Effects of a UV-absorbing greenhouse covering film on tomato yield and quality

Ch. Papaioannou[1], N. Katsoulas[2], P. Maletsika[2], A. Siomos[3] and C. Kittas[2, *]

[1] *Technological Educational Institute of Larissa, Department of Biosystems Engineering
(f/r Agricultural Machinery), Larissa, Greece*
[2] *University of Thessaly, Department of Agriculture Crop Production & Rural Environment, Volos, Greece*
[3] *Aristotle University of Thessaloniki, Department of Horticulture, Thessaloniki, Greece*

Abstract

The effect of blocking the ultraviolet (UV) solar radiation using a UV-absorbing low density polyethylene (PE) film on tomato crop yield and fruit quality was evaluated in a two-year study in two arched roof greenhouses located in Central Greece. The UV-A and UV-B radiation transmission values of the greenhouse covered by the UV-absorbing PE film during the first year were 0.4% and 1.2%, respectively and increased to 0.8% and 1.3% in the 2nd year, while the respective values in the greenhouse covered by a traditional PE film were 20.7% and 12.5% during the 1st year and 28.7% and 26.7% during the 2nd year. Under the UV-absorbing film the number of insect injured fruit was reduced and the marketable yield was similar or higher than that under the common PE film, while fruit quality characteristics (size, shape), nutritional value (ascorbic acid and lycopene) and organoleptic quality (pH, titratable acidity and total soluble solids) were similar under both covering materials. Moreover, the reduction of incoming UV radiation had an appreciable effect on fruit skin color, indicating an effect on pigments other than lycopene.

Additional key words: fruit quality; insects; polyethylene; transmission; ultraviolet radiation; UV-stabilizers.

Resumen

Efectos sobre el rendimiento y la calidad del tomate de un film de cubierta de invernaderos absorbente de UV

Se evaluó, en un estudio de dos años, en dos invernaderos a dos aguas ubicados en Grecia Central, el efecto del bloqueo de la radiación ultravioleta (UV) solar, utilizando un film absorbente de polietileno (PE) de baja densidad absorbente de UV, sobre el rendimiento del cultivo del tomate y la calidad del fruto. Los valores de transmisión de la radiación UV-A y UV-B del invernadero cubierto por el film PE absorbente de UV en el primer año fueron 0,4% y 1,2%, respectivamente, y se incrementaron hasta el 0,8% y el 1,3% en el segundo año. Estos valores en el invernadero cubierto por una película tradicional de PE fueron 20,7% y 12,5%, respectivamente, durante el 1er año y 28,7% y 26,7% durante el segundo año. Bajo la película absorbente de UV se redujo el número de frutos con heridas producidas por insectos y el rendimiento comercializable fue similar o mayor que bajo la película de PE tradicional, mientras que las características de calidad del fruto (tamaño, forma), el valor nutricional (ácido ascórbico y licopeno) y la calidad organoléptica (pH, acidez titulable y sólidos solubles totales) fueron similares con ambos materiales de revestimiento. Por otra parte, la reducción de la radiación UV entrante tuvo un efecto apreciable en el color de la piel de fruta, lo que indica un efecto sobre otros pigmentos distintos del licopeno.

Palabras clave adicionales: calidad de la fruta; estabilizadores de UV; insectos; polietileno; radiación ultravioleta; transmisión.

Abbreviations used: C-PE (common-polyethylene); IR (infrared); PAR (photosynthetically active radiation); PE (polyethylene); TA (titratable acidity); TSS (total soluble solids); UV (ultraviolet); UV-PE (ultraviolet absorbing-polyethylene); VPD (vapour pressure deficit).

Introduction

Greenhouses create an ideal environment not only for crop but also for pest and disease development. Chemicals pest and disease control are common practice for fresh vegetable protection. As an alternative, many growers use insect proof screen use, placing them in the ventilators. Thus, screening reduces ventilation (Katsoulas *et al.*, 2006; Teitel, 2007) making the high internal temperature of Mediterranean greenhouses during summer even worse.

A complement to using insect screens is the use of a UV-absorbing film for greenhouse covering, which creates a light environment unfavourable to harmful insects. UV-absorbing films do not only block insect pests but also reduce spread of insect-borne viruses (Raviv & Antignus, 2004). Furthermore, UV-absorbing films can reduce crop diseases caused by a range of fungi that use UV as an environmental cue for sporulation (Nigel *et al.*, 2005).

