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Research Paper

Cooling systems in screenhouses: Effect on microclimate, productivity and plant response in a tomato crop

R. Leyva [a,b,*], C. Constán-Aguilar [b], E. Sánchez-Rodríguez [b], M. Romero-Gámez [a], T. Soriano [a]

[a] Department of Agricultural Production, IFAPA, Institute of Research and Training in Agriculture and Fisheries, 18004 Granada, Spain

[b] Department of Plant Physiology, Faculty of Sciences, University of Granada, 18001 Granada, Spain

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Mediterranean climates are characterised by summer temperatures that exceed 35 °C, high solar radiation ~ 30 MJ m^{-2}, relative humidity < 20% at around midday, and limited water resources generating yield loss in crops. For this reason, new climate strategy for greenhouses used in Mediterranean climates has been developed to avoid plant injury. Cherry tomato plants were assessed during 2010 and 2011 under different environmental conditions, namely in a screenhouse (S), in a screenhouse equipped with a fogging system (SF) and in a screenhouse with a plastic sheeting to maintain the microclimate created by the fogging system (SFS). SFS improved microclimatic conditions during the 2010 and 2011 growing seasons by, reducing incident radiation 37% and 30%, respectively while increasing relative humidity by 20% and 16%, respectively and respect to S lowering the vapour pressure deficit. These adjustments in microclimate could moderate the extremes of microclimate during the summer, avoiding episodes of physiological stress that affect yield and final quality. The dry mass vegetables plants parts grown under SFS increased while the marketable mass per plant was not significantly different. This was due to 45% increased in mean tomato fruit mass in 2010 and by 20% in 2011. Although tomato leaves grown under SFS registered the lowest values in foliar temperature, they showed the highest values for *LAI*, *SLA*, and *LAR*. It was concluded that a fogging could improve the climatic conditions under screenhouse and extend the growing season during adverse environmental conditions.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is an important horticultural crop in most parts of the world. Under summer Mediterranean conditions, when solar radiation inside the greenhouses is > 22 MJ m^{-2} d^{-1}, high temperatures (<30 °C), can limit crop productivity as well as product quality (Adams & Holder, 1992; Medina, Souza, Machado, Ribeiro, & Silva, 2002; Rosales et al., 2006; Kittas, Katsoulas, & Bartzanas, 2011). Romacho et al.

* *Corresponding author*. Tel.: +34 671532124; fax: +34 958944010. .
E-mail address: roleyva@ugr.es (R. Leyva).
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Nomenclature

CGR	Crop growth rate, g m^{-2} d^{-1}
CWSI	Crop water stress index, °C $°C^{-1}$
DAT	Days after transplanting, d
DM	Dry mass, g pl^{-1}
ET_c	Crop transpiration, mm d^{-1}
FM	Fresh mass, g pl^{-1}
GMT	Greenwich mean time, h
HI	Harvest index, g pl^{-1}
IWP	Irrigation water productivity, kg [FM] m^{-3}
LAI	Leaf area index, m^2 m^{-2}
LAR	Leaf area ratio, m^2 g^{-1}
LSD	Least significant difference
MYWUE	Marketable yield water use efficiency, kg [FM] m^{-3}
NAR	Net assimilation rate, g m^{-2} d^{-1}
PAR	Photosynthetically active radiation, μmol m^{-2} s^{-1}
RH	Relative humidity, %
S	Screenhouse
SF	Screenhouse with a fogging system
SFS	Screenhouse with a fogging system and plastic sheeting
SLA	Specific leaf area, m^2 g^{-1}
SPAD	Soil plant analysis development, units SPAD
T^a	Air temperature, °C
T_{max}	Maximum air temperature, °C
TYWUE	Total yield water use efficiency, kg [FM] m^{-3}
VPD	Vapour pressure deficit, kPa
WUE	Water use efficiency, kg [DM] m^{-3}

