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Effects of Shade Nets on the Microclimate and Growth of the Tomato

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ABSTRACT

This study evaluates the effects of shading nets with photoselective features, with an open-field control. A green-shade net with a shading intensity of 40% intensity and blue, pearl, and yellow-shade nets with shading intensity of 75% were used as netting materials and the total radiation and photosynthetically active radiation (PAR) transmittance of the shade nets were analysed. The environmental conditions such as air temperature, relative humidity, and canopy temperature were measured with the aid of appropriate sensors. Tomatoes were grown to determine the effects of shade nets on crops cultivated under the four shade nets, and an additional treatment (control) was used in which tomatoes were grown under full sun conditions. The vegetative growth parameters, fruit quality parameters and yields were assessed and the findings showed that shading resulted in a significant increase in the total yield and pearl-shade nets are the best choice for producing a high quality tomato crop based on PAR transmittance (between 44.8% and 52.8%).

Keywords: Coloured shade nets, Radiation transmittance, Climate change, Soil water content, Crop growing

1. Introduction

Shade cloths are often used in agricultural production to protect crops from excessive solar radiation, environmental hazards (e.g. hail, strong winds, sand storms), or flying pests (bird, fruit-bats, insects) (Shahak et al. 2004; Castellano et al. 2008a; Castellano et al. 2008b). The preferred shading material for ornamental crops and nurseries is a black-shade net that diminishes light intensity by 40-80%. Anti-hail and insect-proof nets are typically made of clear or white threads or a combination of both, with initial shading factor ranges between 8% and 25% (Shahak et al. 2004). The shade nets typically used in common agricultural practices are transparent, black, or green coloured. Transparent nets are usually shading nets that allow sufficient light to enter, while black or green-shade nets are used over or under the greenhouse cladding materials, predominantly in the Mediterranean countries, to reduce high air temperatures inside the greenhouses during the spring and summer seasons of the year. Shade nets are also used as covering material of special structures, referred to as “shade houses”, and protect plants from intense solar radiation. The mesh size of these nets varies typically between 0.6 mm and 4 mm with a light transmittance ranging from 20% to 70% (Briassoulis et al. 2007b).

The photo-selective (coloured) shade nets increase the relative proportion of scattered light, and also absorb vari-ous spectral bands (visible, far-red light and beyond), thereby modifying the light environment (Shahak 2008; Nemera et al. 2015). Shade net decreases incoming solar radiation, air, leaf and root zone temperature while conserving soil water and thus reducing crop water requirements and increasing water use efficiency (WUE) (Möller & Assouline 2007; Diaz-Perez 2013).

Shade nets may contribute to an increase of crop yield as well as the quality of the harvest by modestly influencing the microclimate under the cover material. Principally shade nets are used to improve the productivity, quality and homogeneity of the plants and fruits by acting as a greenhouse and windbreak, thus providing a comfortable microclimate for the plants and fruits (Briassoulis et al.

2007a). Shahak et al. (2004) reported that blue-shade nets had a wide peak of transmittance (400-540 nm) in the blue-green region of the visible spectrum while yellow nets and red-shade nets transmitted light from 500 nm and above and from 590 nm and above, respectively. Schettini (2011) assessed the radiometric properties of coloured shade nets used to protect peach cultivation; their results showed that grey and pearl-shade nets were less transparent to photosynthetically active radiation (PAR) radiation with a PAR total transmissivity of 46.1% and 50.8% respectively. They found that the red, pearl, yellow and grey-shade nets increased the growth of the peach trees. Statuto & Picuno (2017) studied the effects of two different commercial plastic nets with shading factor of 36% and 60% respectively, on the internal microclimate of a greenhouse. They suggested that the selection of the most appropriate shading factor could significantly impact upon the protection of heat-sensitive crops from both high temperature and sunburn. Löpez et al. (2007) evaluated the correlation between dissimilar spectral compositions of red and pearl-shade nets and the lycopene content of "Bodar", "Cherry" and "Cocktail" tomato cultivars. They found that light quality and the colour of the net used as a covering material noticeably altered the lycopene content of tomatoes in addition to the variety of tomatoes grown.

This study investigates the effects of different coloured shade nets on the total radiation, PAR transmittance, environmental microclimate conditions, and development of the tomato plant.

2. Material and Methods

2.1. Study area

This study was carried out under open field conditions in 1500 m^2 area of land at the research and application farm of the Faculty of Agriculture, Akdeniz University, Antalya, Turkey (latitude 36^o 54' N, longitude 30° 38' E, with an average altitude of 54 m). The research area has a typical Mediterranean climate; hot, dry summers and mild, relatively rainy winters. The annual average temperature is 18.1 °C. The annual average relative humidity and total precipitation are 60.6% and 881.7 mm, respectively. Some physical and chemical properties of the soil are given in Table 1.