It is well documented that UV-absorbing films suppress several foliar diseases (Raviv & Antignus, 2004), but their impact on crop yield and quality still needs investigation. In Israel, no significant differences were found on growth, yield, maturation time and fresh and dry weight values of tomatoes (*Solanum lycopersicum* L.) grown under UV-absorbing films (Raviv & Antignus, 2004). In studies carried out in Spain, an increase in tomato yield was reported when UV-absorbing films were used (González *et al.*, 2004; Monci *et al.*, 2004). Kittas *et al.* (2006) compared the effect of UV-absorbing films on eggplant (*Solanum melongena* L.) crop behaviour and production. In the absence of UV radiation eggplants were taller (21%), with a larger leaf area (17%) and produced more marketable fruit yield. The adoption of UV-absorbing films by growers as an alternative technique to chemical pest and disease control seems promising as long as fruit yield and quality and concomitantly the anticipated economic return is not negatively affected.

In terms of nutritional quality, it is well established that light affects lycopene content (Cox *et al.*, 2003) as well as ascorbic acid (Giuntini *et al.*, 2005) and other compounds that contribute to fruit composition. Some authors report that UV radiation affects plant secondary metabolism by restricting the production of UV-absorbing compounds including flavonoids and other phenolics (Allen *et al.*, 1998; Caldwell *et al.*, 2003). These compounds significantly affect fruit composition and therefore fruit nutritional quality.

Lycopene content and ascorbic acid are crucial quality parameters (Giuntini *et al.*, 2005) but while ascorbic acid is present in all vegetables (Davey *et al.*, 2006); lycopene is found only in red tomato and watermelon [*Citrullus lanatus* (Thunb.)] fruit (Bramley, 2000). Lycopene is considered one of the most important carotenoids in European and North American diet (Giuntini *et al.*, 2005) and has attracted considerable interest as a health promoting phytochemical (Tadmor *et al.*, 2005).

The aim of this work was to study the effects of UV-absorbing greenhouse covering films on fruit yield and quality characteristics of a common tomato cultivar (*Solanum lycopersicum* L., cv. Belladonna) in Greece.

Material and methods

Greenhouse facilities and plant material

The experiments were conducted during spring and summer 2003 and 2004 (transplanting at the end of February until July) in two similar arched roof greenhouses, N-S oriented, located at the University of Thessaly farm (39°22'N 22°44'E, altitude 85 m), on the continental area of Eastern Greece. The geometrical characteristics of each greenhouse were as follows: eaves height of 2.9 m; ridge height of 4.1 m; total width of 8 m; total length of 20 m; ground area of 160 m^2, and volume of 524 m^3. The greenhouses were equipped with two continuous side roll-up windows located at a height of 0.6 m above the ground with a maximum opening area of 27 m^2 (two vents of 15 m length × 0.9 m opening height) for both vents. A flap roof window was also located longitudinally on the whole greenhouse roof (20 m long) with 0.9 m maximum opening height (18 m^2 opening area). The vents were controlled automatically via a controller (Macqu, Geometions SA, Athens, Greece) and opened in steps; they began to open when greenhouse air temperature exceeded 22°C, and reached their maximum aperture when temperature reached 25°C. Heating was achieved by means of PVC pipes, located above ground, near plants' substrates and by means of a fan-coil, located at a height of 2.6 m at the north side of the greenhouse. Heating was controlled by an on-off controller, the sensor of which was located 1.5 m above the ground in the middle of each greenhouse. It started heating at 14°C during the night

or 18°C during the day and interrupted it at 16°C during the night or at 20°C during the day. Greenhouse soil was covered by a white on black plastic sheet.

One greenhouse was covered by a common low density PE film (C-PE, Plastika Kritis S.A., Heraclion, Crete, Greece) and the second one by a UV-absorbing PE film (UV-PE, Plastika Kritis S.A., Heraclion, Crete, Greece). Both films had 180 μm thickness and equal amounts of infrared, diffusion and ethyl-vinyl-acetate additives but had different UV-absorbers content in the main PE master batch formation, which resulted in differences in UV radiation transmissivity.

The tomato crop (*Lycopersicon esculentum,* cv. Belladonna) was transplanted on 22/02/2003 and 25/02/2004, at the stage of 5-6 true leaves in bags filled with perlite at a density of 2.4 plants m^{-2}. Fertigation was automatically controlled by a computer with set points for electrical conductivity of 2.1 dS m^{-1} and pH of 5.6. Plants were pruned to one stem, topped after the 7th truss and treated equally with fungicides [chlorothalonil (72-75% wettable powder, wettable granules, concentrating liquid suspension)] and miticides [clotentezine (50% concentrating liquid suspension) and propargite (30% wettable powder) for *Tetranychus* eggs and adults respectively] application when deemed necessary. A beehive of bumblebees *Bombus terrestris* (L.), was installed in each greenhouse to facilitate pollination. Plants in each greenhouse were divided into four blocks having 90 plants each.