(2006) showed that it is possible to grow a cherry tomato crop under a screen covering house (i.e. a screenhouse) is an option for produce a good quality product at high altitude areas during summer in the south of Spain. Green bean production in screenhouses has been shown to be a promising alternative to cultivation in plastic greenhouse for spring-summer production in coastal in Mediterranean areas (Romero-Gámez, Suárez-Rey, & Soriano, 2012). Under these stressful conditions a good management of the climate control systems, such as evaporative cooling and shading, can prevent episodes of physiological stress that could lower the yield and quality of the final production (González-Real and Baille, 2000; Gázquez, López, Pérez-Parra, & Baeza, 2010). Many studies have already shown that reducing transpiration by altering the microclimate inside the greenhouse improves the physiological adaptation of plants to stress conditions such as unfavourable external climatic conditions (Gázquez et al., 2010). Recent works have focused on the effect of fogging systems on crop growth and quality in pepper (Gázquez et al., 2010), tomato (Leonardi, Guichards, & Bertini, 2000; García, Medrano, Sánchez-Guerrero, & Lorenzo, 2011), green bean (Romero-Gámez et al., 2012), rose (Katsoulas, Baille, & Kittas, 2001) and aubergine (Katsoulas et al., 2001). Leonardi et al., 2000 postulated that the reducing air vapour pressure deficit (*VPD*) by fogging system increases the fresh mass of tomatoes by greater water accumulation. This process was also accompanied by lower dry matter content (Bertin et al., 2000; Dannehl, Huber, Rocksch, Huyskens-Keil, & Schmidt, 2012). Thus, dry matter partitioning is a major determinant of crop yield, involving total fruit production, mass of individual fruits, and fruit quality, these being important factors determining economic yield (Heuvelink, 1995). Temperature and irradiation often have strong effects on the demand for assimilates and therefore on biomass allocation (Marcelis, 1993). According to Marcelis (1993) an increase temperature from 18 to 25 °C in cucumber (*Cucumis sativus*) increased fruit fresh mass production accompanied by a higher fresh mass production per gram as well as fresh-mass production per gram of dry matter produced (i.e. a lower dry matter fraction), but not necessarily by an increase in dry mass.

Gautier, Tchamichian, and Guichard (1999) discussed the effect of a fogging system on the leaf area of tomato plants during summer and reported that the high *VPD* during summer normally decreased tomato leaf area but this reduction was prevented by a fogging system. Previous studies by Romero-Gámez et al. (2012) in a bean crop (*Phaseolus vulgaris*), proposed that under extreme adverse climatic conditions during the summer, the use of a low-pressure fogging system under a screenhouse generated *VPD* values around 1.5–2.0 kPa below unfogged (control) conditions. This *VPD* decrease improved physiological parameters such as a leaf temperature (by up to 4 °C), increasing the marketable production by 22%. However, in their case part of the fogged water seeped through the permeable screen to the outside and it was difficult to maintain their *VPD* target value (2.5 kPa). For that reason, additional equipment, complementary to the fogging system, could improve the microclimate created by the screen. In this work, environmental control technologies for used in screenhouses were studied. They consisted of, a fogging system and fogging system combined plastic sheeting.

The main objective of this study was to investigate how environmental control technologies could influence the response of tomato plants in vegetative growth, fruit yield, and dry matter distribution in cherry tomato plant cultivated in a screenhouse during the summer in an inland Mediterranean area.

2. Material and methods

2.1. *Field experiments*

Cherry tomato seedlings *S. lycopersicum* L. (cv. Alina) were grown for 30 d in a tray with wells 30 mm × 30 mm × 100 mm in the nursery Semillero Saliplant S.L., Granada, Spain. Grafting with Maxifort rootstock was performed when the seedlings had developed of three to four leaves and they were kept in a breeding state for 4 weeks. A screenhouse equipped with refrigeration systems was also used. The study was conducted at the research farm station IFAPA Centro Camino de Purchil, Junta de Andalucía, Spain, situated in an inland area of the province of Granada (3° 38′ W, 37° 10′ N, 600 m altitude), during two spring-summer crop years (2010 and