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Effect of shading with aluminised screens on fruit production and quality in tomato (*Solanum lycopersicum* L.) under greenhouse conditions

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Abstract

The purpose of this study was to identify the effects of using aluminised screens offering different degrees of shading on the production and quality of tomato cv Atlético crops grown under greenhouse conditions. The study was performed in an Almería-type "*raspa and amagado*" commercial greenhouse with an area of 10,000 m^2. The covering material was heat-insulating polyethylene (200 µm thick). The passive ventilation area of the greenhouse was 14%. Transplantation of the plantlets into the sandy mulch soil of the greenhouse was performed to leave a density of 1.78 plants m^{-2}. Plants were grown under extendable aluminised screens offering 40% (T40), 50% (T50) and 60% (T60) shading, as well as under traditional whitewashing conditions (control). The screens were used during the middle hours of the day in summer with a view to reducing radiation, and at night in autumn and winter to prevent the loss of heat via outgoing long-wave infrared radiation. Only the T60 treatment returned significantly different results compared to the control: the T60 fruit had a lower ºBrix but were firmer in both growing seasons.

Additional key words: Brix degrees, climate control, firmness, fruit weight, pH, whitewashing.

Resumen

Efecto del sombreo mediante pantallas aluminizadas sobre la producción y calidad de fruto en tomate (*Solanum lycopersicum* L.) bajo invernadero

El propósito del presente trabajo fue evaluar la posible ventaja del uso de las pantallas aluminizadas con diferentes proporciones de sombreo, sobre los principales atributos de producción y calidad en cultivo de tomate cv Atlético bajo invernadero. El estudio se realizó en un invernadero comercial tipo Almería de "raspa y amagado" de 10,000 m^2. El material de la cubierta fue polietileno termoaislante de 200 µm de grosor y con un 14% de ventilación pasiva. El transplante se realizó en suelo arenado a una densidad de 1,78 plantas m^{-2}. El estudio comparó el uso de pantallas aluminizadas extensibles del 40% (T40), 50% (T50) y 60% (T60) de sombreo frente al testigo (encalado tradicional). Se utilizaron en los meses de verano durante las horas centrales del día con el objetivo de reducir la radiación y, en otoño e invierno, durante la noche para evitar la pérdida de temperatura por radiación infrarroja de onda larga. Tan sólo con T60 se obtuvieron diferencias significativas respecto del testigo, en ambas campañas, en cuanto a menor ºBrix y mayor firmeza del fruto. Un mayor sombreo produjo mayor firmeza y menor cantidad de sólidos solubles (ºBrix) en frutos.

Palabras clave adicionales: blanqueo, control climático, firmeza, grados Brix, peso fruta, pH.

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Abbreviations used: BER (blossom end rot), CTIFL (Centre Technique Interprofessionel des Fruits et des Légumes), dat (days after transplanting), EC (electrical conductivity), NIR (near infrared radiation), PAR (photosynthetically active radiation), PPFD (photosynthetic photon flux), RH (relative humidity).

Introduction

In the horticultural production systems of southeastern Spain, the high temperatures and changing air moisture levels prominent during the first (July, August and September) and the last (May and June) months of cultivation are far from optimal. This causes stress in those crops whose production cycles coincide with these periods, and production is reduced because of setting and fruiting problems. The high solar radiation levels and temperatures experienced lead to high rates of plant water loss (Lapuerta, 1995; CTIFL, 1995), often causing irreversible burns or withering (Castilla, 2005). The main purpose of shading is to reduce the temperature of the plant and so reduce this problem. Low winter temperatures (December, January and February) are a further cause of stress, leading to the aging of plants and a reduction in yield and fruit size (Castilla *et al*., 1986).