Measurements

The following climatic data were recorded outside (on a meteorological mast) and inside (centre) of each greenhouse using sensors calibrated before the experimental period: air temperature, relative humidity, global solar radiation (model Middleton EP08-E, Brunswick Victoria, AUS), photosynthetically active radiation (model LI-190SA; Lincoln, NE, USA), UV-B radiation (290-315 nm, model SKU 430, Sky instruments LTD, UK) and UV-A radiation (315-380 nm, model SKU 420, Sky instruments LTD, UK). Each sensor was scanned every 30 s and averaged every 10 min using a Delta-T data logger system (model DL3000, Delta-T devices, Cambridge, UK).

PE film spectral transmittance measurements were made in the laboratory on three samples per PE film taken before their installation in the greenhouses using a LI-COR portable spectroradiometer (model LI-1800, LI-COR, Lincoln, NE, USA) equipped with a 10 W glass halogen lamp and an external integrating sphere (model LI-1800-12S, LI-COR, Lincoln, NE, USA) (Kittas & Baille, 1998).

Fruit harvesting took place twice a week, at the light red stage of maturity, according to the classification of Grierson & Kader (1986). Harvested fruit from 24 selected plants in each greenhouse were weighed, their dimensions were measured and the total production was calculated. Fruit were sorted into marketable and rejected production. The rejected production was due to (i) physiological problems, including small fruit (weight < 100 g), fruit with defects, breaks, scars, blossom-end rot and other physiological disorders; and (ii) insects damage (was assessed in the scale 1 – 5: 1 = none, 2 = slight, 3 = moderate, 4 = severe, 5 = extreme). The most prevalent insect causing fruit injuries was thrips (*Frankliniella occidentalis*). Thrips number was monitored every week by means of 12 blue sticky HORIVER® traps (25 × 10 cm) and measurements on ten tomato plants (top, middle, bottom leaves) in each greenhouse (Vatsanidou *et al.*, 2009).

Two measuring procedures were used for fruit skin colour measurements. The first one was applied both years (2003, 2004) recording colour of all harvested mature fruit. The second one, applied only during 2004 experimental period, included measurement of fruit on the vein for colour evolution evaluation through the six maturity stages (green, breaker, turning, pink, light red and red). Forty two non-shaded, randomly selected fruit of the same truss with uniform shape and size were labelled in each greenhouse and their colour was measured every 1 to 3 days, according to severity of colour change, from green maturity stage until fully ripe fruit. Colour was measured by a Miniscan™ XE Plus (HunterLab, Hunter Associates Lab, Inc., Reston, VA, USA) tristimulus colour analyzer and colour around fruit equatorial region was recorded (6 measurements per fruit). Measurements were reported in the L*, a*, b* system [CIELAB, L* varies between light (L* = 100) and dark (L* = 0), a* varies between green (a* = −50) and red (a* = 50), and b* varies between yellow (b* = 50) and blue (b* = −50) colour]. Chroma and hue (h°) values were also calculated (McGuire, 1992).

Fresh fruit were macerated in a blender for titratable acidity, total soluble solids, ascorbic acid and lycopene determinations. Total soluble solids (TSS) content was measured using a refractometer (model PR-1, Atago, Tokyo, Japan). Titratable acidity was measured by titra-

tion with 0.1 N NaOH to pH 8.2 and results were expressed as % citric acid. Ascorbic acid was extracted in 1% oxalic acid and measured with reflectoquant ascorbic acid test strips (RQflex 10 Reflectoquant, Merck KGaA, Darmstadt, Germany) in a reflectometer (model 116970 Reflectometer Merck KGaA, Darmstadt, Germany). Lycopene was extracted by homogenizing 1 g sample with 25 mL of acetone in a centrifuge tube shaken in the dark. Absorbance at 503 nm was measured by means of a spectrophotometer and lycopene content was calculated using the molecular extinction coefficient of $17.2 \cdot 10^4$ L mol^{-1} cm^{-1} and expressed as mg per 100 g fruit weight (Mencarelli & Saltveit, 1988).

Data analysis

Comparison of means was performed by one-way analysis of variance at a significance level of 0.05 using the SPSS statistical package (SPSS-16, Chicago, IL, USA).