Table 1- Physical and chemical properties of the soil

Depth (cm)	*Texture class*	*FC[a] (%)*	*PWP[b] (%)*	*Bulk Density (gr/cm^3)*	*EC (mmhos/cm)*	*pH*	*$CaCO^3$ (%)*	*Organic Matter (%)*
0-15	CL	24.3	16.0	1.45	1.22	7.4	21.0	2.0
15-25	CL	20.0	18.0	1.29	0.284	8.1	28.2	1.6
25-35	CL	24.6	18.0	1.33	0.163	8.0	30.8	1.7

[a]FC: field capacity, [b]PWP: permanently wilting point, EC: electrical conductivity, $CaCO_3$: calcium carbonate, CL: Clay loam

Four different coloured shade nets (a green-shade net with 40% shading of the natural sunlight and pearl, yellow and blue-shade nets with 75%) were used in this study. Field tests for evaluating the effects of these nets were performed in an area around 720 m^2. The total land area covered by each coloured shade net was 180 m^2 (three repetitions of 60 m^2 for each one). For control treatment, 180 m^2 of the 720 m^2 remaining area was used. A 54 m long, 2.7 m high and 14 m wide flat-roofed iron skeleton was constructed to lay the nets in the study area. The shading nets were mounted above and around the iron frame (Figure 1).

Figure 1- The coloured shade nets (yellow, green, pearl and blue) used in the study

2.2. Measurements

The following climatic data were measured at the central part of each 60 m^2 of land designated for each coloured shade net and 780 m^2 of land assigned as the open field treatment group:

- Global solar radiation (GSR W/m^2), by means of 5 pyranometers (model CMP 3, Kipp and Zonen, Delft, The Netherlands), at a wavelength range of 300-2800 nm, placed 2.0 m above the ground and in the center of each treatment (Kittas et al. 2006);

- PAR ($mmol/m^2/s$), using 5 quantum sensors (model PQS 1, Kipp and Zonen, Delft, The Netherlands), at a wavelength range of 400-700 nm, placed 2.0 m above the ground and in the centre of each treatment (Kittas et al. 2006);

- Air temperature (T, °C) and humidity (RH, %), using 5 capacitive, negative temperature coefficient thermistor sensors and relative humidity sensors (model 175-H2, Testo Electronics, Istanbul, Turkey), placed at 1.5 m above the ground and in the centre of each treatment (Barroso et al. 1999) (Figure 1).

- Canopy temperature (T, °C), was monitored using an infrared thermometer (model Omega OS530HRE, USA).

Canopy temperature measurements were taken with a field of view estimated to be 15 degrees. The infrared thermometry was held 1 m above the ground with a horizontal angle of 45 degrees during measurements, viewing an elliptical surface having approximately a minor axis of 6 cm, a major axis of 9.5 cm and an area of 40.05 cm^2 (O'Toole & Real 1984). The measurements were taken at 12 PM and 2 PM, in four directions (east, west, north and south) in each treatment.

Total radiation and PAR transmittance were calculated using the following formula (Kittas et al. 1999):

$$\tau_T = \frac{T_i}{T_o} \times 100 \qquad \text{(Eq. 1)}$$

Where; τ_T = total radiation permeability of the shade net (%): Ti = radiation reached the surface of land under the shade net (W/m^2): To = radiation reached the surface of the land in the control group (area with full sun) (W/m^2).

$$\tau_P = \frac{P_i}{P_o} \times 100 \qquad \text{(Eq. 2)}$$

Where; τ_P = PAR permeability of the shade net expressed as a percentage: Pi = PAR reached the surface of land under the shade net ($mmol/m^2/s$): Po = PAR reached the surface of land in the control group (area with full sun) ($mmol/m^2/s$).

All GSR and PAR measurements were performed on days with clear skies. Time periods from 6 AM to 6 PM on five days under clear sky conditions were considered for the determination of monthly GSR and PAR transmittance of the shade nets (Geoola et al. 1998; Geoola et al. 2004; Kittas et al. 2006). The temperature and relative humidity data were analyzed for 24 h during selected days with clear skies in conjunction with the GSR and PAR transmittance measurements. All measurements were collected at intervals of 10 min using a data logger (model DL2e Delta-T Devices, Cambridge, UK) during the study period. The outside sensors for PAR, total radiation, temperature and relative humidity are located on the meteorological station platform which was positioned next to the shade nets.

