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EFFECTS OF ANTITRANSPIRANTS ON WATER RELATIONS AND PHOTOSYNTHETIC RATE OF CULTIVATED TROPICAL PLANT (*POLIANTHES TUBEROSA* L.)

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.) were studied. The 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, used in cultivation of tuberose plants in arid regions. Severe water stress, decreased the stomatal frequency and conductance (g_s), the leaf water potential (Ψ_w), the osmotic potential (Ψ_π) and the turgor potential (Ψ_p), the relative water content (RWC), the chlorophyll content (chl), the 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 arid regions.

KEY WORDS**:** water stress, antitranspirant, photosynthesis, water relations, *Polianthes*.

1. INTRODUCTION

There is a critical need to balance water availability, water requirements and water consumption thus water conserving is becoming a decisive consideration for agriculture, 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 (Prakash and Ramachandran 2000a). Actively growing plants would 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 (Moftah 1997). This 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 the leaf resistance to the diffusion of water vapor. Based on their mechanism of action, such anti-transpirants (AT) were grouped into three categories (Moftah 1997), 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 AT were found to be non- toxic and have longer period of effectiveness than metabolic types (Gawish 1992). Moreover, in contrast to most film-forming AT which are impermeable to CO_2 exchange and thus may reduce the rate of photosynthesis (Moftah 1997), 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 (Nakano and Uehara 1996). Early studies demonstrated that the reflective Kaolin improved the water status and the yield of water-stressed tomato plants, while it did not reduce carbon assimilation (Glenn *et al.* 2003).

Many studies have focused on comparing the effects of AT on vegetables (Prakash and Ramachandran 2000a) fruits (Glenn *et al.* 2003) and field crops (Moftah 1997; Gupta *et al.* 2001; Sutherland and Walters 2001). Unfortunately, data concerning the impact of combined AT and extreme desert climatic conditions on ornamental plants are crucially lacking. Moreover, not a single study has investigated whether or not the use of a specific AT influences on ornamental plants grown under water deficit conditions in warm desert regions. However, a great deal of interest in ornamental plants has recently been shown by landscape gardeners in almost all provinces of Saudi Arabia as in other parts of the world.

Tuberose (*Polianthes tuberosa* L.) is one of the most popular odorous flowering ornamentals and is an excellent summer blooming flowering bulb well suited to the summer. It is commercially grown for its attractive and luring cut flowers and also for the production of new bulbs. Floral arrangements are made from its flowers and also used for floral bouquets and for table decorations because the flowers remain effectively fresh and attractive for days. 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 (El-Naggar 1998). Therefore, the present study was undertaken 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 *P. tuberosa* plants grown in sandy soil under different water regimes, to select the most suitable one for conserving irrigation water in arid regions.

2. MATERIAL AND METHODS

Tuberose (*Polianthes tuberosa* L.) cv. Double bulbs of about 4–5 cm in diameter were planted on April 7th, 2002, in 30 cm (in diameter) plastic pots each filled with 10 kg of air-dried, sandy soil. Pots were placed in a greenhouse and plants were allowed to grow for four weeks at 30/20°C day/night temperatures, 400 $\mu mol\ m^{-2}\ s^{-1}$ photosynthetic active radiation (PAR), enhanced by a high pressure, sodium-lamp supplement from 5 to 21 h. Before planting, the first of three equal doses of "Sangral" (William Sinclair Horticulture LTD, England) compound fertilizer (20N-20P–20K, plus micronutrients) was applied to the soil (600 kg ha^{-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.

Physical and chemical properties of the experimental soil were as following: sand was 95% of soil fractions (silt = 3.6%, clay = 1.1%), pH = 8.2, ECe = 2.06 ms; soluble cations: Na^+ = 11.0, Ca^{2+} = 4.4, and Mg^{2+} = 2.5 meq.L^{-1}; soluble anions: $CO_3^{2-} + HCO_3^- = 3.0$, SO_4^{2-} = 11.7, and Cl^- = 7.6 meq.L^{-1}; $CaCO_3$ = 4.0% and organic matter = 0.23%. In the greenhouse, all pots were irrigated to the field capacity. The field capacity of the soil was 11.50% ± 0.3% (mean of six replications ± SE), measured with the pressure–plate apparatus.