Results and discussion

Greenhouse microclimate

The average transmission coefficients for PAR, UV-A and UV-B radiation, as calculated by the ratio of inside to outside measured value of each parameter during 2003 experimental period were 74.3%, 20.7% and 12.5% in the C-PE greenhouse and 75.5%, 0.4% and 1.2%, in the UV-PE covered greenhouse, respectively. The values changed during the replicate experimental period of 2004 to 73.0%, 28.7% and 26.7% in the C-PE greenhouse and to 72.7%, 0.8% and 1.3% in the UV-PE greenhouse. These results indicate that the UV radiation absorbing properties of the UV-PE film were maintained for two summer seasons after its placement in the greenhouse. In addition, measurements conducted in the laboratory concerning films' spectral transmittance revealed that both films had similar radiation properties in blue (400-500 nm) and green to red (500-700 nm) spectrum regions during both years (data not shown). Thus, any differences that may have emerged on crop yield and fruit quality characteristics could be ascribed to differences of the covering materials in UV-radiation transmittance. According to Krizek *et al.* (2005) plant productivity of greenhouse crops is greatly influenced by the amount of UV radiation, photosynthetically active radiation (PAR) and IR transmitted through the covering material of these structures which is not the case in our tested films since their transmittance in blue, green to red and PAR radiation regions was the same.

Air temperature and vapour pressure deficit (VPD) data during 2003 experimental period are presented in Table 1. Temperature and VPD values followed a similar pattern during the experimental period in both greenhouses. Similar values were also found during 2004 replicate experimental period (data not shown).

The UV-radiation energy flux corresponds to about 3.8% of the total solar radiation energy flux outside the greenhouse (Robaa, 2004). Considering that the films tested differ in UV transmission by about 28%, the difference in the incoming solar energy flux is expected to be about 1% (= 28% × 3.8%), which,

Table 1. Monthly average values of solar radiation, air temperature and vapour pressure deficit measured outside and under the greenhouse covered by the UV-absorbing (UV-PE) and the common polyethylene (C-PE) film during 2003, for the period of day between 08:00 to 20:00. Standard deviation of the values is given in parenthesis

2003 Month	Outside				C-PE			UV-PE		
	T_o (°C)	VPD_o (kPa)	SR_o (W m^{-2})	UV-A (kJ m^{-2} day^{-1})	T_i (°C)	VPD_i (kPa)	UV-A (kJ m^{-2} day^{-1})	T_i (°C)	VPD_i (kPa)	UV-A (kJ m^{-2} day^{-1})
February	10.0 (± 1.9)	0.5 (± 0.1)	380	170 (± 10)	19.3 (± 1.9)	0.6 (± 0.1)	35 (± 2)	19.1 (± 2.7)	0.6 (± 0.1)	0.7 (± 0.1)
March	14.7 (± 2.0)	0.8 (± 0.1)	430	230 (± 12)	20.0 (± 1.7)	1.5 (± 0.1)	50 (± 3)	19.8 (± 1.3)	1.5 (± 0.2)	0.9 (± 0.1)
April	16.6 (± 2.5)	1.1 (± 0.1)	506	520 (± 20)	21.4 (± 2.2)	1.0 (± 0.1)	100 (± 6)	20.9 (± 2.2)	1.1 (± 0.2)	2.0 (± 0.1)
May	20.2 (± 1.7)	1.4 (± 0.2)	622	530 (± 28)	22.3 (± 1.4)	0.9 (± 0.1)	110 (± 5)	22.0 (± 1.7)	0.8 (± 0.1)	2.2 (± 0.2)
June	25.1 (± 2.3)	1.9 (± 0.3)	580	510 (± 32)	26.2 (± 2.4)	1.8 (± 0.2)	115 (± 5)	25.6 (± 2.3)	1.7 (± 0.3)	2.1 (± 0.2)

T_o: outside air temperature. VPD_o: outside air vapour pressure deficit. SR_o: outside solar radiation. UV-A: incoming UV-A radiation. T_i: greenhouse air temperature. VPD_i: greenhouse air vapour pressure deficit.

for an average temperature of 20°C, may induce a 0.2°C temperature difference between the two greenhouses.

Consequently, the only difference between the environments of the two greenhouses could be considered the quality of light.

Fruit yield

No significant differences ($p \geq 0.05$) were found between the two greenhouses in total yield, fruit number, marketable mean fruit weight and non-marketable fruit production ought to physiological problems (meaning zipper, blossom end rot, cutface, sunscald, small size). Under the UV-PE greenhouse, a significant decrease of fruit with insect injuries was observed during both years (Table 2). This could be explained by the significantly lower number of thrips observed in the UV-PE greenhouse, as indicated by the significantly lower number of thrips caught in the sticky traps in the UV-PE greenhouse (Table 3). It has also been observed that under UV-absorbing films some crops such as tomato (González *et al.,* 2004; Monci *et al.*, 2004), eggplant (Kittas *et al.*, 2006) and lettuce (Nigel *et al.*, 2005; Diaz *et al.*, 2006) show better performance and yield.