The tomato crops [industrial tomato (cv. Ancon)] were planted with a distance of 140 cm between the rows and 40 cm between the plants. The transplanting and the last harvest date were April 27 and August 17, 2018 respectively. Nine plants from each plot were randomly selected and tagged for recording plant height (cm), the total number of leaves, plant and stem diameter (mm); these parameters were measured on the plants first at 27 days after transplanting and then at intervals of 15 days until the termination of the study. Five harvests were conducted from the 6th of June to the 17th of August on full grown fruits of at least 50% red colouration. The total yield (t/ha), fruit quality parameters [average fruit weight (gr) and size, EC and pH of the fruit juice and water soluble dry matter (%) (WSDM)] were measured seasonally. To determine the physical properties of the fruit, ten tomatoes were selected randomly from each treatment. The average fruit weight was calculated as the weight of all fruits for each tomato plant divided by the total number of fruits and recorded in grams by a sensitive digital weighing balance. The fruit diameter was measured using callipers. The biochemical parameters of the fruit (such as WSDM, EC, pH and fruit skin colour) were analysed to determine the fruit quality and the quality parameters (such as WSDM, EC and pH) were measured in the juice extracted from 10 fruits from each replication. The WSDM was estimated using a digital refractometer (ATAGO, RX 5000, Tokyo, Japan). The EC and pH values were measured in homogenized juice obtained from the sample tomato fruit via EC and pH probe of a portable multimeter (HACH LANGE HQ40D.99). Each fruit had a specific skin colour indicating its maturity. The fruit's skin colour was measured to determine its ripeness using a "Minolta 200" chroma meter.

Water and fertilisers were supplied via a drip irrigation system. The dripper flow rate was 2 L/h at 1 atm pressure. Intermittent irrigation was carried out at intervals of every 2 days from the beginning of the experiment until the last harvest. The method for determining the irrigation water level was based on evaporation data (Epan, mm) obtained from a Class A pan located next to the control plot. The pan was mounted on a wooden platform at a height of 15 cm above the soil surface and readings were recorded daily. The irrigation level was chosen as 100% of Class-A Pan evaporation for all plots. In this way, by applying the water equally for the parcels, unwanted fluctuations in the irrigation were prevented. 100% of the two-day evaporation values taken from Class A evaporation pan were measured in mm. The irrigation level required for the plants was calculated in mm and then converted into litres (Kırda et al. 2004).

$$I = kp \times kc \times Ep \times A \qquad \text{(Eq. 3)}$$

Where; I = irrigation water (liter/plant): kp = Class A Evaporation Pan coefficient (taken as 1.0 in this study) (Öner et al. 2002): kc = plant coefficient which takes values from 0.45 to 1.25 depending on the plant's growth stage (seedling period 0.45, vegetative period 0.75, flowering 1.15, fruity 0.85, ripening 0.6) (Doorenbos & Kassam 1979): Ep = total evaporation from the A-Class Pan corresponding to the irrigation range and presented in mm; A = area of a parcel in square meters.

The soil water status was monitored gravimetrically from depths of 0-15 cm, 15-25 cm and 25-35 cm at 15 days intervals to determine the effects of the shade nets on soil moisture. First, the weight-based soil water content was computed for each depth (i.e 0-15, 15-25, 25-35 cm). Next, the weight based soil water content was multiplied by the bulk density in each depth to calculate the volumetric water content. Finally, the volumetric water content was multiplied by the depth to measure the soil water content in mm for the entire depth (35 cm).

A suitable fertilization program was prepared based on the soil analysis in the experimental area (228, 152, 290, 56, and 14 kg/ha of N, P_2O_5, K_2O, CaO, and MgO respectively). The fertilizers containing microelements were applied to the soil using the drip irrigation system. Fertilization was carried out the day before planting using 15-15-15 compound fertilizer with 50 kg NPK (15% of N, 15% of P_2O_5 and 15% of K_2O) (half of the requirement).

Data were analyzed using SPSS 16.0. According to the results of variance analysis, the classification of possible differences between the averages of subjects was made using the Duncan test at a significance level $p \leq 0.05$ (5%).

3. Results and Discussion

3.1. Solar radiation and PAR transmittance under the nets

Shading nets were placed over the tomato plants 52 days after planting (Kittas et al. 2009) and the selected physical properties of the shade nets, such as total radiation and PAR transmittance, were evaluated after the shade nets had been placed over the tomatoes. The yellow-shade nets showed the highest PAR transmittance while the green-shade net showed the lowest. The total radiation of the yellow-shade nets ranged between 57.5% and 65.6%, whereas the total radiation of green-shade nets ranged between 42.3% and 48.9%, respectively. The blue and pearl-shade nets showed a moderate transmittance (Figure 2). In their 2007 study, Briassoulis et al. (2007b) reported that the transmittance of shade nets to be between 20-70%. Kotilainen et al. (2018) noted that the spectral composition (light quality) transmitted by climate screens and shade nets used in horticultural applications is affected by shade nets material properties. They reported that shade nets reduce solar radiation transmittance and that green-shade nets can be used for plants where solar radiation is accepted as a limiting factor for them.

In this study, Figure 3 shows the daily evolution of solar radiation both in an open field and under the shade nets throughout the daylight hours of a summer day. The transmittances of the shade nets changed depending on the incidence angles of the sun's rays varying during the day.