Pots were then transferred to the open air under field conditions and plants were irrigated to field capacity for another four weeks to prevent water stress, to ensure the establishment of seedlings and to allow adaptation to the field conditions before drought treatments were imposed. The second remaining two doses of fertilizer were applied fortnightly thereafter (i.e. 70 and 84 days after planting). Eight weeks after planting, water stress was imposed by withholding irrigation for a period of three days, during which AT were applied and the watering of pots, as assigned to the required water stress levels, was resumed on the 4th day of water deprivation.

Depending on a preliminary experiment and recommendations of earlier studies on different crop species (Gawish 1992; Nakano and Uehara 1996; Moftah 1997; Martinez *et al.* 2001), Vapor Gard (Miller Chemical & Fertilizer Corp., Hannover, PA, USA) was applied at 2% and Surround WP (Engelhard Corp., Iselin, NJ, USA), a hydrophilic Kaolin particle film, with wetting and sticking agent, was applied at 3%. The treatments of both AT were prepared using only water (Sutherland and Walters 2001; Glenn *et al.* 2003;). Thus AT treatments were: i) 0 (control), ii) 2% VG emulsion film, and iii) 3% Kaolin particle film. Starting from 59 days after planting, tuberose plants were sprayed with fine mist of the AT solutions, using a hand pressure-sprayer, until run-off the whole plant. Water was sprayed as a control treatment.

At the beginning of water stress treatments (60 days after planting), the evapotranspiration (ET) was determined gravimetrically (weighing pots with plants). The amount of water lost during the three days 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 irrigation events.

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.

The experimental layout was a randomized complete block design, with 35 pots in each block, and 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.

At three stages of plant growth, vegetative, flowering, and maturity, the following data were recorded: a) 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 by spreading paint 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 (Sing 1982).

Leaf temperatures were measured using a steady-state porometer (LI–1600; LI-COR, Lincoln, Neb., 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.

Leaf water potential (Ψ_w) was measured using a pressure chamber (PMS Instrument Co., Corvallis, OR, USA) as described by Scholander *et al.* (1965). Leaf osmotic potential (Ψ_π) was measured with a vapor pressure osmometer Wescor 5500. Leaf pressure potentials (Ψ_p) were calculated by subtracting Ψ_π from Ψ_w. All measurements were made in mega pascal (MPa) units. Relative water content (RWC) was calculated according to the equation: RWC = 100 x (FW – DW)/(TW –DW) as described by De Pascale *et al.* (2003). 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 h, and dry weight (DW) was determined after oven drying at 75°C for 48 h. 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.

Leaves were detached and chlorophyll was extracted immediately by placing discs of known area in liquid N and crushing with a mortar and pestle. Acetone (80% + 20% distilled water) was added to the crushed tissues. Chlorophyll *a*, chlorophyll *b* and total chlorophyll were extracted and analyzed spectrophotometrically as described by Wettestein (1957). Chlorophyll concentration (μg) , on leaf area bases (dm^2), was recorded.

The net CO_2 assimilation rate (A) as μmol CO_2 m^{-2} (leaf area) s^{-1} (time of exposure to light), the stomatal conductance (g_s) as mmol (water vapor) m^{-2} (leaf area) s^{-1} (time of exposure to light), and the transpiration rate (E) as H_2O m^{-2} (leaf area) s^{-1} (time of exposure to light), 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, Neb., USA). Water use efficiency (WUE) was calculated as the ratio A/E. Measurements were taken at 13 h. The cuvette conditions (air temperature, relative humidity, and CO_2 concentration) were set to ambient, and measurements were performed at PPFD of 1400 μmol m^{-2} s^{-1}.

All measurements were taken in three replicates, unless otherwise indicated, between 11 and 13 h in the first, uppermost, fully expanded leaves from different plants in each treatment.

All data were statistically analyzed according to Snedecor and Cochran (1980) with the aid of COSTAT computer program for statistics. Differences among treatments were tested with LSD at a 5% level of significance.

