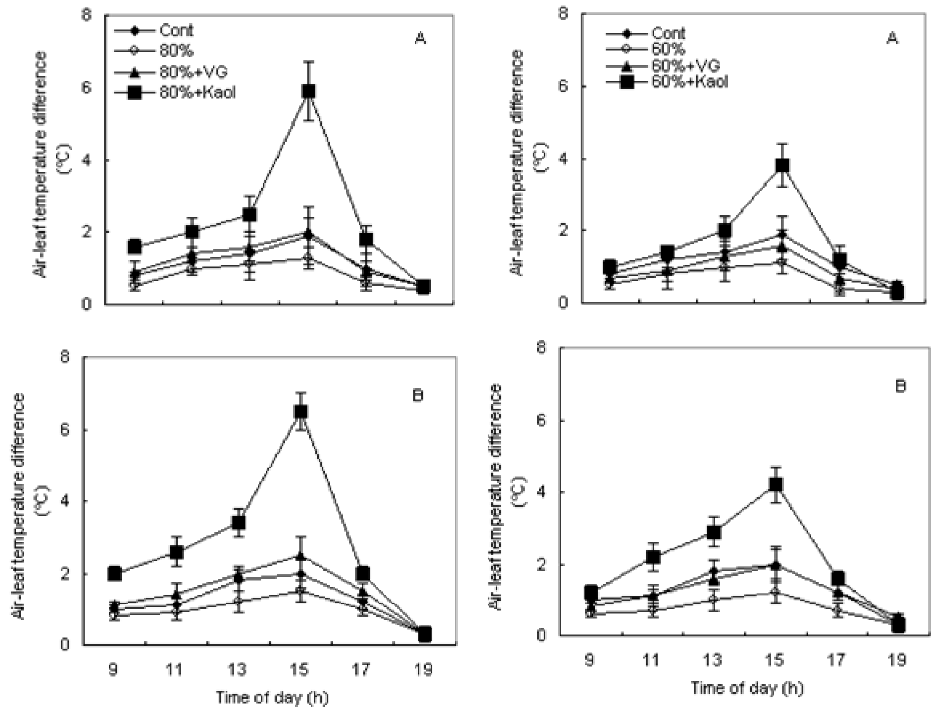

Fig. 1. Effect of Vapor Gard (VG) and Kaolin (Kaol) on air-to-leaf temperature differences in leaves of tuberose (*Polianthes tuberosa*) plants grown under 80% or 60% irrigation and control during vegetative (A) and flowering (B) stages. Error bars indicate SE (n = 3).

Stomatal frequency

Data in Fig. 2 show that water deficit conditions strongly reduced the number of stomata per mm^2 of tuberose leaves at all stages of plant growth with later stages being most affected. Since stomatal frequency and size were strongly correlated with the rhythm of leaf appearance [17], the negative effect of water stress on stomata formation as a result of decreasing leaf cell division and enlargement was reported by Taiz and Zeiger [15]. Several studies indicated that water stress decreased the number of stomata per leaf area [17, 18]. Therefore, plants appeared to reduce the transpiration loss of water under moisture stress conditions by reducing the number and/or size of stomata. These results are in accordance with those reported by Prakash and Ramachandran [1] in brinjal plants. The number of stomata per unit area of Vapor Gard and Kaolin-sprayed leaves had increased significantly compared with unsprayed, stressed plants, with Kaolin having greater effects at all growth stages.

