Water use efficiency response of field-grown muskmelon and pepper to environmental water status

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Abstract

The effect of water deficit on muskmelon and pepper leaf water potential, gas exchange and water use efficiency was evaluated. Both species were submitted to three watering treatments in open field conditions: irrigation only at transplanting (the control), irrigation at transplanting and fruit-setting, and full irrigation restoring 100% maximum crop evapotranspiration (*ETc*). Leaf water potential (ψ_l) in pepper markedly decreased with increasing evaporative demand during the day and it was lower in the stressed than in well-watered plants. In contrast, muskmelon maintained a near constant ψ_l from 10:00 h to 16:00 h both in stressed and in well-watered plants. Muskmelon exhibited greater net assimilation and leaf water use efficiency than pepper. With varying air vapour pressure deficit, stomatal conductance of muskmelon markedly changed while it varied slightly in pepper. Above-ground total dry biomass was much higher in muskmelon than in pepper and total biomass water use efficiency in muskmelon was about 2-fold higher than in pepper (on average 1.6 and 0.82 kg m^{-3}, respectively), demonstrating a greater efficiency of the former in using water.

Media summary

Gas exchange response of field-grown muskmelon versus pepper to environmental water status, highlighted greater stomatal sensitivity and higher water use efficiency in the former crop.

Key Words

Cucumis melo L., *Caspicum annuum* L., gas exchange, *VPD* response, water deficit.

Introduction

On a global basis, drought (assumed to be soil and/or atmospheric water deficits), in conjunction with coincident high temperature and radiation, poses the most important environmental constraints to plant survival and to crop productivity (Chaves *et al*., 2003). Mechanisms involved in the stomatal response to environmental conditions are manifold and have different quantitative effects (even sometimes opposite effects) on stomatal conductance and gas exchange (Tardieu and Simonneau, 1998). Research focusing on water stress response is becoming increasingly important. The involved mechanisms are resulting in plants being grouped into classes that account for the observed different physiological behaviours among species and environmental conditions (Tardieu and Simonneau, 1998; Chaves *et al.*, 2003). As for muskmelon and pepper in particular, most of the experiments have been conducted in controlled conditions, while field studies on the effect of water deficit on growth and gas exchange are still lacking. The objective of this study was to compare the gas exchange and water use efficiency responses of field-grown muskmelon and pepper to soil and atmospheric water status.

Methods

The research was carried out during 2003 in an open field at Matera (Basilicata, South Italy, 40?00'N, 16?00'E). Two species were compared: *Cucumis melo* L. var. inodorus Naud. cv Cocorito and *Caspicum annuum* L. cv Quadrato. Both species were submitted to three different watering treatments: a control irrigated only at transplanting (V0), a treatment irrigated at transplanting and fruit-setting (Vf) and a full irrigated treatment with restoration of 100% *ETc* (V100). Muskmelon was transplanted on 28 May and pepper on 26 May 2003. To characterize the ecophysiological response of the two species, leaf gas exchanges and leaf water potential were measured weekly during the growing cycle, between 12:00 h and 14:00 h, on the most recently fully-expanded leaves of four plants in each treatment, and daily (24 hours) on 28 July at two hours interval. Leaf gas exchange parameters: rate of CO_2 assimilation (*A*), transpiration (*T*), and stomatal conductance (*gs*) were measured using an ADC-LCA-4 portable gas exchange system, and the leaf water potential (ψ_l) by the Scholander pressure chamber. Leaf water use efficiency (WUE_L) was calculated as the ratio of *A* to *T* normalised for the vapour pressure deficit (*VPD*), while the total biomass water use efficiency (WUE_{tb}) as the ratio of the above-ground dry matter at the harvesting time to the total water use. Furthermore, gas exchange response curves to leaf vapour pressure deficit (VPD_L) on fully-expanded leaves of V100 treatments of both crops were measured using a LI-6400 portable gas exchange system, on 28 and 29 July. Sequential increase of VPD_L was obtained by using an external vapour source.