The application of a solution of whitewash and water (known as "Spanish White") to the greenhouse covering is a widespread practice in southeastern Spain, the aim of which is to reflect some the solar radiation that would otherwise reach the plants; the energy reflected by the whitewash does not accumulate inside the greenhouse. Under such conditions transmissivity levels are around 30% of the overall exterior radiation (Morales *et al.*, 1998). The raw materials required to make whitewash are cheap and no expensive equipment is required to apply it; it can therefore be used with any greenhouse structure. The main disadvantages of whitewashing include a lack of uniformity of the layer of whitewash applied (Garzoli, 1989), which is difficult to remedy (see Fernández-Rodríguez *et al.*, 1999). Too much whitewash may reduce the solar radiation entering a greenhouse too strongly, affecting growth (Cockshull *et al.*, 1992; Challa and Bakker, 1998). Further, whitewash may not last very long since the coat applied is easily damaged by rainfall, dew and exterior condensation. Chemical additives can be used to improve its permanence, but in the winter, when it is not required, its inadequate removal can mean transmissivity levels remain below those desired This problem compounds that caused by dust etc., deposited on the greenhouse surface (Montero *et al.*, 1985; Garzoli, 1989). Detergents can be used to help remove unwanted whitewash (Fernández-Rodríguez *et al.*, 1999), but these can corrode the wires mesh used to hold the plastic sheeting in place.

Some authors attribute variations in greenhouse tomato production to the use of aluminised screens and to the electrical conductivity (EC) of the nutrient solution provided (Lorenzo *et al.*, 2006). Magán (2005) fixes an EC threshold of 3.5 dS m^{-1} for the nutrient solution in the soil-less cultivation of tomato, while Castilla (1986) indicates that the use of sandy soil in greenhouse crop production reduces evaporation losses and allows the use of more saline water without reducing the harvest.

Kittas *et al.* (1999) reported that whitewashing does not interfere with greenhouse ventilation, while shading screens (both internal and external) represent obstacles that negatively affect roof ventilation. They also highlight the need for detailed *in situ* characterisation of the light environment when new greenhouse covers or shading materials are proposed. For example, these authors found that aluminised screens tend to very slightly lower the photosynthetically active radiation (PAR) reaching the plants while slightly increasing that in the near infrared (NIR) waveband. Screens are also expensive and favour the emergence of fungal diseases by raising humidity inside the greenhouse (Kittas *et al*., 2003). Compared to non-shaded greenhouses, shaded greenhouses can suffer a greater incidence of blossom end rot (BER). This can lead to significant reductions in marketable production although total production may not be affected (Medrano *et al.*, 2005).

The installation of an aluminised shading screen to reflect the strong radiation received by Mediterranean greenhouses is not cheap, but it does solve some of the problems of whitewash. First it allows shade to be provided and removed when required. Also, the homogeneity of the shade achieved allows a more homogeneous light-flow to the plants (Zami, 1992; Bakker and Van Holsteijn, 1995). This allows more adequate temperatures be maintained inside the greenhouse (Post and Maaswinkel, 1984; Van Holsteijn, 1987). Further, they are associated with remarkably better water use efficiency in tomatoes due to a reduction of water uptake (Lorenzo *et al.*, 2006). The working life of can be screen is very long since it is installed inside the greenhouse and not exposed to the wind and rain.

Studies performed in Almería in *raspa and amagado*-type greenhouses on the change in the density in photosynthetic photon flux (PPFD) over a tomato growing season (August to June) show greater uniformity is achieved when aluminised screens provide 40, 50 or 60% shade compared to simple whitewashing (Fernández-Rodríguez *et al.*, 1998, 1999) (see Fig. 1).