The majority of the reports that concern the effect of UV-absorbing films on crop, focus on pest and disease control. They measure the efficiency of UV-absorbing films on insect population and its impact on marketable yield, although Antignus *et al.* (1996) mention that the effect of UV-absorbing films on crop yield due to a decrease of virus transmission may be higher than the effect on yield due to reduced insect population.

Park *et al.* (2007) found that the number of marketable fruit decreased as thrips density increased and they also suggest that thrips fruit damage should not be evaluated in terms of yield loss, but in terms of the percentage of damaged fruit. They stated that thrips caused direct damage to fruit by feeding on and laying eggs in the developing fruit causing darkness and malformation. Similar impacts on crop yield were also observed in the present study. Rheinländer *et al.* (2006) stated that between thirteen species of insects and mites found on tamarillo leaves and fruit, most of these were not likely to cause any damage on fruit (*e.g.* spiders, lacewings ladybirds and beetles) and declared that thrips was the only insect which could cause such scarring.

The cosmetic scars that were observed in the harvested fruits of the present study were similar to those presented by Rheinländer *et al.* (2006), according to which thrips was the major cause for fruit damages. It was found that, compared to the C-PE greenhouse, thrips' population was 70% lower in the UV-PE than in the C-PE greenhouse, during the total experimental period and that the percentage of harvested fruit affected by thrips (injury score > 2), varied from 5% to 25% during both experimental periods.

Fruit quality

Tomato specific fruit weight (g mL^{-1}) was similar in the two greenhouses ranging from 1.08 to 1.16 and from 0.93 to 0.95 for 2003 and 2004 experimental periods, respectively. Fruit shape parameters, which are components of fruit quality according to the European Commission (1983), were similar in both greenhouses (Table 4).

Table 2. Marketable yield, fruit number per greenhouse area, fruit weight and rejected production due to physiological problems such as zipper, blossom end rot, cutface, sunscald, small size, and insect damage in the tomato crop grown under the greenhouse covered by the UV-absorbing (UV-PE) and the common polyethylene (C-PE) film during the two experimental periods. Values [mean ± SE (standard error)] followed by different letters within year are significantly different ($p \leq 0.05$)

Year	Greenhouse	Total yield (kg m^{-2})	Marketable yield (kg m^{-2})	Total fruit # per greenhouse area (# m^{-2})	Mean fruit weight (g)	Rejected production (kg m^{-2}) due to	
						physiological problems	insect damage
2003	C-PE	10.5 ± 0.6a	6.8 ± 0.4a	58.0 ± 1.8a	181.5 ± 5.7a	2.8 ± 0.3a	0.9 ± 0.3a
	UV-PE	9.4 ± 0.6a	7.0 ± 0.3a	54.9 ± 2.4a	170.7 ± 9.3a	2.1 ± 0.5a	0.3 ± 0.2b
2004	C-PE	11.6 ± 0.8a	7.4 ± 0.2a	59.8 ± 2.0a	194.1 ± 6.3a	3.1 ± 0.2a	1.1 ± 0.2a
	UV-PE	12.5 ± 0.3a	8.5 ± 0.8b	62.2 ± 1.7a	201.8 ± 4.8a	3.4 ± 0.4a	0.6 ± 0.2b

Table 3. Mean number of thrips caught on sticky traps per week under the greenhouse covered by the UV-absorbing (UV-PE) and the common polyethylene (C-PE) film during the two experimental periods. Values [mean ± SE (standard error)] followed by different letters within year are significantly different ($p \leq 0.05$)

Treatment	Mean # of thrips on sticky trap per week	
	2003	**2004**
C-PE	252.3 ± 14.8a	49.6 ± 5.0a
UV-PE	118.1 ± 7.4b	20.1 ± 3.4b

In fruit shape formation, pollinators play a major role (Al-Attal *et al.*, 2003). As fruit shape parameters did not differ among UV environments of the present work it could be assumed that bumblebees' activity was not affected by the UV-absorbing film.

Total soluble solids (TSS), ascorbic acid, lycopene content, pH and titratable acidity values were similar under both PE-films (Table 4). TSS were increased with time as truss number also increased under both greenhouses (Fig. 1). Similar results have been also reported by Bertin *et al.* (2000) The influence of low UV-B radiation levels on ascorbic acid, lycopene (Giuntini *et al.*, 2005) and TSS content (Krizek *et al.*, 2006) depends on tomato genotype and accordingly, the results of the present study may be valid only for the tomato cultivar studied. The non significant differences in fruit ascorbic acid and TSS content that was found in the present study may indicate a neutral reaction to UV radiation reduction of the specific cultivar tested.