Results

At harvesting, the above-ground total dry biomass was much higher in muskmelon than in pepper (8.4, 5.5 and 3.5 t ha^{-1} for muskmelon V100, Vf and V0 treatments, respectively; 5.5, 3.4 and 1.9 t ha^{-1} for pepper V100, Vf and V0 treatments, respectively). WUE_{tb} (Fig. 1) was 2-fold higher in muskmelon than in pepper for any compared treatment; it was 2.1, 1.7 and 1.1 kg m^{-3} for V100, Vf and V0 treatments of muskmelon, respectively, and 1.0, 0.9 and 0.6 kg m^{-3} for V100, Vf and V0 treatments of pepper, respectively. These findings show that melon is able to use water more efficiently than pepper.

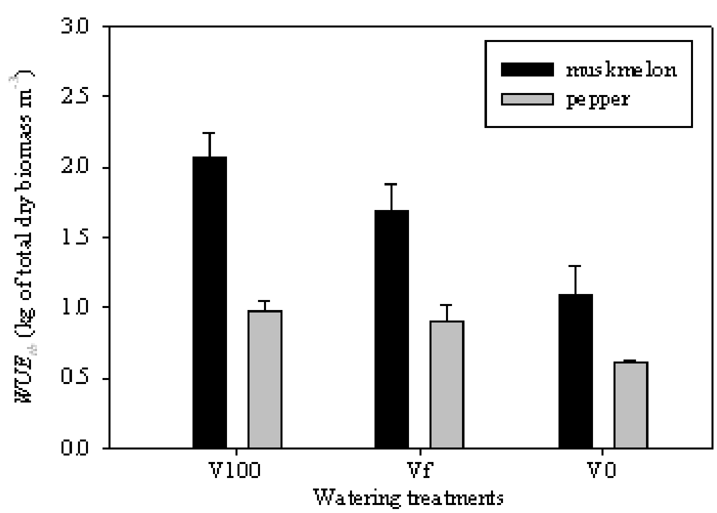

Figure 1. Effect of different watering treatments on the above ground total biomass water use efficiency (WUE_{tb}) of muskmelon and pepper. Values are average (n =4) ? s.e.

The plot of water use efficiency at leaf scale (WUE_L) versus stomatal conductance (*gs*) referred to all treatments of both crops is given in Fig. 2. Average WUE_L values are 36% higher in muskmelon than in pepper, further confirming what was observed at canopy scale (Fig. 1). WUE_L of all pepper treatments remained almost constant, around 7.6 μmol $mmol^{-1}$ kPa, over the whole *gs* range (from 0.04 to 0.95 mol m^{-2} s^{-1}), while the WUE_L of muskmelon varied greatly (from 5.9 to 15.4 μmol $mmol^{-1}$ kPa), and tended to increase slightly at low *gs* values; this agrees with the leaf gas exchange theory, and it is probably due to a greater stomatal sensitivity of the muskmelon crop.

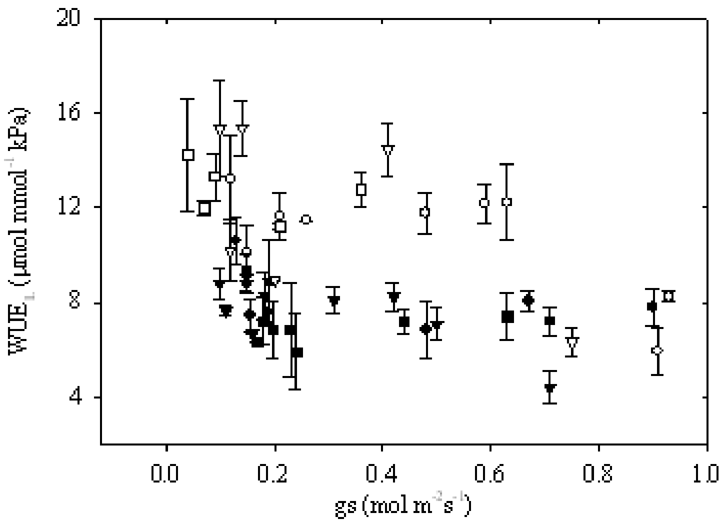

Figure 2. Leaf water use efficiency (*WUE_L*) normalised for vapour pressure deficit (*VPD*) versus stomatal conductance (*gs*) of muskmelon (open symbols) and pepper (closed symbols), subject to full irrigation (●○), irrigation at transplanting and fruit-setting (▼ ▽) and water deficit (■□). Values are average (n =4) ? s.e.