3. RESULTS AND DISCUSSION

3.1. 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, and 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 (2002) indicated, plants in such regions can experience some degree of heat stress, which may negatively affect or even inhibit 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 (13–15 h) 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.* (2003) 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 15 h. The reduction in leaf temperature of the 60% ET treated plants was less pronounced than 80% ET. Vapor Gard, however, did not show significant reduction in leaf temperature, while control plants showed slight reduction in leaf temperature, particularly at 13–17 h. 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 (2003). 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 and somehow retard transpiration-cooling process.

3.2. 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 mature stages being most affected. With 60% irrigation, the number of stomata was reduced by about 31, 33, and 36% at vegetative, flowering, and mature stages, respectively. Since stomatal frequency and size are strongly correlated with the rhythm of leaf appearance (Tucci *et al.* 2000), 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 (2002). Concurrent increases in abscisic acid (ABA) level in xylem sap and plant tissues have been reported under water stress conditions (Gupta *et al.* 2001). ABA has been proposed as the common link between the development of root stress and consequent reductions in stomatal frequency (Tucci *et al.* 2000) and conductance (Broadley *et al.* 2001). 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 (2000a) in *Solanum melongena* L.

The number of stomata per unit area of Vapor Gard and Kaolin-sprayed leaves had increased compared with unsprayed, stressed plants, with Kaolin having greater effects at all growth stages. The superiority of Kaolin over VG in stomata regulation and ontogeny may