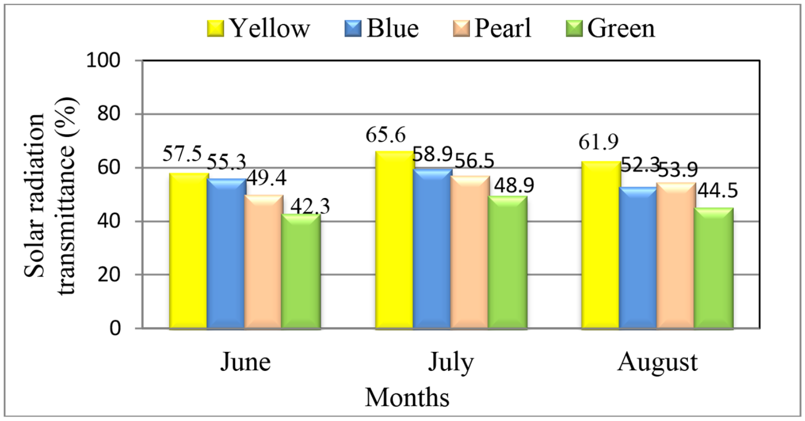

Figure 2- Solar radiation transmittance of different coloured nets (%)

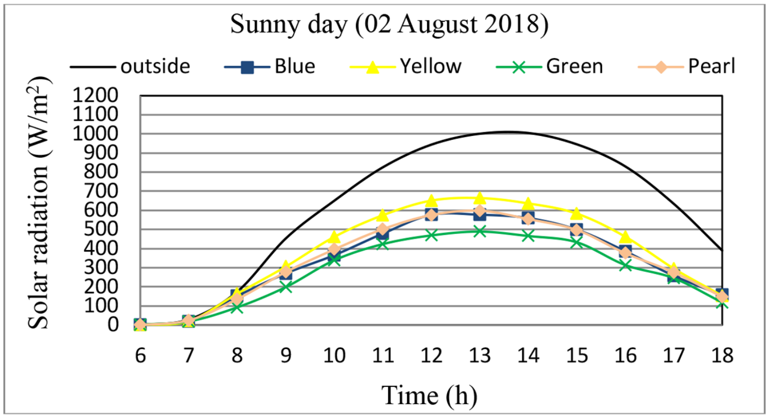

Figure 3- Solar radiation outside and under the shaded nets; on a typical summer day

As shown in Figure 4, the yellow-shade nets showed the highest PAR transmittance (56.5%) in June, while the pearl-shade nets showed the highest transmittances in July and August (48.7 and 44.8%, respectively). The pearl-shade net appears to be the most suitable net in terms of PAR region because it showed the highest transmittance in both July and August. At the same time, the total yield under the pearl-shade net was the highest of all the shade nets. The blue-shade nets showed the lowest PAR transmittance throughout the study. The PAR transmittance values of the blue-shade net varied between 28.8% and 41.1%. Figure 5 shows the daily evolution of PAR radiation in the open field and under different coloured shade nets on a typical summer day.

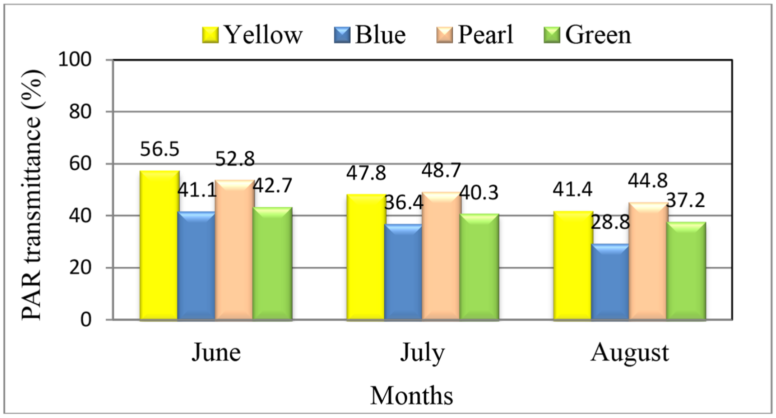

Figure 4- PAR transmittances of different coloured shade nets (%)