Kurahashi and Takahashi (1995) report the ºBrix of fruit exposed to relatively intense illumination to tend to be higher than that of fruit growing in the shade. Growers often use the ºBrix value to indicate the sugar con-

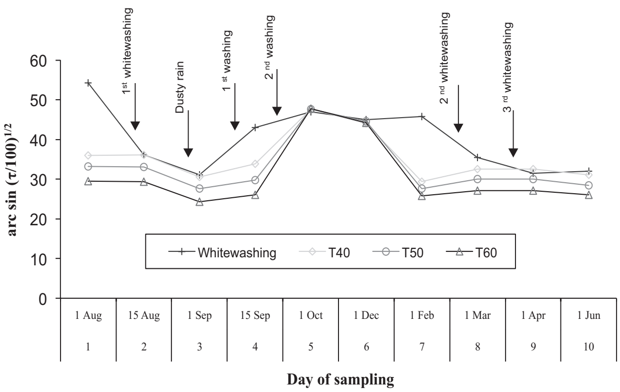

Figure 1. Change in arcsine-transformed density of photosynthetic photon flux (PPFD, in %) over a growing season (Fernández-Rodríguez *et al.*, 1998), where "τ" is the transmissivity (PPFD).

tent of tomato fruit. However, this value does not reflect the presence of sugars alone but also other soluble solids, including organic acids. Using ºBrix as a representation of total sugar content can therefore be misleading. Further, sweetness is not only a reflection of the sugar concentration since perception of sweetness is different for each sugar (Sato *et al.*, 2006). Fernández-Rodriguez *et al.* (1997) analysed the quality of greenhouse-grown cv Atlético tomatoes, and recorded values of around 5.2 ºBrix.

The EC of the soil solution can also affect the sensorial quality of tomatoes. Growers often increase the EC by applying salts and/or inducing drought stress before harvest to enhance the sweetness of their fruit (Ehret and Ho, 1986; Adams and Ho, 1992); this can limit vegetative growth but it improves fruit sweetness (Awang *et al.*, 1993; Sato *et al.*, 2006). Petersen *et al.* (1998) reported that tomatoes hydroponically-produced with an NaCl-enriched nutrient solution were associated with a greater consumer preference and increased sweetness and flavour. It also make the fruit harder.

The aim of this study was to determine the effect of using aluminised screens with different degrees of shading on the key production and quality attributes in tomato cv Atlético grown under greenhouse conditions.

Material and methods

Experimental greenhouse and crop

All experiments were performed in the intensive horticultural production area of Almería (southeast Spain), in a *raspa and amagado*-type greenhouse at 36º 52' 12.43" N and –2º 22' 15.61" W (ED50 system), in the growing seasons 2003-2004 and 2004-2005. The floor area of the greenhouse used was 10,000 m^2; Figure 2 shows the greenhouse used in cross section. Ventilation was passive through extendable side windows and retractable roof windows providing a ventilation area of 14% (8% roof, 6% side). These windows were protected with 35-mesh anti-insect screens. The side windows were opened and closed manually at the producer's discretion according to the weather conditions. The roof windows were opened and closed automatically depending on the wind speed and direction (determined by an anemometer and wind vane).

The greenhouse was covered with co-extruded, three-layered heat-polyethylene (200 µm thick) with thermal insulating properties (80% transmittance in the 400–800 nm range under laboratory conditions). Microspay tubes were fitted to the roof of the greenhouse to regulate the relative humidity (RH). The criterion for switching on this system was that of maintaining an RH of at least 50%; each time the RH dropped below 60% the system was activated.

The plant material used was tomato (*Solanum lycopersicum* L.*)* cv Atlético. Germination and nascence was undertaken by a specialised industrial nursery. Transplanting was performed when the plantlets showed three true leaves; the substrate into which they were transplanted was a sand-mulch (Castilla *et al.*, 1986) with a pH of 8.7 and an organic-matter content of 1%. The planting density was 1.78 plants m^{-2}. The transplant dates were 28th August 2003 and 12th August 2004.