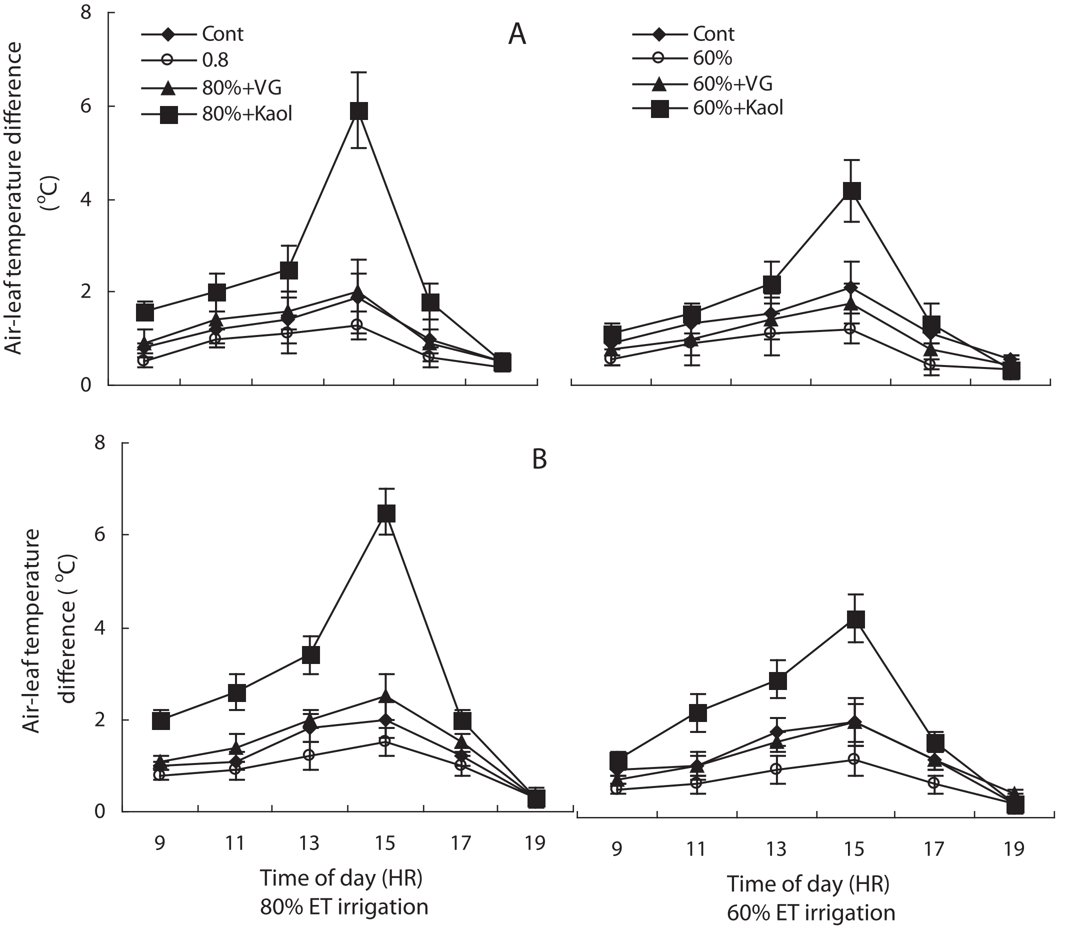

Fig. 1. Effect of Vapor Gard (VG) and kaolin (Kaol) on air-to-leaf temperature differences in leaves of tuberose (*Polianthes tuberosa* L.) plants grown under 80% or 60% ET irrigation and control during vegetative (A) and flowering (B) stages. Error bars indicate SE (n = 3).

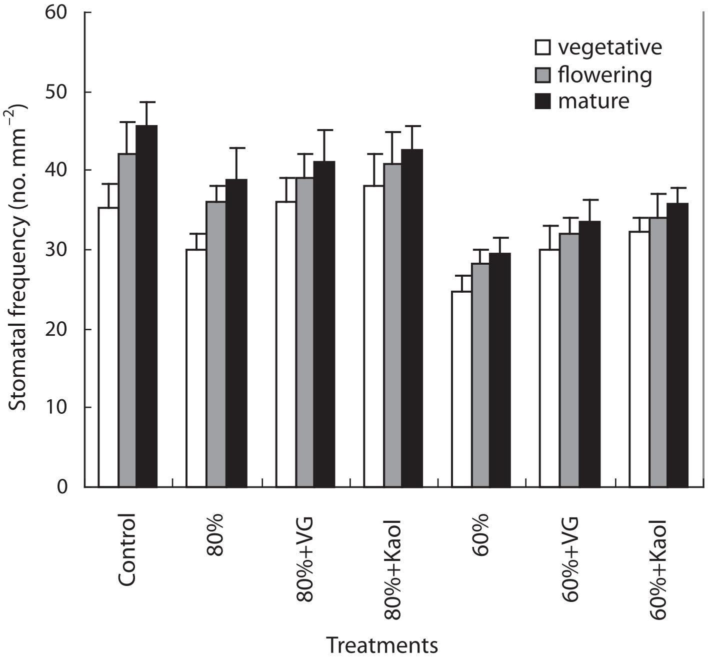

Fig. 2. Effects of Vapor Gard (VG) and Kaolin (Kaol) on stomatal frequency (average of adaxial + abaxial sides) in tuberose (*Polianthes tuberosa* L.) plants grown under 80% and 60% ET irrigation regimes. Each bar is a mean ± standard error (n = 5).

have been brought about by the great ability of Kaolin particles to reduce heat stress and solar injury (Glenn *et al.* 2003) causing only partial closure of stomata.

3.3. Water relations

Our 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 1). It is 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 mega pascal, 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 reduction rates 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 mega pascal (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, the trend observed for Ψ_π of water-stressed plants did not differ significantly from that observed for Ψ_w during vegetative, flowering and maturity stages. The decrease in water relation parameters in water-stressed plants is a well-documented phenomenon (Gupta *et al.* 2001; De Pascale *et al.* 2003). It is well known that, when transpiration exceeds water absorption, cell turgor falls as RWC and cell volume decreased, whilst the concentration of cellular contents increased, so Ψ_π and Ψ_w fall (Lawlor and Cornic 2002) and, as discussed later, low turgor and RWC slow plant growth and decrease of stomatal conductance (g_s).

Vapor Gard and Kaolin treatments seemed to enhance plant water status considerably, particularly at later stages of plant growth. Substantial 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 reduced leaf temperature and transpiration rate (Glenn *et al.* 2003), not only due to the formation of a physical barrier against water loss, as in the case of the emulsion film-forming materials, VG (Davenport *et al.* 1974).