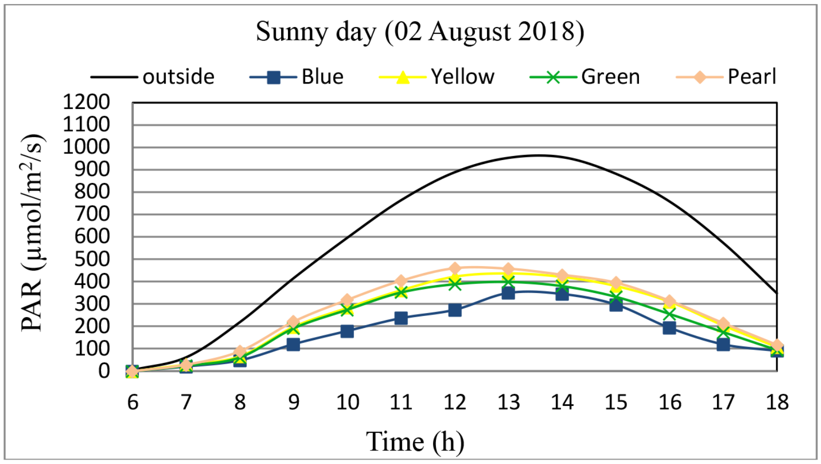

Figure 5- PAR radiation outside and under the shade nets; on a typical summer day

These findings are in line with those of Kittas et al. (2009) who investigated the spectral properties of four different-coloured shade nets with different shading intensities (two black nets with a shading intensity of 40% and 49%, a green net of 34% and mixed green and black net of 40%) in a study conducted along the coastal areas of Eastern Greece using a pyranometer and spectra radiometer to calculate measurements. Their study found no significant differences the transmittance of the nets in different wavebands (PAR: 400-700 nm, near infrared radiation: 700-1100 nm, total radiation: 400-1100 nm). Schettini (2011) examined the influence of the radiometric properties of shade nets (blue, red, pearl, gray, yellow and transparent) on peach tree morphogenesis, by studying the modification of the spectral distribution of transmitted radiation. Their results found that red, blue, yellow and pearl-shade shade nets showed a non-uniform transmittance in the PAR region. Ilic et al. (2017) studied the effects of four different coloured shade nets (red, pearl, blue and black) with a shading intensity of 40% on environmental conditions and plant development in the "net houses" and "plastic greenhouse + shade net" conditions in southern Serbia. They noted that the pearl and blue-shade nets showed 59.8% and 53.6% transmittance in the PAR region, respectively. Based on the findings obtained from our study, all shade nets significantly reduced total radiation between 34.4% and 57.7%. The reduction in PAR transmittance was found to be between 43.5% and 71.2% when compared to the uncovered area; in addition, the transmittance of shade nets in the PAR region was not constant over the entire 3 months period. Furthermore, PAR transmittance of the pearl-shade nets was found to be higher than the other nets in July and August.

3.2. Microclimate under the nets

The effects of shade nets on the microclimate environment were assessed by the recorded values of the relative humidity, and the environment and leaf temperatures. The monthly variations of the temperature and relative humidity under different coloured shade nets from June to August 2018 are shown in Table 2 and Table 3. As seen in Table 2, the average daily minimum temperature was similar among the different coloured shade nets but lower to that of the open field. The average daily temperature was also similar among the different coloured shade nets but higher to the open field group. The results suggest that average daily maximum temperature values correlate strongly with the microclimate environment. With the exception of the green-shade net for July, the average daily maximum air temperatures under the nets were higher when compared to the open field (Table 2). The highest air temperatures were recorded under blue-shade nets in June (4.5 °C higher than outside) and under yellow-shade nets in July and August (1.7 °C and 2.6 °C higher than outside, respectively). The green and pearl-shade nets were found to have similar temperature values. The lowest air temperatures among the nets in June, July and August were recorded under yellow, blue and pearl-shade nets, respectively.

The average daily relative humidity was found to be higher under the nets when compared with the control treatment without shade nets (Table 3). This may be due to the limited air circulation within the shade nets. The average daily relative humidity values among the nets varied between 54.4% and 84.2%, whereas the average daily relative humidity values recorded outside fluctuated between 49.3% and 71.9% (Table 3).

Table 2- Temperature recorded inside and outside the net houses

Months	*Temperature inside shade nets (°C)*												*Outside (oC)*		
	Yellow			*Blue*			*Pearl*			*Green*					
	Min	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*
June	17.9*	33.0	26.0	18.0	36.2	27.1	17.7	34.3	26.6	18.0	34.1	26.4	19.1	31.7	25.8
July	18.5	43.7	30.2	18.9	41.6	30.5	18.7	42.9	30.3	18.9	42.0	30.1	20.0	42.0	30.3
August	19.4	43.1	31.1	19.4	41.9	31.1	19.2	41.1	30.6	19.2	42.0	30.8	21.0	40.4	30.6

*Values in the table represent the average temperatures of five clear sky days. Max: Maximum, Min: Minimum, Avg: Average

Table 3- Relative humidity recorded outside and inside shade nets

Months	*Humidity inside shade nets (%)*												*Outside (%)*		
	Yellow			*Blue*			*Pearl*			*Green*					
	Min	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*	*Min*	*Max*	*Avg*
June	43.2*	99.9	84.2	38.0	99.9	74.7	48.1	99.9	82.6	43.0	99.9	75.3	45.8	90.2	71.9
July	15.5	99.9	58.2	20.5	99.9	54.4	21.7	99.9	60.2	19.7	97.8	55.2	15.8	84.7	49.3
August	18.9	99.9	63.1	18.2	99.9	56.7	27.5	99.9	61.3	24.0	99.9	65.4	18.3	90.0	51.6