Treatments and experimental design

The design of the experiment in both growing seasons was one of random blocks with four treatments and four repetitions (separated by plastic sheeting): T0 (control) = the traditional whitewashing used in the production area ($CaCO_3$ at a dose of 30-40 g m^{-2}); and T40, T50 and T60 = extendable aluminised shading screens offering 40%, 50% or 60% shading (Fig. 3). All plots

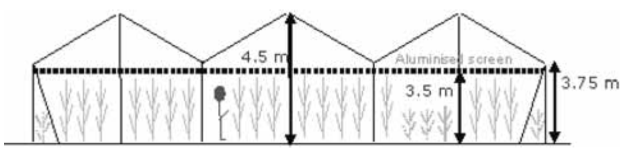

Figure 2. Cross-section of the experimental greenhouse.

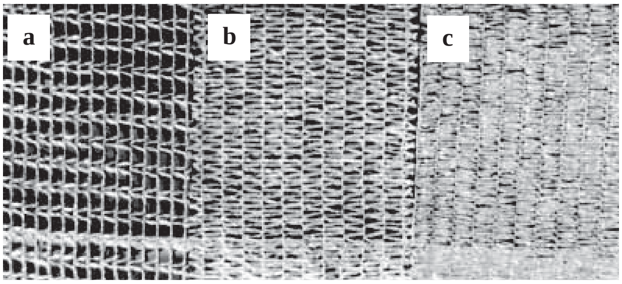

Figure 3. Mesh structures of the aluminised screens: a) 40%, b) 50%, and c) 60%.

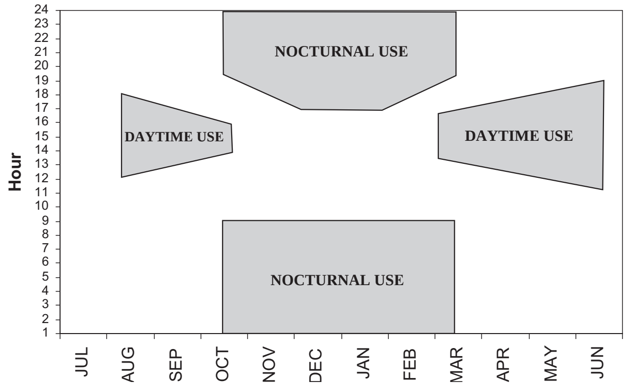

Figure 4. Periods and times of day when screens were extended in both growing seasons.

measured 13.5 x 64.0 m. The aluminised screens were oriented horizontally N–S, 3.5 m above ground level. These treatments were the same for both growing seasons. To avoid the edge effect, four central subplots of 12 x 2.25 m (27 m^2) were established in each plot, with 48 plants per treatment.

The screens were used in the summer months to reduce the high temperatures during the middle hours of the day. In the autumn and winter months, they were used at night to avoid heat losses via long-wave infrared radiation.

Variables measured

The opening and closing of the screens to maintain the maximum PAR radiation inside the greenhouse (McCree, 1972) was controlled by a Belux 50-SR PB System that measures exterior light levels. Screens were closed during the day when the outside light level was 55-60 klux. During the night the shades were extended when the internal temperature fell to 12°C. Figure 4 shows the periods and times of the day when the screens were extended in both growing seasons. Temperature and RH were measured using a HOBO Pro RH/Temp datalogger at the centre of each treatment plot. All dataloggers were protected from sunlight, ventilated, and placed 1.85 m above the ground. The EC of the substrate was measured using a Delta Ohm conductivity meter (Model DO 9786TR1) and soil solutions collected in probes at a depth of 15 cm (Himarcan, Almería, Spain) (three replicates per treatment).

Total production was recorded for each 27 m^2 subplot using a Philips digital balance (precision 100 g). During the 2003–04 growing season, 16 harvests were made (at 84, 98, 108, 112, 123, 137, 150, 164, 184, 206, 227, 242, 259, 272, 284 and 297 days after transplanting [dat]); in the following growing season (2004–05) there were 21 harvests (72, 78, 82, 89, 94, 109, 120, 133, 152, 170, 181, 192, 205, 219, 232, 241, 253, 262, 272, 279 and 285 dat).