Colour values (L*, hue, chroma) of harvested fruit were similar under both greenhouses and experimental periods (Fig. 2A, B and C, data for 2004 are not shown). The fruit colour is mainly attributed to the β-carotene and lycopene content (Grierson & Kader, 1986). Since lycopene content was similar under both greenhouses (Table 4) it could be
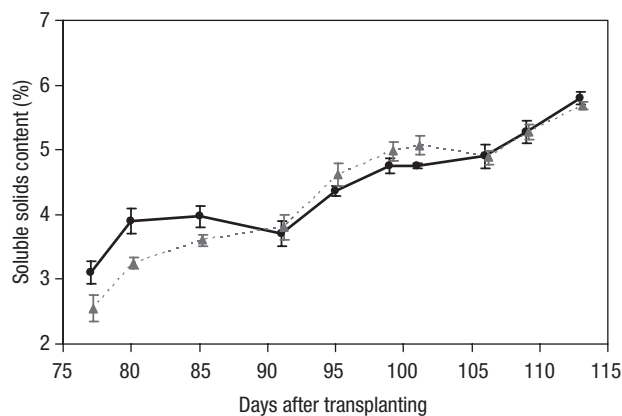

Figure 1. Evolution, along the crop cycle, of tomato fruit soluble solids content measured in the two greenhouses. Triangles: UV-PE greenhouse; circles: C-PE greenhouse. The vertical bars represent the standard error of means.

assumed that the observed colour differences are attributed to the differences in β-carotene content. Hue colour parameter could be used as an objective colour index for vine ripened tomato fruit (Lopez-Camelo & Gomez, 2004). In the present work, hue values did not show any difference (Figs. 2B, 2E) between the two greenhouses and accordingly, it could be concluded that tomatoes produced under the UV-PE greenhouse are not inferior of those produced under the C-PE covered greenhouse. Lastly, on the vein colour evolution evaluation through the six maturity stages (green, breaker, turning, pink, light red and red) showed that fruit under the UV-PE greenhouse had significantly higher chroma values than under the C-PE during light red and red maturity stages (Fig. 2F). These differences could be attributed to differences in synthesis rate of others than lycopene pigments.

It could be concluded that use of UV-absorbing greenhouse covering films that modify the UV radiation light environment leads to reduction of number of insect injured

Table 4. Maximum/minimum fruit equatorial diameter ratio, polar/maximum fruit diameter ratio, total soluble solids (TSS) content, titratable acidity (TA), lycopene, ascorbic acid and pH of fruit under the greenhouse covered by the UV-absorbing (UV-PE) and the common polyethylene (C-PE) film during the two experimental periods. Values [mean ± SE (standard error)] followed by different letters within year, are significantly different ($p \leq 0.05$)