*Values in the table represent the average relative humidity of five clear sky days. Max: Maximum, Min: Minimum, Avg: Average

The relative humidity values under the shade nets predominantly ranged in levels that maintain optimal conditions for crop growth during the study period. Ozturk (2008) suggested that the optimal relative humidity for plant growth typically varies between 50% and 80%. Figure 6 shows the daily evolution of temperature and relative humidity outside and under the shade nets on a typical summer day.

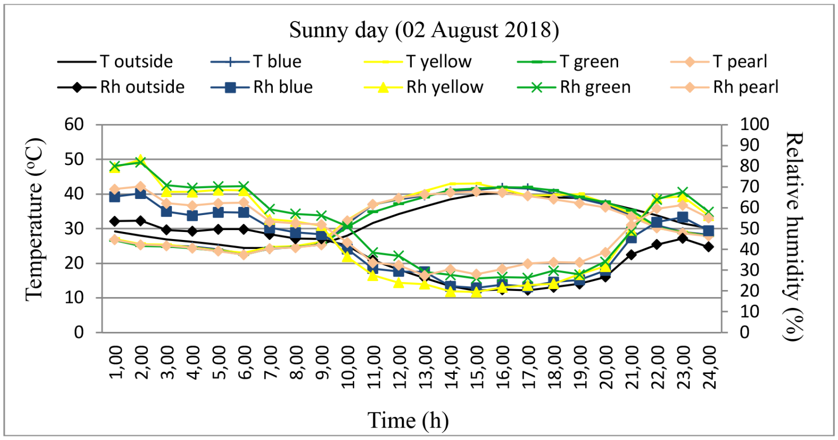

Figure 6- Temperature and relative humidity outside and under the shade nets on a typical summer day T: temperature; Rh: relative humidity

Arthurs et al. (2013) studied environmental factors including (air temperature and humidity) both in the net houses (red, blue, black, pearl) and under open field conditions. Their study evaluated the average daily maximum temperature values and found the values in the net houses to be higher than those in the external environment. In their 2009 study, Kittas et al. (2009) noted that the average air temperature values recorded under the nets (29.5 °C) and outside (29.6 °C) were remarkably close. Their study reported that this was because the shading nets were only mounted above and not around the structures. Abdrabbo et al. (2010) found that the use of shade nets exerted a limited influence on mean air temperature and noted that air temperatures were typically lower under the nets (2-6 °C). In their 2014 study, Gaurav (2014) found that the temperature and light intensity decreased with the increase in shading density, while relative humidity increased. They determined that temperature reduction was highest in 90% shade followed by 75%, 50% and 35%. Meena et al. (2014a) investigated the change in the microenvironment under different colour shade nets and noted that light intensity, incoming radiation, canopy temperature, air temperature, and soil temperature were found to be lower under different coloured shade nets compared to those without shade netting. Ilic et al. (2017) found that the microclimates under shade nets (red, blue, pearl and black) were noticeably similar and temperature and relative humidity values were slightly lower than those of the outside environment. They also reported that shading nets were useful in controlling the rise in temperature as the nets prevented the plants from damage from excessive sunlight; this protection from excessive sunlight also significant affected productivity. In another study, Shahak et al. (2004) reported that shading in several locations in Israel caused decreases from 1 °C to 5 °C in maximum daily temperature and an increase in the daily maximum relative air humidity by 3% to 10%. Nangare et al. (2015) investigated the effects of three green shade nets with a shading intensity of 35%, 50% and 75% on the growth of tomato crops growing in Pakistan. They found that the average monthly maximum temperatures varied substantially among these nets between 15 °C and 33.4 °C from November to April, whereas the relative humidity was between 30.4% and 61.2%. Their results showed that these values were not significant when compared to those under open field conditions.

The plant leaf temperature measurement values obtained under the shade net treatments are given in Table 4.