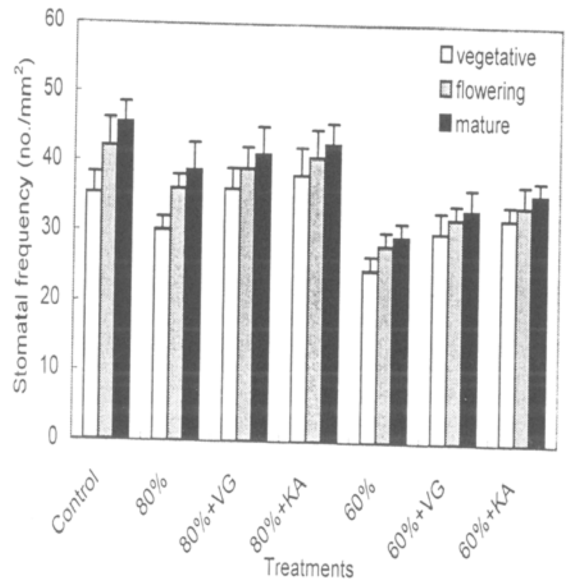

Fig. 2. Effects of Vapor Gard (VG) and Kaolin (KA) on stomatal frequency in tuberose plants grown under different irrigation regimes. Each bar is a mean ± standard error (n = 5).

Water relations

Data indicate that Ψ_w, Ψ_π, and Ψ_p as well as RWC were higher in non-stressed control plants compared to water-stressed plants (Table 2). It was clear that control plants had a good water supply and thus, their Ψ_w was always high and fluctuated within a narrow range (–0.82 to –0.96 MPa) during the vegetative and flowering stages.

Under water-deficit conditions, on the other hand, all water relation parameters were reduced compared to non-stressed plants. The reductions observed in their values were proportional to the levels of soil dryness. Thus, the decrease was greater at 60% than at 80% ET. For instance, Ψ_w of plants grown at 60% ET declined sharply from –0.82 and –0.96 MPa to –1.31 and –1.62 MPa at vegetative and flowering stages, respectively. While at maturity, Ψ_w changed only from –1.27 (control) to –1.77 MPa. It was obvious that, although Ψ_π of non-stressed plants decreased with plant growth age, the trend observed for Ψ_π of water-stressed plants did not differ much from that observed for Ψ_w during vegetative and flowering stages, but during maturity, the reduction in Ψ_π was more pronounced than that in Ψ_w. The decrease in water relation parameters in water-stressed plants is a well-documented phenomenon [6, 13]. It is well known that when transpiration exceeds water absorption, cell turgor falls as RWC and cell volume decreases, whilst the concentration of cellular contents increases, so Ψ_π and Ψ_w fall [19] low turgor, RWC slow plant growth and decrease g_s.

Vapor Gard and Kaolin treatments seemed to enhance plant water status considerably, particularly at later stages of plant growth. Significant increases in Ψ_w, Ψ_π, and Ψ_p were recorded in plants treated with either the emulsion film VG or the particle film Kaolin antitranspirants. However, Kaolin was much more effective in maintaining water balance and hence, increasing water relation parameters, than VG. This may be due to the reflective nature of Kaolin which may have reduced the absorption of radiant energy and thereby reduces leaf temperature and transpirational rate [5], not only due to its formation of a physical barrier against water loss, as in the case of the emulsion film-forming materials, VG [20].

Table 2. Effects of Vapor Gard (VG) and Kaolin sprays on leaf water potential (Ψ_w), leaf osmotic potential (Ψ_π), and leaf turgor potential (Ψ_p) of tuberose plants grown under different irrigation regimes at different growth stages. Each value represents the mean of three replicates

		Ψ_w (MPa)			Ψ_π (MPa)			Ψ_p (MPa)		
Water regime (% ET)	**AT spray**	**Vegeta-tive**	**Flower-ing**	**Mature**	**Vegeta-tive**	**Flower-ing**	**Mature**	**Vegeta-tive**	**Flower-ing**	**Mature**
Control	00	-0.82a*	-0.96a	-1.27a	-1.83a	-1.78a	-2.03b	1.01a	0.82a	0.86a
80%	00	-0.96b	-1.41c	-1.52b	-1.91b	-2.15d	-2.31c	0.95b	0.74b	0.79b
	VG	-0.86a	-0.98a	-1.10a	-1.84a	-1.77a	-1.93a	0.98a	0.79a	0.83a
	Kaolin	-0.88a	-1.10a	-1.22a	-1.85a	-1.87b	-2.00b	0.97a	0.77b	0.80b
60%	00	-1.31c	-1.62d	-1.77c	-2.09c	-2.34d	-2.47c	0.78d	0.72c	0.70c
	VG	-0.94b	-1.21b	-1.23a	-1.90b	-1.96c	-1.99a	0.96b	0.75b	0.76b
	Kaolin	-0.96b	-1.26b	-1.30b	-1.92b	-1.98c	-2.04b	0.86c	0.72c	0.74c