The marketable production was obtained eliminating any fruit with BER or that was unripe, split, deformed or otherwise below EU standards (DOCE, 2001). The quality of the tomato fruit was assessed in accordance with other authors (Johansson *et al.*, 1999; Thybo *et al.*, 2005). Average fruit weight was measured using a Philips electronic scale (sensitivity 1 g), pulp firmness (kg cm^{-2}) was measured by making three perforations with a penetration gauge (a Bertuzzi FT-327 model with a 0.5 cm^2 head and 0–13 kg cm^{-2} scale) in each fruit, the soluble solids content (°Brix) was measured using a Milwaukee MR32ATC refraction gauge (sensitivity 0.2 ºBrix), and fruit acidity was measured using a WTW 340i pH meter. For the 2003–04 growing season the sampling days were 123, 164, 184, 206, 227, 242, 259, 272, 284 and 297 dat; in the following growing season they were 152, 181, 192, 232, 241, 262 and 285 dat. The sample size for each assessment was 25 fruits per subplot and harvest.

Statistical analysis

The collected data were subjected to ANOVA ($p<0.05$). All calculations were made using the Statgraphics Plus 4.0 package for Windows.

Results and discussion

The mean temperature (Table 1) and RH (Table 2) for both seasons were higher inside the greenhouse than

Table 1. Mean daily temperature (ºC) outside and inside the greenhouse in the different shading treatments

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
2003/04											
Outside	26.2	23.5	19.1	15.2	12.4	12.4	12.3	13.3	15.4	17.5	23.8
T0	27.3	24.5	19.9	15.1	12.5	12.7	17.4	16.5	17.3	18.2	25.2
T40	27.3	24.5	19.8	15.2	12.7	12.8	17.4	18.4	17.5	17.5	25.3
T50	27.2	24.3	19.6	15.0	12.6	13.4	17.1	18.1	17.3	17.4	25.4
T60	27.2	24.4	19.7	15.2	12.6	13.8	17.7	18.4	17.4	17.5	25.5
2004/05											
Outside	25.2	23.9	19.8	14.6	12.8	10.1	10.2	13.3	16.1	20.4	24.0
T0	26.0	24.6	20.4	14.5	12.9	11.3	15.3	16.5	18.0	21.1	25.4
T40	26.2	24.7	20.4	14.5	13.1	11.4	15.3	18.4	18.2	20.4	25.4
T50	25.9	24.5	20.3	14.4	12.8	11.1	15.0	18.1	17.8	20.3	25.5
T60	26.0	24.7	20.4	14.6	13.1	11.5	15.6	18.4	18.1	20.4	25.6

T0 (traditional whitewashing), T40 (40% aluminised shading screen), T50 (50%), and T60 (60%).

outside. This higher temperature inside the greenhouse and the lower level of ventilation caused the RH inside the greenhouse to rise in both growing seasons, but especially in 2004-05. This phenomenon has also been reported by Kittas *et al.* (2003).

Since irrigation was uniform in all treatments it was expected that those providing greater shading be associated with lower EC values owing to a more efficient use of water (Lorenzo *et al. (*2006). However, in the present work, no significant differences were seen between treatments in the first growing season, although they were seen in the second. In general EC values recorded for the second years were higher than those recorded for the first year (Table 3). In the second year the EC was highest in the T50 treatment, followed by whitewashing, the T60 and the T40 treatments. The reason for the lack of linearity may due to the heterogeneous nature of the sand-mulch substrate (for example compared to hydroponic systems).

The mean fruit weight (Table 4) was lower in the second growing season. Figure 5 shows the values for the two experimental seasons. This might explain the differences seen in marketable production for the T0 treatment (difference between years = 2.29 kg m^{-2}) and for the T40 treatment (difference between years =4.25 kg m^{-2}). This could be due to the increased EC of the soil solution in the second year (Lorenzo *et al.*, 2006) as well as an increased moisture level (Kittas *et al.*, 2003; Medrano *et al.*, 2005). Figure 6 shows the change in marketable production between the two seasons.