Table 4- Monthly mean canopy temperature values of the treatments

Months	*Shade nets (oC)*				*Outside (oC)*	*P > F*
	Yellow	*Blue*	*Pearl*	*Green*		
June	30.3[†c£]	32.1[a]	31.4[b]	30.9[bc]	32.6[a]	*
July	33.0[b]	32.0[c]	33.1[b]	32.8[b]	34.2[a]	*
August	35.7[b]	34.3[c]	36.1[b]	35.6[b]	37.9[a]	*

[†]Data are mean of 3 replicates, [£]Data in rows followed with different letters are significantly different based on the Duncan test ($p<0.05$). Values in the rows with different letters are significantly different ($p<0.05$) based on one-way ANOVA post-hoc Duncan's Multiple Range tests. *Significantly important at α=0.05 probability level

The canopy temperature was 37.9 °C in the open field in August, the highest among all treatments ($p<0.05$). In addition, the differences between the groups were relatively significant for July and August. In the months of July and August, while the blue-shade shade net showed the lowest canopy temperature value, no significant difference was found in the canopy temperature values between yellow, pearl and green-shade net. Comparable results were verified in a study by Kittas et al. (2009) who noted that the canopy temperature was significantly lower in coloured shade net groups when compared to the open field treatment. Diaz-Perez & John (2019) found that the leaf temperature was highest in the unshaded treatment (34.2 °C) and lowest under the red net (33.2 °C).

As shown in Figure 7, the soil water contents were higher for shading applications when compared with those under the open field conditions. The difference in soil water content may be the result of reduced evapotranspiration caused by the effects of the shade nets. Throughout the growing season, the total soil water content of the pearl-shade net was found to be higher than those of the blue-shade net. The lowest value of soil water content among all the treatments was observed in the control group (Figure 7).

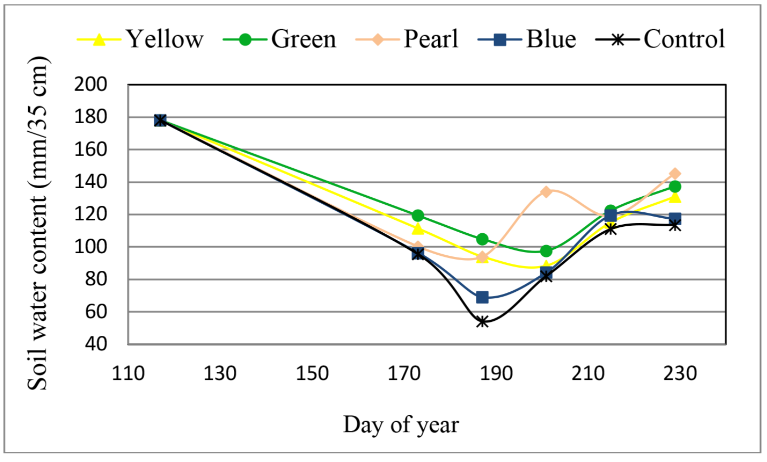

Figure 7- The changes in the soil water content during the study

Jifon & Syvertsen (2003) found that crops grown in open fields in a semi-arid climate are subjected to direct sunlight, high temperatures, and wind, resulting in high crop evapotranspiration (ETc). For this reason crops grown in these conditions require larger amounts of water. In contrast, shade-houses promoted the growth of plants by providing them a more pleasant environment with less stress and protection from direct sunlight and high temperatures. The impact of strong winds was reduced, ETc values were lower and humidity was relatively higher. The irrigation water requirement of 23% to 31% pan evaporation was used for plants grown under 70% light reduction. In addition, water-use efficiency increases under shady conditions. Meena & Vashisth (2014b) reported that WUE was higher under nets (black, white, red and green) than the control during the summer season. Tezcan (2018) studied the influence of four shade factors (95%, 75%, 55% and 40%) of green shade netting on soil water content and plant root distributions. The highest soil moisture was obtained from 95% green shade nets and the lowest soil moisture was obtained from 40% green shade nets in covered plots. Soil moisture of 95%, 75%, and 55% green shade nets was found to be similar during the study. In addition, Tezcan (2018) noted that soil water content for the open field condition was the lowest among all treatments and showed a fluctuating trend.

3.3. Effect on the plant growth

Table 5 shows some vegetative growth parameters, yield and fruit quality parameters of the tomato plant for the four coloured shade nets and outside conditions. Statistical analysis revealed that significant differences were found between the crops grown under the shade nets and outside.

Table 5- Plant growth, yield and fruit quality parameters for all the treatments

Parameters Yellow		***Shade nets***				***Outside***	***P > F***
		Green	***Pearl***	***Blue***			
Plant height (cm)		$69.0^{\dagger}$	66.7	77.8	74.5	70.5	ns
Stem diameter (mm)		$25.1^{\dagger}$	25.6	23.0	25.0	25.8	ns
Number of leaves per plant		$72^{\dagger}$	83	110	101	70	ns
Total yield (t/ha)		$26.3^{c£}$	29.3^{b}	30.0^{a}	20.9^{d}	20.8^{d}	*
Average fruit weight (g)		$89.3^{b£}$	91.2^{a}	88.4^{c}	75.6^{d}	67.5^{e}	*
Fruit diameter (mm)		$51.5^{c£}$	52.3^{b}	53.4^{a}	49.1^{d}	46.7^{e}	*
WSDM (%)		$4.6^{b£}$	4.0^{d}	4.2^{c}	4.0^{d}	4.7^{a}	*
EC (dS/m)		$4.6^{a£}$	4.2^{b}	4.2^{b}	4.2^{b}	4.1^{c}	*
pH		4.4^{b}	4.4^{b}	4.4^{b}	4.4^{b}	4.5^{a}	*
Fruit skin color	L	43.4	44.8	44.2	43.5	44.4	ns
	a	33.9	34.0	33.5	33.1	35.1	ns
	b	31.0	33.8	32.5	32.4	34.1	ns