* Means in the same column followed by the same letter are not significantly different at the 5% level according to Tukey's test.

Chlorophyll content

Mild water stress (80% ET), unexpectedly, increased total chlorophyll (ch1) content expressed on leaf area basis. Such an increase was also observed if the chlorophyll concentration was expressed on a FW basis (data not shown). Both chl a and chl b contributed to this increase (Table 3). As moisture stress became severe, chl a, chl b and total chlorophyll content were reduced at all growth stages when compared to the control. The present results are consistent with those reported by Younis *et al*. [21], who have found that a mild water deficit increased chl a, chl b and total chl content in different sorghum cultivars, while prolonged severe water stress decreases chl content significantly. The increase in chl content under mild water stress may be due to the increased thickness of leaves and compacted mesophyll cells of stressed-leaves, consequently more chloroplasts per unit area develop as often the case under stress conditions [22]. Results of decreasing chlorophyll content under advanced water stress was similar to that reported by Prakash and Ramachandran [23] in brinjal, who postulated that moisture stress would have inhibited the biosynthesis of chl a precursor, which in turn would have reduced the total chlorophyll content.

Data showed that Kaolin treatments significantly increased chlorophyll content in water-stressed plants compared to the control plants, while VG did not cause significant changes in chl content. Reducing heat stress and sustaining suitable leaf water content of Kaolin-sprayed plants could enhance chl formation and increased chl concentration in plant leaves (Table 3). Earlier work by Prakash and Ramachandran [23] showed that among several antitranspirant materials, limewash particle type enhanced chl formation in moisture-stressed brinjal plants compared with the untreated plants. Recently, Tworkoski *et al*. [24] indicated that the particle-film-type antitranspirant enhanced chl biosynthesis and increased the chl content of bean leaves.

Table 3. Effects of Vapor Gard (VG) and Kaolin sprays on chlorophyll a, chlorophyll b and total chlorophyll (μg dm^{-2}) in leaves of tuberose plants grown under different irrigation regimes at different growth stages. Each value represents the mean of three replicates

Water regime (% ET)	AT spray	Vegetative			Flowering			Mature		
		Chl a	Chl b	Total	Chl a	Chl b	Total	Chl a	Chl b	Total
Control	00	0.64b*	0.28a	0.92b	0.70b	0.29b	0.99b	0.60a	0.22a	0.82a
80%	00	0.72a	0.30a	1.02a	0.62c	0.26b	0.88c	0.54b	0.20c	0.72b
	VG	0.63b	0.27b	0.90b	0.71b	0.28b	0.99b	0.58b	0.21a	0.79a
	Kaolin	0.85a	0.32a	1.17a	0.88a	0.34a	1.22a	0.66a	0.26a	0.92a
60%	00	0.50c	0.22c	0.72d	0.54d	0.22c	0.76c	0.42d	0.12c	0.54c
	VG	0.60b	0.25b	0.85c	0.65c	0.27b	0.92b	0.48c	0.16b	0.64b
	Kaolin	0.60b	0.26b	0.86c	0.65c	0.28b	0.93b	0.50c	0.19b	0.69b

* Means in the same column followed by the same letter are not significantly different at the 5% level according to Tukey's test.