Table 2. Mean daily relative humidity (%) outside and inside the greenhouse in the different shading treatments

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
2003/04											
Outside	57.6	64.0	67.7	68.3	63.1	68.3	65.8	69.3	61.8	65.9	62.6
T0	67.8	68.4	72.3	74.4	75.2	68.9	70.1	70.8	68.9	66.7	63.8
T40	65.6	66.7	73.1	75.3	75.3	69.1	71.3	73.2	66.6	65.9	66.1
T50	64.7	68.5	75.7	76.1	75.2	71.2	72.9	74.1	68.5	68.3	67.4
T60	66.8	69.1	75.7	78.2	76.2	75.9	73.5	75.5	69.2	69.3	70.0
2004/05											
Outside	65.4	69.5	65.9	59.2	59.0	57.5	57.2	67.0	63.1	58.7	58.4
T0	73.6	72.9	70.5	75.8	77.6	65.7	64.5	68.5	70.2	59.5	59.6
T40	71.4	71.2	71.3	77.9	79.8	67.8	65.7	70.9	67.9	58.7	61.9
T50	70.2	73	73.9	78.5	80.4	70.2	67.3	71.8	69.8	61.1	63.2
T60	72.1	73.6	73.9	82.1	84.6	75.3	67.9	73.2	70.5	62.1	65.8

Treatments: see Table 1.

Table 3. Seasonal means for soil solution electrical conductivity (dS m^{-1}) in both growing seasons

	2003-04	2004-05
T0	4.89a	5.81ab
T40	4.88a	5.47c
T50	4.75a	6.12a
T60	4.76a	5.62bc

Treatments: see Table 1. Numbers followed by a different letter denote statistical significance (P<0.05; LSD test).

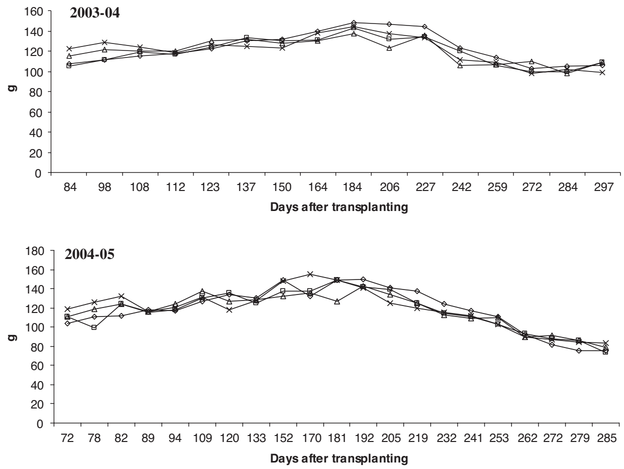

Figure 5. Average weight (g) of marketable tomato fruits in the different treatments: T0 (◇), T40 (□), T50 (△), and T60 (X).

Marketable production in the second growing season was significantly higher in the whitewashing treatment than in the other treatments. Since no differences were seen, however, in the average weight of the fruit, marketable production in the T40, T50, and T60 treatments appears to have been more influenced by the shading-modified climatic conditions than by the EC of the soil.

The mean soluble solids content of the fruits (all treatments combined) was 5.09 ºBrix in the first year and 5.28 ºBrix in the second (Table 5). In both growing seasons, the ºBrix of the fruits generally increased with the advancing phenology of the crop, with the values in the second growing season being higher than in the first (Fig. 7). These differences may be due to the differences in weather conditions and soil EC between the two growing seasons.

The ºBrix of the fruit (Table 5) decreased as the density of shade increased; significant differences were seen between the T60 and all other treatments. This agrees with the results of Kurahashi and Takahashi (1995). The relationship between shading and ºBrix was not affected by EC since the trend was the same in both seasons.