3.4. Chlorophyll content

During vegetative stage, mild water stress (80% ET) increased unexpectedly total chlorophyll content, expressed on leaf area basis (Table 2). Such an increase was also observed if the chlorophyll concentration was expressed on a fresh weight basis (data not shown). As moisture stress became severe,

Table 1. Effects of Vapor Gard (VG) and Kaolin sprays (AT) on leaf water potential (Ψ_w), leaf osmotic potential (Ψ_π), and leaf turgor potential (Ψ_p) in mega pascal (MPa) units at vegetative (65 DAP[1]), flowering (80 DAP) and mature (95 DAP) stages of tuberose (*Polianthes tuberose* L.) plants grown under 60% and 80% of ET[2] irrigation regimes. Each value of MPa represents the mean of three replicates.

Water regime (% ET)	AT spray	Ψw			Ψπ			Ψp		
		Vegetative	Flowering	Mature	Vegetative	Flowering	Mature	Vegetative	Flowering	Mature
Control	00	−0.82a[3]	−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

[1] DAP = Days after planting.
[2] ET: Evapo-transpiration.
[3] Means in the same column followed by the same letter are not significantly different at the 5% level according to Tukey's test.

Table 2. Effects of Vapor Gard (VG) and Kaolin sprays (AT) on chlorophyll *a*, chlorophyll *b* and total chlorophyll (μg dm^{-2} leaf area) at vegetative (65 DAP[1]), flowering (80 DAP) and mature (95 DAP) stages in leaves of tuberose (Polianthes tuberose L.) plants grown under 60% and 80% of ET[2] irrigation regimes. Each value of chlorophyll units 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	0.64b3	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

[1] DAP = Days after planting.
[2] ET: Evapo-transpiration.
[3] Means in the same column followed by the same letter are not significantly different at the 5% level according to Tukey's test.

chlorophyll *a*, chlorophyll *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.* (2000), who found that a mild water deficit increased chlorophyll *a*, chlorophyll *b* and total chlorophyll content in different *Sorghum vulgare* cultivars, while prolonged severe water stress decreased chlorophyll content significantly. The increase in chlorophyll 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 as often in the case under stress conditions (Delperee *et al.* 2003). Results of decreasing chlorophyll content under advanced water stress was similar to that reported by Prakash and Ramachandran (2000b) in *Solanum melongena*, who postulated that moisture stress would have inhibited the biosynthesis of chlorophyll *a* precursor, which in turn would have reduced the total chlorophyll content.

Under 80% irrigation regime, Kaolin treatments significantly increased chlorophyll content in water stressed-plants compared to the control plants, while VG did not cause significant changes in chlorophyll content. Reducing heat stress and sustaining suitable leaf water content of Kaolin-sprayed plants may have enhanced chlorophyll formation in plant leaves. Prakash and Ramachandran (2000b) showed that among several antitranspirant materials, Limewash particle type enhanced chlorophyll formation in moisture-stressed *Solanum melongena* plants compared with the untreated plants. Recently, Tworkoski *et al.* (2002) indicated that the particle-film-type antitranspirant enhanced chlorophyll biosynthesis and increased the chlorophyll content of *Phaseolus vulgaris* leaves.

3.5. CO_2 assimilation and transpiration rates

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 3). Data show that the decreases in both A and E are associated with significant reduction in stomatal conductance (g_s). A large body of evidence shows that reduced g_s and A are attributed mainly to low Ψ_w of water-stressed plants as RWC decreases under water deficit conditions. Three lines of evidences indicate the significant effect of low RWC on the photosynthetic rate. The first one is consistent with Lawlor and Cornic

Table 3. Effects of Vapor Gard (VG) and Kaolin sprays (AT) on the net CO_2 assimilation rate (A), the transpiration rate (*E*) and the stomatal conductance (gs) at vegetative (65 DAP[1]), flowering (80 DAP) and mature (95 DAP) stages of tuberose (*Polianthes tuberose* L.) plants grown under 60% and 80% of ET[2] irrigation regimes. Each value of measurements represents the mean of three replicates.