CO_2 assimilation and transpiration rates

In line with the results of plant water status (Table 2), photosynthetic CO_2 assimilation (A) and transpiration (E) rates were significantly lower in water-stressed tuberose plants relative to non-stressed plants at all growth stages (Table 4). Data show that the decreases in both A and E were associated with significant reductions in stomatal conductance g_s. Three lines of evidence indicate the significant effect of low RWC on the photosynthetic rate. The first line is consistent with Lawlor and Cornic [19], who reported that decreasing RWC reduces g_s and thus the concentration of CO_2 supply inside the leaf [C_i]. As a consequence, *A* value declines according to the equation: $A = g_s$ [C_i]. The second line of evidence shows that the supply of CO_2 to the photosynthetic key enzyme "Rubisco" could be limiting because of the physical alteration in the structure of intercellular spaces due to leaf shrinkage at low RWC [19]. A third explanation was reported by Prakash and Ramachandran [23] who attributed the reduction in the photosynthetic rate mainly to the decrease in chlorophyll content under severe water-deficit conditions.

Although the application of both antitranspirants was found to improve *A* in water-stressed plants, Kaolin particle film was found to have greater effect than VG. The increase in *A* due to particle film and VG antitranspirants was also reported by Prakash and Ramachandran [23], who found that the photosynthetic rate was higher in water-stressed plants treated with particle film-type antitranspirants than untreated stressed plants. The present study indicated that the increased *A* in Kaolin treated plants was found to be associated with reduced leaf temperature and increased g_s with heat stress being reduced. The study of Glenn *et al.* [5] on the use and the effect of Kaolin indicated that the reflective coating spray on plants under water stress provided more benefit in reducing the heat load than a reduction in CO_2 assimilation due to light obstruction. In a similar study, Tworkoski *et al.* [24] found that particle application did not affect photosynthesis, while leaf temperatures, g_s and *E* of bean plants were reduced. An explanation of the mechanism of Kaolin application on treated plants was reported by Jifon and Syvertsen [16], who demonstrated that Kaolin particle film increased leaf reflectance and reduced midday leaf temperature and leaf-to-air vapor pressure differences (VPD). They also found that reductions in leaf temperatures and VPD were accompanied by increased g_s and *A* of Kaolin-treated leaves.

Water stress significantly reduced *E*, while antitranspirants enhanced it either at 60% or 80% ET irrigation (Table 4). It was clear that during active growth periods, i.e., vegetative and flowering stages, the g_s of the control plants varied within a narrow range (176 – 170 mmol m^{-2} s^{-1}), and *E* also changed between 3.0 and 3.6 mmol m^{-2} s^{-1}, while the corresponding values for the 60% ET stressed-plants were about 134 to 101 mmol m^{-2} s^{-1} and 2.0 to 2.4 mmol m^{-2} s^{-1} for g_s and *E*, respectively. As was found in the present study, and in consistence with Liang *et al.* [25], g_s and *E* were significantly reduced when Ψ_w declined when RWC decreased with water stress. The effect of low g_s in reducing the transpiration rate with the decrease of available soil water could be a combination of several phenomena. Some of these phenomena might be increased hydrolic resistance within the xylem, increased resistance at the soil-root interphase [26], and increased irradiance energy supply [15].

The potential of both antitranspirants to reduce transpiration rates was more pronounced at 60% than at 80% ET irrigation level. However, Kaolin was more effective in reducing the transpiration rate than VG, particularly at the later stages of plant growth.

The present data also showed that the g_s of VG or Kaolin sprayed-plants did not reach that of the control plants. But, both antitranspirants caused a significant increase in g_s of water-stressed plants compared to non-sprayed, stressed-plants. A highly positive correlation (r = 0.84) between the E and g_s values for each antitranspirant was found along the experimental period. The close association between E and g_s was also recorded in earlier studies [9]. The effects of antitranspirants on E and g_s discussed in the present study were consistent with those reported by Darlington *et al.* [27].

