Greenhouse Cooling Strategies for Mediterranean Climate Areas

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Abstract

A common trend in the markets nowadays is to consume high quality fresh fruit and vegetables all year round, thus forcing to grow with these quality standards during the summer as well. Controlling the greenhouse climate during this season is a problem of increasing importance in Mediterranean climate areas, such as Spanish south east. A good management of the climate control equipment (ventilation, evaporative cooling and shading), could attenuate crop physiological stress situations, thus having a positive effect on the final yield and the product quality. During two years, different cooling strategies (white washing, fogging and natural and forced ventilation) and its effects on the microclimate, growth and yield of a substrate grown sweet pepper crop were evaluated in three multi-tunnel experimental greenhouses. Fogging was the most efficient method in controlling the maximum temperature and VPD values but was the least efficient in controlling canopy temperature. Neither fogging nor forced ventilation improved the total and marketable yield in relation to white washing, despite the radiation reduction. The crop subjected to the fog system showed the highest incidence of blossom end rot (B.E.R.). An economic evaluation showed that whitening was the most profitable cooling treatment. Thus, we can consider that combination of whitening of the plastic cover and natural ventilation as the most efficient cooling system in terms of water and energy use.

INTRODUCTION

During the last decades a great expansion of the protected horticultural surface has occurred in the Mediterranean area, based on the climatic advantages of the region, such as high radiation and smooth temperatures in autumn and spring. In Almería, most part of the year, except for the months between November and March, maximum temperatures inside the greenhouse are well above 30 ºC, being necessary to use some kina of cooling system to permit cultivation inside the greenhouse.

Besides natural ventilation, the growers resort to shading by means of plastic cover whitening in order to decrease the amount of radiation transmitted inside the greenhouse, and therefore, the accumulation of sensible heat, in such a way that the combination of natural ventilation and plastic whitening is the most used combination to cool the greenhouses. However, the whitening has more than one inconvenient such as the permanence of the product during cloudy days, the lack of homogeneity in its application, the labour needed for the application/cleaning activities and its non-selectivity to the long wave of incident radiation (Montero et al., 1998). Therefore, other cooling systems, such as mechanical ventilation of evaporative cooling, may be alternatives, due to their high efficiency.

During the season 2004/2005, Gázquez et al. (2006) compared three greenhouse cooling systems:

1. Forced ventilation. During the operation of the fans, the roof vents were opened to about 30% of their maximum aperture and the side vents were closed.
2. Natural ventilation with evaporative cooling (high-pressure water fogging system). The set point of the air vapour pressure deficit, VPD, was fixed at 1.5 kPa.
3. Natural ventilation plus whitening, (about 30% reduction in greenhouse solar radiation transmission) during the first 2 months of the crop cycle, and only natural ventilation after washing off the whitening on September 17th de 2005.

During the first growing weeks, with a low leave development, the mechanical ventilation technique was unable to maintain values of temperature and VPD within the crop optimal ranges. The marketable yield was not affected by the used cooling method. However, there was a higher incidence of Blossom end rot on the fruits grown in the greenhouse with the fog system..The economic evaluation showed a lower profitability of the mechanical ventilation and fogging techniques in relation to whitening.

From the previous results it was proposed to continue the study of the different greenhouse cooling systems during the season 2005/2006, combining this time the evaporative cooling with the whitening.

2.- MATERIALS AND METHODS

The experiments were carried out in two multi-span greenhouses, E-W oriented, located near Almería (36º 47´ N, 2º 43´ W) on the coastal area of South-Eastern Spain. The geometrical characteristics of the greenhouses were: 3 m height at the eaves, 4.5 m height at the ridge, total width 22.5 m, total length 28 m and ground area 630 m^2. The greenhouse cooling strategies were:

1. Greenhouse T1: Natural ventilation plus whitening, (25 Kg of calcium carbonate per 100 l of water) during the first 2 months of the crop cycle, and only natural ventilation after washing off the whitening on September 21th de 2005.
2. Greenhouse T2: Natural ventilation with evaporative cooling (high-pressure water fogging system) and whitening at reduced concentration (12,5 Kg of calcium carbonate per 100 l of water). The set point of the VPD was fixed at 2 kPa.

Crop and cultural practices: The rows of sweet peppers (cv. Melchor) were planted on 7th July 2005 in containers with perlite. The plant density was 3 plants m^{-2}. The plants were managed following the "trellis" technique, which consists of keeping two main stems per plant and pruning all auxiliary shoots.