Water regime (% ET)	AT spray	A (μmol CO_2 m^{-2} s^{-1})			E (mmol H_2O m^{-2} s^{-1})			g_s (mmol m^{-2} s^{-1})		
		Vegetative	Flowering	Mature	Vegetative	Flowering	Mature	Vegetative	Flowering	Mature
Control	00	12.1a[3]	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

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[1] DAP = Days after planting.

[2] ET: Evapo-transpiration.

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

(2002), 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 declines according to the equation: $A = g_s [C_i]$. The second 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 (Lawlor and Cornic 2002). A third explanation was reported by Prakash and Ramachandran (2000b) 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 (2000b), 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 indicates 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.* (2003) on the use and 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.* (2002) 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 (2003), who demonstrated that Kaolin particle film increased leaf reflectance and reduced midday leaf temperature and leaf-to-air vapor pressure differences (VPD). They found also 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 3). It is 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 found in the present study, and consistent with Liang *et al.* (2002), g_s and E are 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 are increased hydrolic resistance within the xylem, increased resistance at the soil-root interphase (Passioura 1988), and increased irradiance energy supply (Taiz and Zeiger 2002). In addition, stomatal frequency and distribution might also be involved as already discussed in this study.

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 later stages of plant growth. The present data also show 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 by Martinez *et al.* (2001). The effects of antitranspirants on E and g_s discussed in the present study are consistent with those reported by Darlington *et al.* (1996).

3.6. Water use efficiency

Water use efficiency (WUE) was highest during vegetative and flowering growth stages but declined at maturity (Fig. 3). Vapor Gard and Kaolin sprays had positive effects on the WUE of water stressed plants compared to unsprayed plants. As discussed earlier, VG and Kaolin enhanced the net CO_2 assimila-

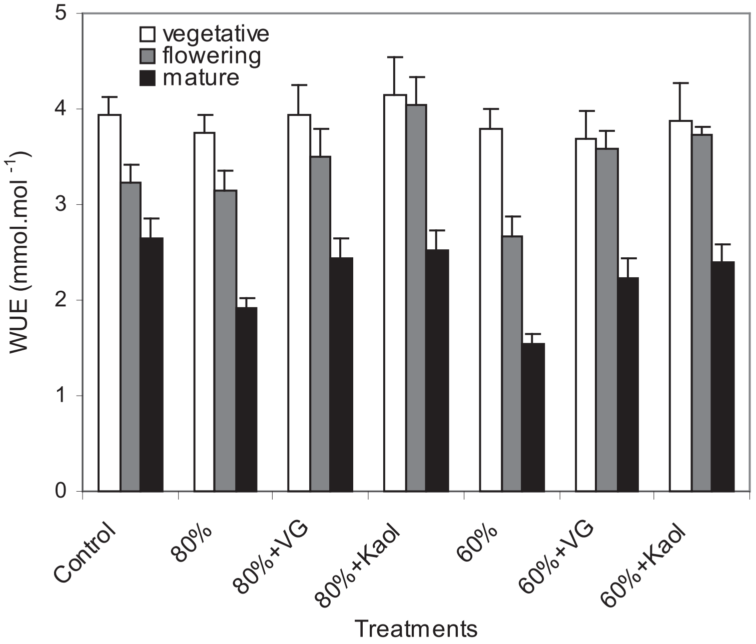

Fig. 3. Effects of Vapor Gard (VG) and Kaolin (Kaol) on water use efficiency (WUE) in tuberose (*Polianthes tuberosa* L.) plants grown under 60% and 80% ET irrigation regimes. Error bars indicate SE (n = 4).

tion 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 (Jifon and Syvertsen 2003), 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 the valuable ornamental plants, is an important aspect to consider in arid warm regions. Applications of emulsion film type, "Vapor Gard", and Kaolin particle film type, "Surround WP", were found to enhance positively all parameters 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 fall on leaf surfaces, thus to reduce the leaf temperature and the transpiration rate, and to increase the photosynthetic rate and the water use efficiency.

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