Table 4. Effects of Vapor Gard (VG) and Kaolin sprays on the net CO_2 assimilation rate (A), the transpiration rate (E) and the stomatal conductance (g_s) of tuberose plants grown under different irrigation regimes at different growth stages. Each value represents the mean of three replicates

		A (µmol CO_2 m^{-2} s^{-1})			E (mmol H_2O m^{-2} s^{-1})			g_s (mmol m^{-2} s^{-1})		
Water regime (% ET)	AT spray	Vegeta-tive	Flower-ing	Mature	Vegeta-tive	Flower-ing	Mature	Vegeta-tive	Flower-ing	Mature
Control	00	12.1a	11.6a	6.0a	3.08a	3.60a	2.65a	176a	170a	108a
80%	00	10.7b	9.2b	4.8b	2.86b	2.92b	2.50a	157b	140b	86c
	VG	10.5b	9.8b	5.0b	2.66b	2.80b	2.44a	168a	152a	92b
	Kaolin	11.4a	10.7a	5.8a	2.75 b	2.65 b	2.30b	171a	156a	98b
60%	00	7.8d	6.3d	3.0d	2.05d	2.36c	1.94c	134c	101c	71d
	VG	9.2c	8.8c	4.7c	2.50c	2.46c	2.10b	160b	130b	90b
	Kaolin	9.9c	8.7c	5.0b	2.56c	2.34c	2.09b	158b	148b	88c

*Means in the same column followed by the same letter are not significantly different at the 5% level according to Tukey's test.

Water use efficiency

Water use efficiency (WUE) was the highest during vegetative and flowering growth stages but declined at mature stage (Fig. 3). Vapor Gard and Kaolin sprays had positive, though insignificant, effects on the WUE of water stressed plants compared to unsprayed plants. As discussed earlier, VG and Kaolin enhanced the net CO_2 assimilation rate (A) and decreased the transpiration rate (E) of plants grown under water-deficit conditions, particularly 80% ET. Thus, the instantaneous WUE, estimated as the ratio between A and E, was significantly higher in antitranspirant-treated plants compared to the control or stressed unsprayed-plants. Because WUE declines with increasing incident radiation [16], increasing reflection of incident radiation from Kaolin-sprayed tuberose leaves may be the main reason for the superiority of Kaolin over the VG in causing substantial increases in WUE of water-stressed plants.

In conclusion, the negative effect of water deficit, imposed at different developmental stages of growth, on stomata, water status, photosynthesis, and the transpiration rate in tuberose, as an example of valuable ornamental plants, is an important aspect to consider in arid regions. Applications of emulsion film type, "Vapor Gard", and Kaolin particle film type, "Surround WP", were found to enhance parameters of water relation and CO_2 assimilation in plants subjected to mild water stress (80% ET), while at higher water stress (60% ET) antitranspirants could not induce suitable physiological performances. Under the conditions of high water deficit and heat stress with high evaporative demands, such as that prevailing in arid and semi-arid regions, Kaolin sprayed-plants would perform better than VG-sprayed plants due to its ability to reflect most of the radiant energy falling on leaf surfaces, thus to reduce the leaf temperature and the transpiration rate, and to increase the photosynthetic rate and the water use efficiency.