Measurements: The relevant climatic variables were continuously monitored outside and inside the two greenhouses. Air temperature (ºC), and VPD (kPa), were measured by aspirated psychrometers, located 1.5 m above ground, and solar radiation, Rs (W m^{-2}) by a solarimeter. The control and management of the climate was performed from measurements taken every 30 seconds and averaged over 5 minutes, by a climate controller. With the aim of easing the analysis and the comprehension of the climate data, they were grouped into week periods and the crop cycle was divided into two parts, period 1, from transplant to the washing off of the whitening (21th of September, 77 days after transplanting (dat)) and period 2, from 77 dat until the end of the crop cycle.

In each greenhouse the transmissivity of the covering material for PAR radiation was determined by measuring with a linear sensor (LICOR Inc, Lincoln, Nebraska, USA), on clear days at 12:00 (GMT time). In each greenhouse, four Pt-100 sensors were placed on two plants, to measure the average temperature of the crop.

The total, marketable and non marketable yields, yield by category, early yield and average weight of marketable fruits were analyzed.

An economic evaluation of the different treatments was made. The gross incomes were calculated using the weighted average weekly prices for the respective harvest colours for the 05/06 season and as the average of the last three seasons (Frutas y Hortalizas, magazine). The cost of the equipment and its installation have been included, as well as the electricity costs of the fog system, also the costs of applying and washing off the whitening and the average production costs of the pepper crop.

3.- RESULTS AND DISCUSSION

Climate

At the beginning of the crop cycle, the PAR radiation transmissivity of the greenhouses was 20% for T1 and 32% for T2. During the shading period (1-76 dat) the global radiation integral was 12.5% lower in T1 in relation to T2.

The temperature values (Table 1) of both strategies analyzed have been similar during the whole growing cycle. At the beginning of the crop cycle, the only period in which the cooling devices (including the shading by whitening) were operating,. the average maximum temperatures were high (close to 33 ºC) in both greenhouses, above the optimal values for the pepper crop (20-22ºC Bakker and Van Uffelen, 1988; 25-26ºC Wien, 1997; 21-22 ºC Portree, 1996). In this period, the absolute maximum temperatures were 37.5 ºC for T1 and 35.5 for T2. During period 2 (77 dat - 196 dat) the maximum temperature values started to decrease progressively in both treatments possible due to the reduction in the incident radiation (period autumn-winter) and the increase in the leaf area index (LAI).

Table 2 shows the average VPD values, maximum and minimum, being the average of the maximum values slightly higher in T1 (2.4 kPa), versus T2 (2.2 kPa). In our study, a pepper crop with a high plant density, well irrigated, in a greenhouse with a good natural ventilation and shaded (plastic whitening), was able to maintain the VPD around 2 kPa.

Air Temperature, VPD and Canopy temperature

The efficiency of both cooling strategies for a standard day is shown on Figure 1. Thus, on day 46 after transplant (LAI≈1 m^2m^{-2}), the maximum reached values were 32 ºC and 3 kPa in T1, 2 ºC y 0.8 kPa higher than values reached in T2. As the crop developed these differences tended to decrease. These results confirm that with little developed crops with low transpiration rate, the joint application of shading and water evaporative cooling is an efficient method to control ambient temperature, achieving temperature decreases of 8-12ºC (Lansdberg et al., 1979), 10 to 15 ºC (Alpi and Tognoni, 1984) and 6ºC under Mediterranean conditions (Urban, 1997). These results are similar to those obtained by other authors (Peréz-Para *et al*.,2005; Gázquez *et al*., 2006; Meca *et al*., 2007).

The canopy-to-air temperature difference (Δ=Tcanopy-Tair), considered as an indicator of the stress conditions experienced by the crop (Jackson *et al*., 1981), exhibited marked differences between the two greenhouses. Figure 1c shows more negative values, -3.9 ºC in T1 versus – 2.1 ºC in T2, indicating that the set VPD value (2 kPa) limited the transpiration rate (data not showed). Gázquez *et al*. (2006) observed this same behaviour concluding that pepper is a species able to maintain a high transpiration rate under high radiation, VPD and temperature.

Therefore, evaporative cooling was the most efficient method to decrease temperature and air VPD, and the less efficient to decrease the canopy temperature, in agreement with the results obtained by other authors (Arbel, 2000; Baille *et al*. 2001; Baille *et al*. 2006; Gázquez *et al*., 2006; Montero, 2006).