Daily monitoring of leaf water potential (ψ_l) and gas exchange parameters for both species are given in Fig. 3. ψ_l declined during the day for both crops and reached the minimum value of -1.95 and -1.55 MPa for V0 and V100 treatments of pepper, respectively; -1.50 and -1.13 MPa for V0 and V100 treatments of muskmelon, respectively (Fig. 3a). The ψ_l trend was different for the two species, showing the typical bell-shape in pepper, with the peak ψ_l value at about 13:00 h, and a plateau in muskmelon between 10:00 h and 16:00 h. Both net assimilation (*A*) and transpiration (*T*) rates progressively increased during the day; *A* reached the maximum value of 20.2 and 28.5 µmol m^{-2} s^{-1} for V0 and V100 treatments of melon and of 17.3 and 20.1 µmol m^{-2} s^{-1} for V0 and V100 treatments of pepper (Fig. 3b). *T* exhibited a similar trend in both crops, with the maximum values of 9.5 and 11.4 mmol m^{-2} s^{-1} for V0 and V100 treatments of muskmelon and 8.9 and 10.6 mmol m^{-2} s^{-1} for V0 and V100 treatments of pepper (Fig. 3c).

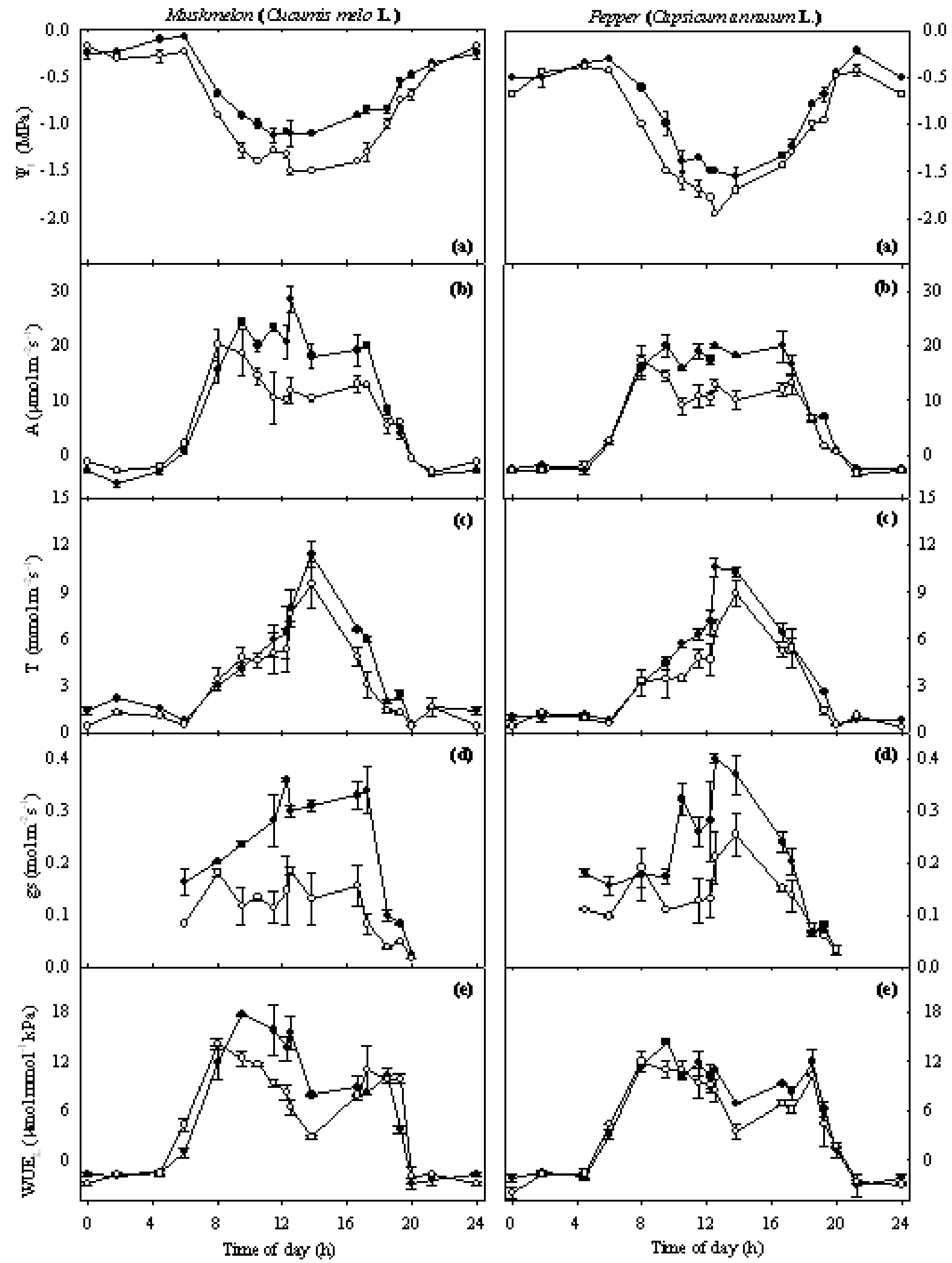

Figure 3. Daily monitoring of: (a) leaf water potential (ψ_l), (b) net assimilation (*A*), (c) transpiration (*T*), (d) stomatal conductance (*gs*) and (e) leaf water use efficiency (WUE_L) of field-grown muskmelon (left) and pepper (right). Plants were subject to full irrigation (●) and water deficit (○). Values are average (n =4) ? s.e.