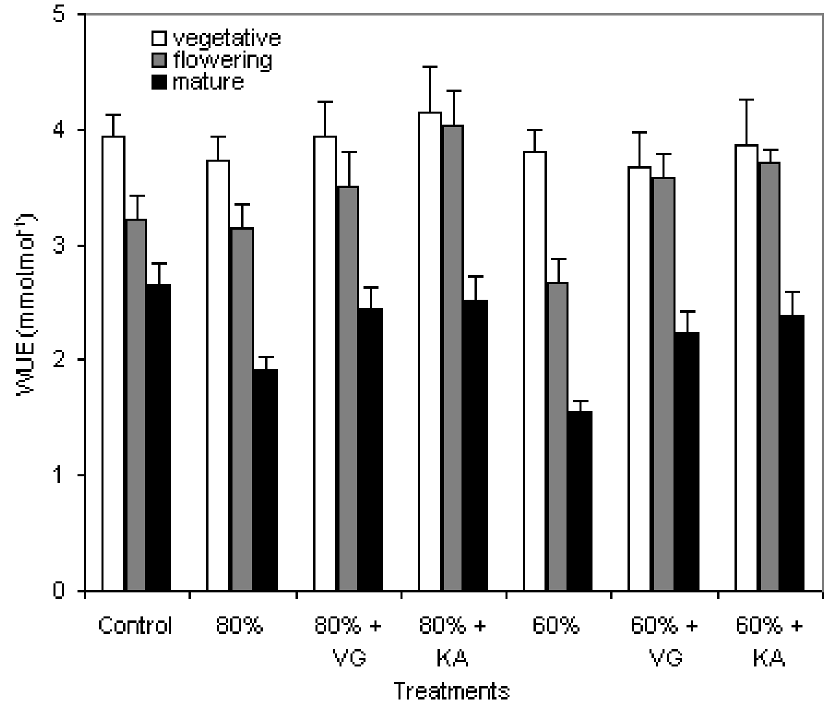

Fig. 3. Effects of Vapor Gard (VG) and Kaolin (KA) on water use efficiency (WUE) in tuberose plants grown under different irrigation regimes. Error bars indicate SE (n = 4).

References

[1] Prakash, M. and Ramachandran, K. "Effects of Chemical Ameliorants in Brinjal (*Solanum melongena* L.) under Moisture Stress Conditions." *J. Agron. Crop Sci*., 185 (2000), 237-239.

[2] Moftah, A.E. "The Response of Soybean Plants, Grown under Different Water Regimes, to Antitranspirant Applications." *Ann. Agric. Sci.*, 35 (1997), 263-292.

[3] Gawish, R. "Effect of Antitranspirants Application on Snap Bean (*Phaseolus vulgaris* L.) Grown under Different Irrigation Regimes." *Minufiya J. Agric. Res.*, 17 (1992), 1309-1325.

[4] Nakano, A. and Uehara, Y. "The Effect of Kaolin Clay on Cuticle Transpiration in Tomato." *Acta Hort*., 440 (1996), 233-238.

[5] Glenn, D.M., Erez, A., Puterka, G.J. and Gundrum, P. "Particle Films Affect Carbon Assimilation and Yield in 'Empire' Apple." *J. Amer. Soc. Hort. Sci.*, 128 (2003), 356-362.

[6] Gupta, N.K., Sunita, G. and Arvind, K. "Effect of Water Stress on Physiological Attributes and Their Relationship with Growth and Yield of Wheat Cultivars at Different Stages." *J. Agron. Crop Sci*., 186 (2001), 55-62.

[7] Sutherland, F. and Walters, D.R. "*In vitro* Effects of Film-forming Polymers on the Growth and Morphology of *Pyrenophora avenae* and *Pyricularia oryzae*." *J. Phytopath.*, 149 (2001), 621-624.

[8] El-Naggar, A.I. "Investigation on the Responses of Tuberose Plants (*Polianthes tuberosa*, L.) cv. "Double" to Biofertilization with Azospirillum Strains Mixture and Nitrogen Fertilization under Four Different Soil Textures." *J. Agric. Mansoura Univ*.**,** 23 (1998), 6177-6203.

[9] Martinez, P.F., Tartoura, S.A.A. and Roca, D. "Air Humidity, Transpiration and Blossom-end Rot in Soilless Sweet Pepper Culture." *Acta Hort*.**,** 559 (2001), 425-429.

[10] Snedecor, G.W. and Cochran, W.G. *Statistical Methods*., 18th ed., Ames, Iowa, USA: The Iowa State College Press, 1980.