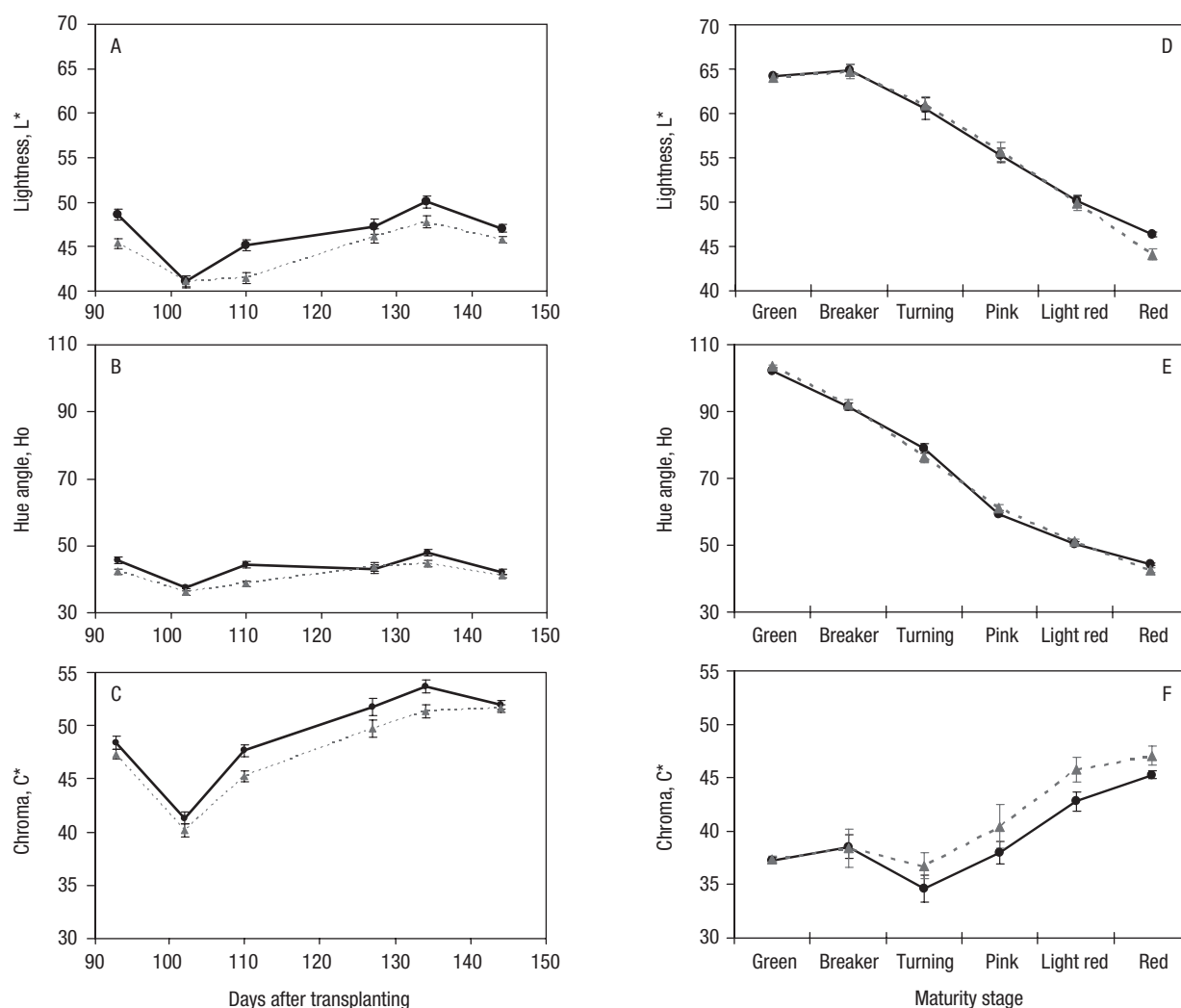| Year	Greenhouse	Max/Min fruit equatorial diameter ratio	Polar/Max fruit diameter	TSS (%)	TA (% citric acid)	Lycopene (mg/100 g fw)	Ascorbic acid (mg/100 g fw)	pH
2003	C-PE	1.06 ± 0.01a	0.92 ± 0.02a	6.28 ± 0.18a	–	–	–	4.57 ± 0.08a
	UV-PE	1.06 ± 0.01a	0.90 ± 0.03a	5.84 ± 0.14a	–	–	–	4.49 ± 0.10a
2004	C-PE	1.05 ± 0.01a	0.87 ± 0.01a	4.84 ± 0.10a	0.37 ± 0.003a	3.21 ± 0.04a	7.75 ± 0.12a	3.67 ± 0.07a
	UV-PE	1.05 ± 0.00a	0.85 ± 0.02b	4.86 ± 0.11a	0.37 ± 0.002a	3.08 ± 0.06a	8.40 ± 0.13a	3.62 ± 0.08a

Figure 2. Skin colour values of harvested fruit (A, B, C) (experimental period 2003) and skin colour change on fruit on the vein (D, E, F) (experimental period 2004). Triangles: UV-PE greenhouse; circles: C-PE greenhouse. The vertical bars represent the standard error of means.

fruit and to similar or higher marketable yield, while fruit quality characteristics (size, shape), nutritional value (ascorbic acid and lycopene) and organoleptic quality (pH, titratable acidity, total soluble solids) are not affected. Therefore, UV-absorbing films can be considered as an effective practice in tomato crop protection from insect, without negative effects on fruit quality attributes.

Acknowledgements

References

Al-Attal YZ, Kasrawi MA, Andnazer IK, 2003. Influence of pollination technique on greenhouse tomato production. J Agric Mar Sci 8: 21-26.

Allen DJ, Nogués S, Bakker NR, 1998. Ozone depletion and increased UV-B radiation: is there a real threat to photosynthesis? J Exp Bot 49: 1775-1788.

Antignus Y, Mor N, Ben-Joseph R, Lapidot M, Cohen S, 1996. UV-absorbing plastic sheets protect crops from insect pests and from virus diseases vectored by insects. Environ Entomol 25: 919-924.

Bertin N, Guichard S, Leonardi C, Longuenesse J, Langois D, 2000. Seasonal evolution of the quality of fresh glasshouse tomatoes under Mediterranean conditions, as affected by vapour pressure deficit and plant fruit load. Ann Bot 85: 741-750.

Bramley PM, 2000. Is lycopene beneficial to human health? Phytochem 54: 233-236.

Caldwell MM, Ballare CL, Bornman JF, Flint SD, Bjorn LO, Teramura AH, Kulandaivelu G, Cox SE, Stushnoff C, Sampson DA, 2003. Relationship of fruit color and light exposure to lycopene content and antioxidant properties of tomato. Can J Plant Sci 83: 913-919.