Maximum stomatal conductance values (Fig. 3d) were similar in V100 treatments of pepper and muskmelon ranging, on average, around 0.37 mol m^{-2} s^{-1}, while they were different in V0 treatments (0.18 and 0.25 mol m^{-2} $^{-1}$ for muskmelon and pepper, respectively). Moreover, in V0 treatment, *gs* of muskmelon maintained low values and varied much less during the day than in pepper, indicating that, at least under water stress conditions, stomatal regulation of muskmelon seems to be more sensitive to water deficit as compared to pepper. In both crops, the maximum WUE_L values (Fig. 3e) occurred early in the morning (between 8:00 h and 10:00 h), whereas they tended progressively to decline as the day advanced, reaching the minimum values around 13:00-14:00 h and rose again in the late afternoon (17:00-18:00 h). The peak WUE_L values were 14.0 and 17.7 µmol mmol^{-1} kPa, for V0 and V100 treatments of muskmelon, respectively and 11.9 and 14.4 µmol mmol^{-1} kPa, for V0 and V100 treatments of pepper, respectively. Over the whole day, WUE_L was greater in muskmelon than in pepper.

Focusing on the gas exchange response to the atmospheric water status of the well-irrigated treatments of both crops (Fig. 4), it emerges that muskmelon showed a greater stomatal sensitivity to a raised VPD_L. Over a wide range of VPD_L, between 0.7 and 5.0 kPa, *gs* of muskmelon decreased steeply from 1.54 to 0.18 mol m^{-2} s^{-1}, while *gs* of pepper declined slightly from 1.0 to 0.15 mol m^{-2} s^{-1}. Similar responses were observed for both assimilation and transpiration rates, and consequently for WUE_L. Moreover, while the responses during the two investigated days matched the same regression in muskmelon, they were quite well separated in pepper. This was likely due to different Ψ_l values in the two measured leaves of pepper.