[11] Sing, A. "Techniques to View Stomata." In: *Practical Plant Physiology*. pp. 64-72. New Delhi, India: Kalyani Pub., 1982.

[12] Scholander, P.F., Hammer, H.T., Bradsteel, E. and Henningsen, E.A. "Sap Pressure in Vascular Plants." *Science*, 148 (1965), 339-346.

[13] De Pascale, S., Ruggiero, C., Barbieri, G. and Maggio, A. "Physiological Response of Pepper to Salinity and Drought." *J. Amer. Soc. Hort. Sci*.**,** 128 (2003), 48-54.

[14] Wettestein, D.W. "Chlorophyll-lethal under submikroskopische formwechsel der plastiden." *Exp. Cell Res.*, 12 (1957), 427-506.

[15] Taiz, L. and Zeiger, E. "Stress Physiology." In: *Plant Physiology*, 3rd ed., pp. 591-620. Sunderland, Massachusetts, USA: Sinauer Assoc. Inc. Pub., 2002.

[16] Jifon, J.L. and Syvertsen, J.P. "Kaolin Particle Film Application Can Increase Photosynthesis and Water Use Efficiency of 'Ruby Red' Grapefruit Leaves." *J. Amer. Soc. Hort. Sci*., 128 (2003), 107-112.

[17] Tucci, M.L.S., Bovi, M.L.A., Spiering, S.H. and Machado, S. "Stomatal Frequency and Size in Leaves of Pejibaye (*Bactris gasipaes* Kunth)." *Acta Hort*.**,** 516 (2000), 145-154.

[18] Broadley, M.R., Escobar-Gutierrez, A.J., Bums, A. and Bums, G. "Nitrogen-limited Growth of Lettuce is Associated with Lower Stomatal Conductance." *New Phytologist*, 152 (2002), 97-106.

[19] Lawlor, D.W. and Cornic, G. "Photosynthetic Carbon Assimilation and Associated Metabolism in Relation to Water Deficit in Higher Plants." *Plant, Cell and Environ*., 25 (2002), 275-294.

[20] Davenport, D.C., Uriu, K. and Hagan, R.M. "Effects of Film Antitranspirants on Growth." *J. Exp. Bot*.**,** 25 (1974), 410-419.

[21] Younis, M.E., El-Shahaby, O.A., Abo-Hamed, S.A. and Ibrahim, A.H. "Effects of Water Stress on Growth, Pigments and CO_2 Assimilation in Three Sorghum Cultivars." *J. Agron. Crop Sci*.**,** 185 (2000), 73-82.

[22] Delperee, C., Kinet, J.M. and Lutts, S. "Low Irradiance Modifies the Effect of Water Stress on Survival and Growth-related Parameters During the Early Developmental Stages of Buckwheat (*Fagopyrum esculentum*)." *Physiol. Plant*., 119 (2003), 211-220.

[23] Prakash, M. and Ramachandran, K. "Effects of Moisture Stress and Anti-transpirants on Leaf Chlorophyll." *J. Agron. Crop Sci*.**,** 184 (2000), 153-156.

[24] Tworkoski, T.J., Glenn, D.M. and Puterka, G.J. "Response of Bean to Application of Hydrophobic Mineral Particles." *Can. J. Plant Sci*., 82 (2002), 217-219.

[25] Liang, Z., Zhang, F., Shao, M. and Zhang, J. "The Relations of Stomata Conductance, Water Consumption, Growth Rate to Leaf Water Potential During Soil Drying and Rewatering Cycle of Wheat (*Triticum aestivum*)." *Bot. Bull. Acad. Sin*., 43 (2002), 187-192.

[26] Passioura, J.B. "Water Transport in and to Roots." *Annu. Rev. Plant Physiol. Mol. Biol*., 39 (1988), 245-265.

[27] Darlington, A., Vishnevetskaia, K. and Blake, T.J. "Growth Enhancement and Antitranspirant Activity Following Seed Treatment with a Derivative of 5-hydroxybenzimidazole (Ambiol) in Four Drought-stressed Agricultural Species." *Physiol. Plant*., 97 (1996), 217-222.