Davey MW, Van Montagu M, Inzé D, Sanmartin M, Kanellis A, Smirnoff N, Benzie IJJ, Diaz BM, Biurrun R, Moreno A, Nebreda M, Fereres A, 2006. Impact of ultraviolet-blocking plastic films on insect vectors of virus diseases infesting crisp lettuce. HortSci 41: 711-716.

European Commission, 1983. Commission Regulation (EEC No 778/83 of 30 March 1983 laying down quality standards for tomatoes. J Europ Commun 86: 14-19.

Giuntini D, Graziani G, Lercari B, Fogliano V, Soldatini GF, Ranieri A, 2005. Changes in carotenoid and ascorbic acid contents in fruits of different tomato genotypes related to the depletion of UV-B radiation. J Agric Food Chem 53: 3174-3181.

González A, García-Alonso Y, Espí E, Fontecha A, Salmerón A, 2004. Viral diseases control with UV-absorbing films in greenhouses of southern Spain. Acta Hortic 659: 331-338.

Grierson D, Kader AA, 1986. Fruit ripening and quality. In: The tomato crop. A scientific basis for improvement (Atherton JG & Rudich J, Eds). Chapman & Hall, London, pp: 241-280.

Katsoulas N, Bartzanas T, Boulard T, Mermier M, Kittas C, 2006. Effect of vent openings and insect screens on greenhouse ventilation. Biosyst Engin 93: 427-436.

Kittas C, Baille A, 1998. Determination of the spectral properties of several greenhouse cover materials and evaluation of specific parameters related to plant response. J Agric Eng Res 71: 193-202.

Kittas C, Tchamitchian M, Katsoulas N, Karaiskou P, Papaioannou Ch, 2006. Effect of two new UV-absorbing greenhouse-covering films on growth and yield of an eggplant soilless crop. Sci Hortic 110: 30-37.

Krizek D, Clark D, Mirecki R, 2005. Spectral properties of selected UV-transmitting covering materials with application for production of high-value crops in high tunnels. Photochem Photobiol 81: 1047-1051.

Krizek D, Saftner R, Park E, Abbott J, Camp M, Clark H, 2006. Yield data from 2005 and instrumental and sensory evaluation of tomato fruit from plants grown in high tunnels at Beltsville, MD or obtained from commercial sources. HortSci 41: 1083.

López-Camelo A, Gómez P, 2004. Comparison of color indexes for tomato ripening. Horticult Brasileira 22: 534-537.

McGuire RG, 1992. Reporting of objective color measurements. HortSci 27: 1254-1255.

Mencarelli F, Saltveit ME, 1988. Ripening of mature-green tomato fruit slices. J Am Soc Hortic Sci 113: 742-745.

Monci F, García-Andrés S, Sánchez F, Moriones E, Espí E, Salmerón A, 2004. Tomato yellow leaf curl disease control with UV-absorbing plastic covers in commercial plastic houses of southern Spain. Acta Hortic 633: 537-542.

Nigel DP, Rob JJ, Taylor A, Wargent JJ, Moore JP, 2005. The use of wavelength-selective plastic cladding materials in horticulture: understanding of crop and fungal responses through the assessment of biological spectral weighting functions. Photoch Photobiol 81: 1052-1060.

Park H, Lee JHH, Uhm KB, 2007. Economic thresholds of western flower thrips (thysanoptera: thripidae) for unripe red pepper in greenhouse. J Asia-Pacific Entom 10: 45-53.

Raviv M, Antignus Y, 2004. UV radiation effects on pathogens and insects pests of greenhouse-grown crops. Photoch Photobiol 79: 219-226.

Rheinländer P, Meier X, Jamieson L, Manning M, Andersen M, 2006. Sustainable management of diseases in three emerging crops. Part A: Sustainable management of fruit disorders in persimmon, tamarillo and feijoa. HortResearch Client Report No. 18527. HortResearch Contract No. 20578, pp: 1-60.

Robaa SM, 2004. A study of ultraviolet solar radiation at Cairo urban area, Egypt. Solar En 77: 251-259.

Tadmor Y, King S, Levi A, Davis A, Meir A, Wasserman B, Hirschberg J, Lewinsohn E, 2005. Comparative fruit colouration in watermelon and tomato. Food Res Intern 38: 837-841.

Teitel M, 2007. The effect of screened openings on greenhouse microclimate. Agr For Meteorol 143: 159-175.

Vatsanidou A, Bartzanas T, Papaioannou Ch, Kittas C, 2009. Efficiency of physical means of IPM on insect population control in greenhouse crops. Acta Hortic 893: 1247-1254.