Production

Table 3 shows the accumulated production data (g m^{-2}) achieved at the end of the crop cycle under the two studied cooling strategies. The whitening treatment achieved the larger marketable yield, with 10.2 kg m^{-2} versus 8.4 kg m^{-2} for T2, with statistically significant differences ($P<0.05$) between treatments. These data are in agreement with those obtained by Gázquez *et al*., (2006) and Meca *et al*., (2007). For the first category marketable fruits production, values of 6.7 kg m^{-2} for T1 and 5.7 kg m^{-2} for T2 were obtained. For non marketable production statistically significant differences ($P<0,05$) were found with 2.5 kg m^{-2} for T2 versus 1.1 kg m^{-2} for T1, mainly because of a larger number of fruits affected by B.E.R. and TSWV. The higher incident of B.E.R. has been associated to maintained high humidity levels which cause physiological disorders (Gázquez *et al*., 2006). Also a high fruit growth rate, due to high incident radiation and air temperature promote a high photosynthesis activity, which could increase the calcium demand (Ho *et al*., 1995).

Economic evaluation

The economic evaluation (Table 4) shows a lower profitability of the fogging plus low concentration whitening strategy (T2) versus T1 mainly because the higher installation cost of the fog system is not compensated by a higher, quality yield.

4.- CONCLUSIONS

The general conclusions from this comparative study are:

1. The evaporative cooling plus whitening at reduced concentration strategy was the most efficient to decrease air temperature and VPD, but the least efficient to decrease canopy temperature.
2. The temporal reduction of 12.5% of the incident global radiation on the crop, by means of whitening of the cover at a normal concentration, did not affect the total yield, significantly increasing the marketable yield and first category fruits.
3. The evaporative cooling plus whitening at reduced concentration strategy caused a higher incidence of blossom-end-rot.

4. The natural ventilation plus whitening at normal concentration of the cover strategy was the most appropriate cooling strategy for an autumn-winter pepper crop, being necessary to optimize its use, determining the efficiency of different whitening products, its dose and to establish physiological criteria to define the most appropriate moments for application and washing off.

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Tables

Table 1. Average air temperatures (^{o}C) in the two cooled greenhouses and outside.

Period	Temperature	T1: Whitening	T2: Fogging + Whitening$_{(50\%)}$	Outside
Complete crop cycle (1-196 dat)	**Mean**	*20.6*	*20.6*	*18.8*
	Maximum	*28.1*	*28.8*	*23.5*
	Minimum	*15.5*	*15.2*	*14.8*
Period 1* (1-76 dat)	**Mean**	*25.8*	*25.7*	*24.5*
	Maximum	*33.1*	*32.8*	*29.7*
	Minimum	*20.1*	*20*	*19.8*
Period 2 (77-196 dat)	**Mean**	*16.5*	*16.7*	*15.0*
	Maximum	*24.2*	*25.5*	*19.4*
	Minimum	*11.8*	*11.4*	*11.4*

*The cooling treatments were only neccesary during period 1. The whitening was washed Hawai in both greenhouses 76 dat (21-09-05).

Con formato: Inglés (Reino Unido)

Table 2. Average vapour pressure deficit values (kPa) in the two cooled greenhouses and outside.

Period	VPD	T1: Whitening	T2: Fogging + Whitening$_{(50\%)}$	Outside
Complete crop cycle (1-196 dat)	**Mean**	*1.0*	*1.0*	*1.1*
	Maximum	*1.7*	*1.7*	*1.7*
	Minimum	*0.2*	*0.2*	*0.2*
Period 1* (1-76 dat)	**Mean**	*1.5*	*1.4*	*1.6*
	Maximum	*2.4*	*2.2*	*2.4*
	Minimum	*0.3*	*0.3*	*0.3*
Period 2 (77-196 dat)	**Mean**	*0.6*	*0.7*	*0.8*
	Maximum	*1.1*	*1.2*	*1.2*
	Minimum	*0.2*	*0.2*	*0.2*

* The cooling treatments were only neccesary during period 1. The whitening was washed Hawai in both greenhouses 76 dat (21-09-05).

Table 3. Accumulated pepper production (g m^{-2}) from greenhouses with the two cooling strategies.

Cooling strategies	Production				
	Total	Marketable	Category 1	Category 2	Non marketable
T1:Whitening	11,345.2 a	10,230.2 a	6,734.1 a	3,496.1 a	1,115.0 b
T2: Fogging + Whitening$_{(50\%)}$	10,949.3 a	8,409.7 b	5,705.2 b	2,704.5 b	2,539.6 a

Values followed by different letters indicate significant differences (P>0.05). Each value is average of 5 replicates

Table 4. Economic analysis of pepper crops grown under two different cooling strategies.