In both growing seasons, the firmness of the fruits depended on the shade provided. The pulp with the least resistance to penetration was seen in the T0 treatment (2.02 kg cm^{-2} for the first season and 2.34 kg cm^{-2} for the second). T60 produced the firmest fruits in the first growing season and T50 the firmest in the second (Table 5; Fig. 8).

Compared to the control treatment, fruit firmness was significantly higher in the T60 treatment in both growing seasons. This variable acted as a clear indicator of improvement in fruit quality. The differences in pulp firmness seen between the growing seasons may be a consequence of the EC and/or the degree of shading provided. Several authors (Ehret and Ho, 1986; Adams and Ho, 1992; Petersen *et al.*,1998) have attributed a higher ºBrix and pulp firmness to a higher EC of the soil solution, but this was not the case in the present work in either growing season.

The pH of the fruit was affected significantly by the different shading systems in both growing seasons, although the values recorded in each year were different

Table 4. Effect of the shading treatments on production components

Treatments	Marketable production (kg m^{-2})		Average fruit weight (g)	
	2003-04	2004-05	2003-04	2004-05
T0	20.83a	18.54a	123a	118a
T40	21.44a	17.19b	120a	117a
T50	20.66a	17.18b	120a	117a
T60	20.54a	17.05b	121a	119a
P-value	0.1643	0.0368	0.1198	0.1426

Treatments: see Table 1. Numbers followed by a different letter denote statistical significance (P<0.05; LSD test).

Table 5. Effect of the shading systems on tomato fruit quality components

Treatments	ºBrix		pH		Firmness of the pulp (kg cm^{-2})	
	2003-04	2004-05	2003-04	2004-05	2003-04	2004-05
T0	5.11a	5.35a	4.22ab	4.01ab	2.02b	2.34b
T40	5.15a	5.32a	4.15c	4.07a	2.40a	2.42b
T50	5.12a	5.31a	4.21b	3.91c	2.14b	2.88a
T60	4.97b	5.15b	4.24a	3.97bc	2.42a	2.68a
P-value	0.0469	0.0289	0.0035	0.0263	0.0189	0.0464

Numbers followed by a different letter denote statistical significance (P<0.05; LSD test).

(Table 5). In the second growing season the pH fell with progressing phenology, as reported by Fernández-Rodríguez *et al.* (1997). However, this was not seen in the first year. Further, in the second growing season, greater shade was associated with a lower pH – the opposite to that seen in the first season. Figure 9 shows the change in pH over the two growing seasons.

Conclusions

Shading provided by aluminised screens (T60, T50 and T40) inside a *raspa and amagado* greenhouse with a sand-mulch soil, did not improve the marketable production of tomatoes compared to traditional whitewashing (T0). Compared to the whitewashing treatment, the fruits of the T60 treatment showed significantly lower ºBrix but higher fruit firmness values; this was seen in over both growing seasons.

Acknowledgements

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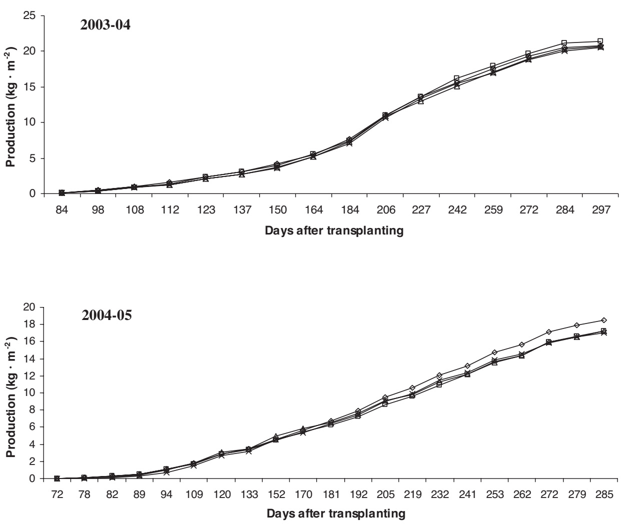

Figure 6. Cumulative marketable production in the different treatments: T0 (◇), T40 (□), T50 (△), and T60 (X).