تأث   الكاول   وبلوم ات البابنول   على العلاقات ا ائية ومعدل البناء الضوئي لنباتات التيوب وز النامية   ت ظروف نقص ا ياه

أنصاري إدريس مفتــاح و عبد الر ن إبراهيم ا ميــد

قسم إنتاج النبات ووقايته، كلية الزراعة والطب البيطري،

جامعة القصـيم، المملكة العربية السعودية

(قدم للنشر في ١٤٢٥/٤/٣هـ؛ وقبل للنشر في ١٤٢٥/١١/٧هـ)

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 مستحلب مادة "فابور جارد". ومضادات النتح المكونة لطبقة من دقائق وجسيمات مادة "كاولين" على أسطح الأوراق على كل من الجهد المائي والاسموزي ومعدل النتح ومعدل البناء الضوئي والمحتوى المائي وكفاءة استخدام الماء لنباتات التيوبيروز النامية تحت معدلات ري ١٠٠٪ و ٨٠٪ و٦٠٪ من كمية الماء المفقود بواسطة البخر-نتح، كما استهدفت الدراسة معرفة أي أنواع مضادات النتح أكثر ملاءمة للاستخدام تحت ظروف نقص الماء السائدة في منطقة القصيم وذلك في محاولة لتوفير ماء الري عن طريق تقليل الماء المفقود خلال عملية النتح، وقد تبين من النتائج نقص معدل تكوين الثغور وانخفاض عددها بالنسبة لوحدة المساحات في أوراق النباتات النامية تحت ظروف نقص الماء (٦٠٪ و٨٠٪)، كما نقص الجهد المائي (Ψ_w) والاسموزي (Ψ_π) لتلك النباتات وأيضا محتوى الماء النسبي. كما نقص محتوى الأوراق من الكلوروفيل نتيجة نقص الماء وذلك بالمقارنة بنباتات المقارنة. وعند معدل الري الأقل من ١٠٠٪ زادت مقاومة الثغور للتبادل الغازي وقل معامل التوصيل وبالتالي نقص معدل البناء الضوئي وأيضا معدل النتح بدرجة شديدة بالمقارنة بنباتات الكنترول (١٠٠٪).

وجد أن كلا النوعين من مضادات النتح المستخدمة حسنت من النشاط الفسيولوجي ونمو النباتات تحت معدلات الري المنخفضة (٦٠٪ و ٨٠٪) وذلك بمقارنتها بتلك النامية تحت ظروف الإجهاد المائي (بدون رش بالمواد المضادة للنتح)، ولكن لم تصل لمستوى نباتات المقارنة خصوصا عند المعاملة ٦٠٪.

كانت الزيادة في كل من الجهد المائي والجهد الاسموزي والمحتوى المائي ومعدل البناء الضوئي في النباتات المعاملة بمادة الكاولين أعلى كثيرا من تلك الناتجة من استخدام الفابور جارد، حيث كانت مشابهة تقريبا لنباتات المقارنة النامية تحت معدلات ري ١٠٠٪. أدت مادة الكاولين إلى زيادة معنوية في كفاءة النباتات المعاملة في استخدامها الماء الممتص (WUE) وذلك بالمقارنة بمضاد النتح "فابور جارد".

وجد أن مادة الكاولين أكثر ملاءمة لاستخدامها على نباتات التيوبيروز النامية تحت الأجواء الصحراوية الجافة السائدة في منطقة القصيم وذلك بسبب تكوينه طبقة عاكسة لأشعة الشمس القوية على أوراق النباتات التي تؤدي إلى خفض درجة حرارتها بدرجة ملموسة عن حرارة الجو المحيط، وفي نفس الوقت تقلل من كمية الماء المفقود عن طريق النتح دون أي تأثير ضار على نمو النباتات.