Economic parameter	**T1:Whitening**	**T2: Fogging + Whitening$_{(50\%)}$**
Crop production cost (€ m^{-2})	3.50	3.50
Electricity consumption (€ m^{-2})		0.02
Water consumption of fog system (€ m^{-2})		0.01
Whitening cost (€ m^{-2}) 1)	0.09	0.09
Cost and installation (€ m^{-2} $year^{-1}$) 2)		0.82
Gross weighted income, prices for 04/05 season (€ m^{-2}) 5)	3.68	3.21
Gross weighted income, average prices over 03/04 to 05/06 seasons (€ m^{-2}) 3)	6.45	5.57
Net income (04/05 prices) (€ m^{-2})	0.09	-1.23
Net income (00/01 to 04/05 prices) (€ m^{-2})	2.86	1.13

1) For the crop cycle with 2 applications and 1 washing off.

2) Costs provided by installer. High pressure fog system, with filters and calcium exchanger, 1 nozzle per 10 m^2, flow of 5 l h^{-1}, plus maintenance (nozzle replacement, salt, etc). 6 years amortisation with an interest rate of 5%. Costs provided by installer.

3) The prices used to evaluate the incomes were the daily prices published by the "Frutas y Hortalizas" magazine, and they are averaged weighted prices which distinguish harvest colour but not categories.

Figures

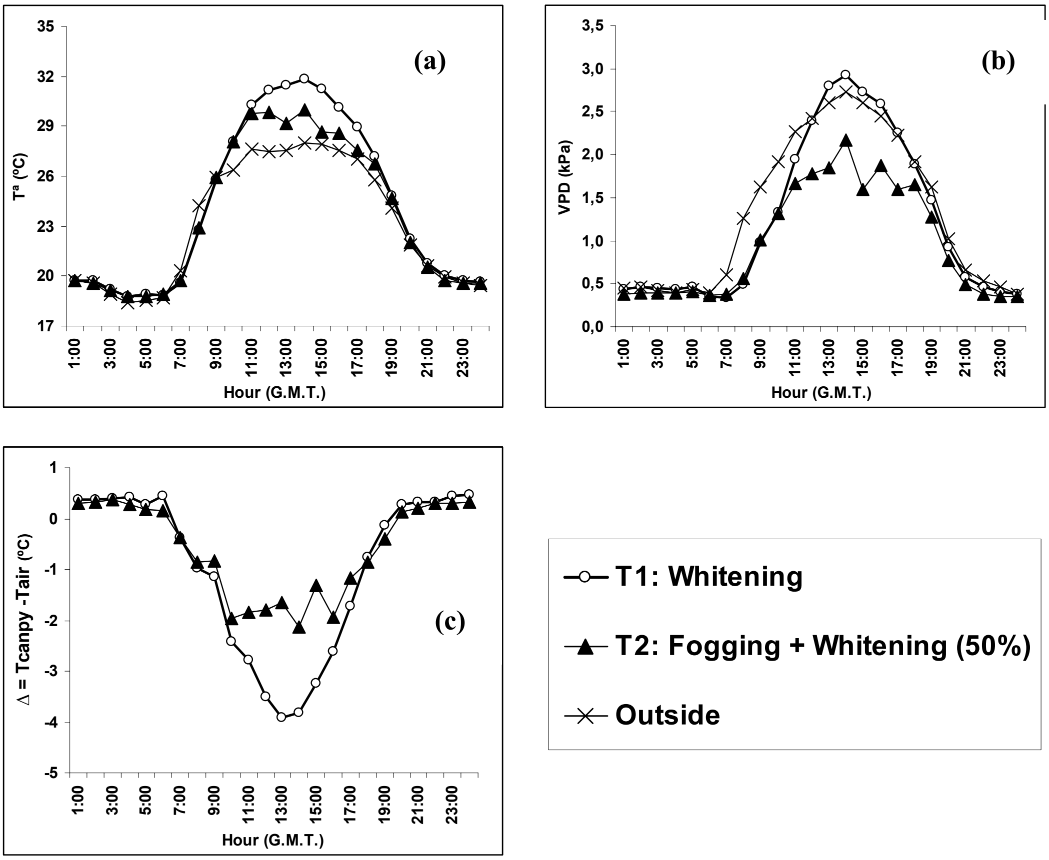

Figure 1. Hourly evolution of the air temperature (a), air VDP (b) and the canopy-to-air temperature difference (c) at DAT=46 (22 August 2005) whit LAI ≈ 1 m^2 m^{-2} for pepper crops grown under two different cooling strategies.