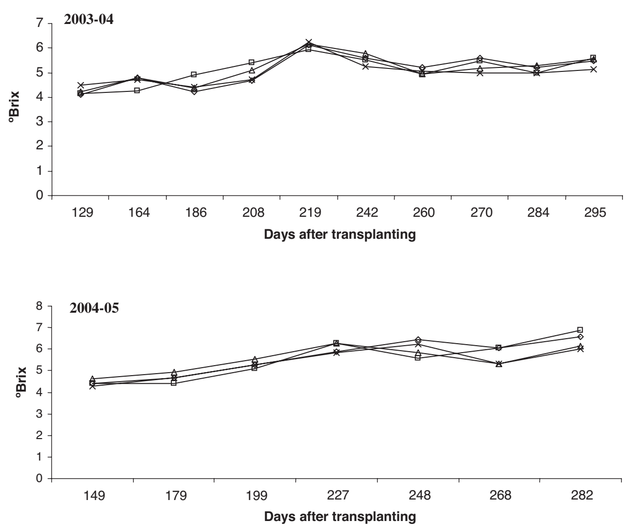

Figure 7. ºBrix degrees of marketable tomato in the different treatments: T0 (◇), T40 (□), T50 (△), and T60 (X).

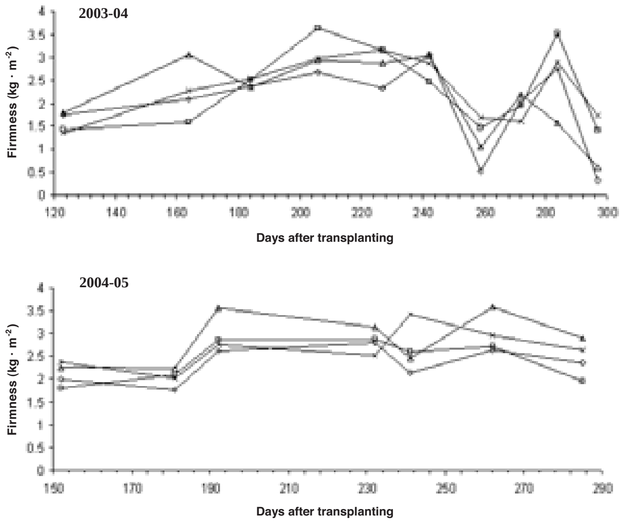

Figure 8. Firmness of the pulp of marketable tomato fruits in the treatments: T0 (◇), T40 (□), T50 (△), and T60 (X).

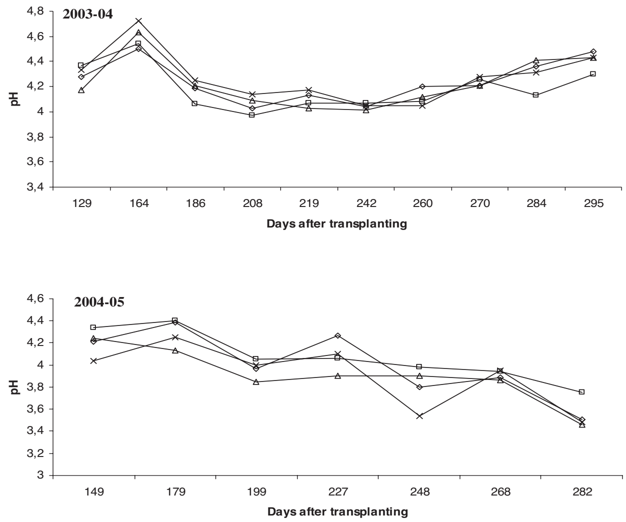

Figure 9. pH of marketable tomato fruits in the different treatments: T0 (◇), T40 (□), T50 (△), and T60 (X).

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