†Data represent the mean of 3 replicates, *Significantly important at α=0.05 probability level, £Data in rows followed with different letters are significantly different based on the Duncan test (p<0.05), ns: Non-significant. WSDM: water soluble dry matter, EC: electrical conductivity, CIE L a*b*: CIELAB color space defined by the International Commission on Illumination (CIE)

As shown in Table 5, the effects of shade nets on vegetative growing parameters such as plant height, stem diameter and the number of leaves were not statistically significant. The differences between the total yield values were considered statistically significant at a value of less than 0.05. Shading with yellow, green and pearl-shade nets increased the total yield by about 26%, 41% and 44%, respectively when compared to non-shade conditions. Shade nets also eliminated sun scalds appearing on tomatoes during the hot summer season more effectively than the open field conditions. The effects of shade nets on fruit quality parameters, such as average fruit weight, fruit diameter, WSDM and EC-pH in the fruit juice, were found to be statistically significant. The greatest fruit weight (91.2 g) was obtained from the green-shade net group whereas the lowest fruit weight (67.5 g) was recorded in the control group. The highest fruit diameter (53.4 mm) was measured in the pearl-shade nets group while the lowest fruit diameter (46.7 mm) was observed in the control group. The highest WSDM (4.7%) and pH values (4.5) were found in the control group, while the highest EC (4.6 dS/m) value occurred in the yellow-shade net group.

De Castro Ferreira et al. (2010) found that the best results in terms of growth rate, productivity, and energy efficiency for cucumbers were obtained under T3 conditions (30% red filter net in the visible and 40% transmission in the far red spectrum). Milenkovic et al. (2012) reported that total and marketable yield increased with a 40% shading level and then decreased (with 50% shade). The relative difference between the coloured and the black shade nets with regards to export-quality fruit yield was even more prominent. Milenkovic et al. (2012) noted that total fruit yields (t/ha) under the coloured shade nets were higher by 113% to 131%, relative to the equivalent black shade net. Ombodi et al. (2016) reported that shade net coloured significantly affected the vitamin C and total polyphenol contents of pepper fruits due to the effect of shade nets on the light level and light quality. Tafoya et al. (2018) reported that the cucumber yield obtained with blue, aluminized, red or pearl net increased from 46% to 71% compared to conventional black net. Zhang et al. (2022) found that a red shade was effective in improving green tea quality by increasing the content of L-theanine and free amino acids in tea leaves collected in spring and fall when compared to the unshaded control.

This study has demonstrated that the use of shade nets for open-field tomato production increased the total crop yield, with pearl-shade nets being the most suitable type of net for tomato production when taking into account PAR transmittance and total yield values. During the study period, working under the shade nets also provided a far more comfortable work-environment for the growers and researchers participating in the study.

4. Conclusions

Our results showed that the lowest light transmittance (ranging from 42.3% to 48.9%) was obtained from 40% green-shade net and the highest light transmittance (ranging from 57.5 to 65.6%) was obtained from 75% yellow-shade net in covered plots. The light transmittance of the blue and pearl-shade nets was determined as moderate. The pearl-shade net should be the optimal choice for agricultural applications in terms of PAR transmittance since it demonstrated the best performance regarding crop yield. The shade application of colour nets affected environmental variables and provided a more favorable microclimate for tomato plants compared to non-shading conditions during the spring and summer seasons in Antalya. Shade nets were found to have a positive impact on both fruit quality parameters and yield. This study also found a statistically significant decline between 0.5 ^{o}C and 3.6 ^{o}C in the leaf temperature under the shade nets compared to the open field conditions. Soil moisture was significantly higher under the shade nets than soil moisture measured in the open fields. For this reason, the application of shade nets may allow farmers to use less irrigation water on their crops and contribute to the wider global efforts towards water conservation. In addition, other related studies reported that shade nets are also used to protect the plants from wind, hail, birds and viral diseases transmitted by insects. Due to the noticeable increase in plant viral diseases, future studies may wish to examine the effects of the shade nets on the transmission of insect mediated plant viral diseases. According to the data obtained in this study, green-shade nets are better used for plants that thrive in shade, while the agricultural applications of yellow-shade nets are more suited for plants whose growth is promoted by low solar radiation. Finally, concerning the effects of shading on the crop, this study found that shading applications with coloured nets clearly led to an increase in total yield.

Data availability: Data are available on request due to privacy or other restrictions.

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