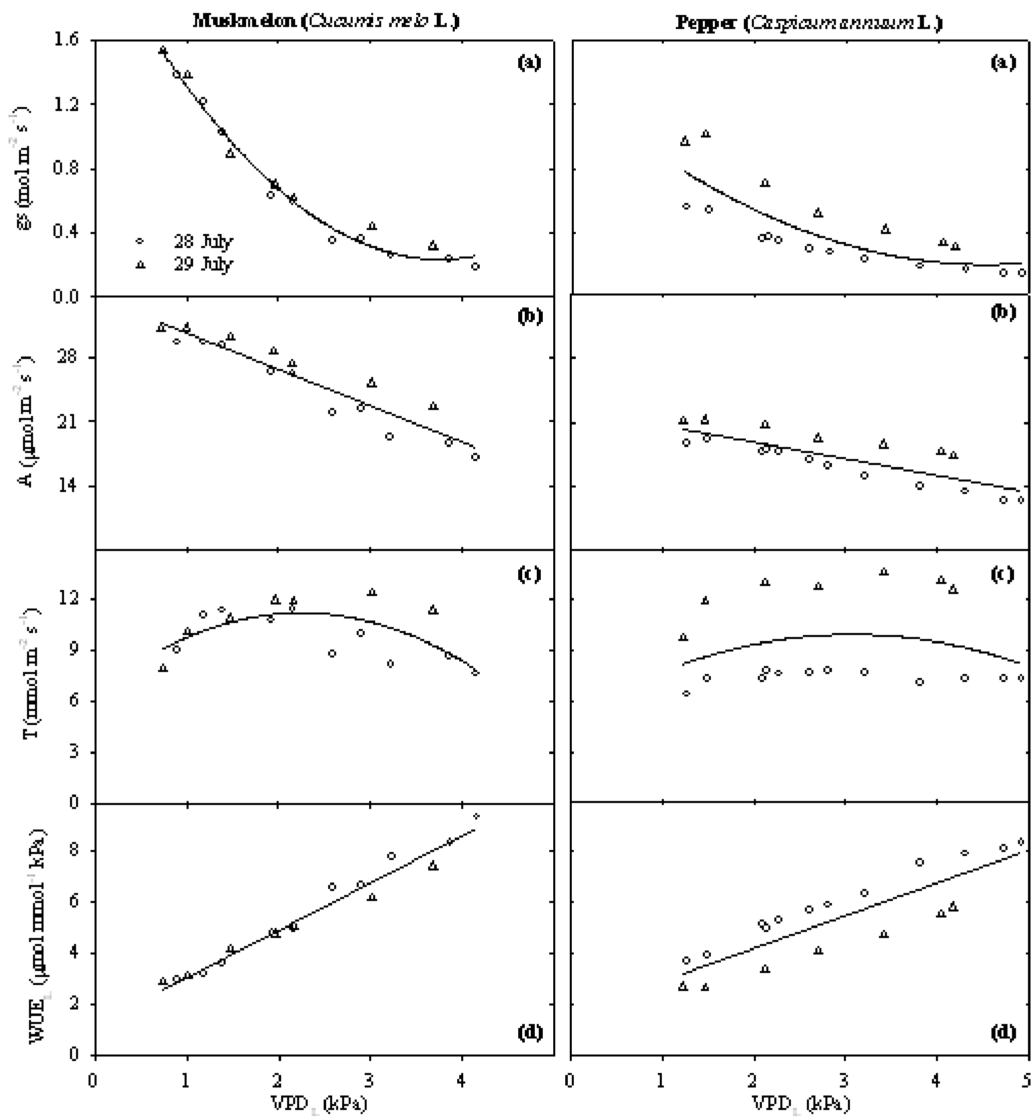

Figure 4. Response of: (a) stomatal conductance (*gs*), (b) assimilation (*A*), (c) transpiration (*T*) and (d) leaf water use efficiency (WUE_L) to leaf vapour pressure deficit (VPD_L) regime in muskmelon (left) and pepper (right).

Conclusion

Muskmelon maintains its tissue water potential around slightly negative values and at equilibrium with soil water potential by reducing maximum transpiration rate through reduced water gradient in the soil-plant system. Partial or total stomatal closure during the hours of high evaporative demand of the atmosphere, allows this crop to limit transpiration, to tolerate periods of water deficit, and to recover its full physiological functionality, once more favourable environmental condition are re-established. Pepper responds to water deficit by reducing its tissue water potential and keeping the transpiration rate almost unchanged.

Although muskmelon can reach a greater assimilation rate than pepper, in both species, leaf gas exchanges take place more intensively in the hours of the day (early morning and late afternoon) when thermal and radiative regimes are more favourable to the assimilative processes. This allows the crops to maintain high photosynthetic efficiency and an elevated efficiency in the use of water.

Muskmelon reached higher above-ground total dry biomass and WUE_{tb} values than pepper, demonstrating a greater efficiency to use water.

References

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