

Effects of External Coloured Shade Nets on Sweet Peppers Cultivated in Walk-in Plastic Tunnels

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Abstract

Shading effect of external nets of different colours (white, green, yellow and red) on the yield of two “kapija” pepper (*Capsicum anuum* L.) cultivars was examined in walk-in plastic tunnels in Hungary under real cultivation circumstances. Shading nets decreased incoming radiation by 23-39% and reduced photosynthetically active radiation by 32-46%. The highest retention was obtained by yellow and green nets, in the range of 450-550 nm and 550-670 nm, respectively. Relation was reported between the degree of shading and the average air temperature of the tunnels, however, treatments did not decrease tunnel air temperature significantly, compared to that of unshaded and paint-shaded control tunnels. This can be explained by the applied proper ventilation and mist irrigation. A strong and negative relation was noted between the intensity of shading and the relative chlorophyll content (SPAD value) of leaves. Shading net treatments did not increase yields, yellow and green nets even decreased it. Instead of tunnel air temperature, yield was mainly affected by photosynthetically active radiation in the experiment. Strong positive linear relation was declared between the chlorophyll content of the leaves and the yield. Results of the current research led to the conclusions that under Hungarian climatic conditions the use of shading nets was less justified if proper cooling techniques (ventilation and mist irrigation) were applied; even under the relatively high incident radiation experienced during the trials. In greenhouses of less favourable climatic conditions, red or white shading nets are recommended instead of commonly used green ones in Hungary.

Keywords: air temperature, photosynthetically active radiation, relative chlorophyll content, relative shading, solar radiation, yield

Introduction

Low-cost walk-in plastic tunnels are still very commonly used for vegetable – including pepper (*Capsicum anuum* L.) – cultivation in East-Central Europe (FruitVeB, 2013). Overheating could be a serious problem in these tunnels considering high summer temperatures. To control air temperature generally ventilation, shading paint, external shading nets and/or mist irrigation are applied (López-Marín *et al.*, 2012; Zhu *et al.*, 2012).

In the Mediterranean area the use of screens to protect plants is a usual strategy in the horticulture (Legarrea *et al.*, 2010). Sweet pepper is proved to be well-adaptable to shaded environment (Kitta *et al.*, 2014b). Moderate shading (30-50%) protected bell pepper from sunburns, reduced water use and resulted in high yields of good quality, however, more intensive shading reduced

leaf photosynthesis and adversely affected productivity (Díaz-Pérez, 2013; Shahak *et al.*, 2008; Zhu *et al.*, 2012). Shading rate even more than 20% was not recommended for sweet pepper production by Kitta *et al.* (2014a) under Mediterranean conditions. According to the literature photosensitive shading nets of red, pearl and yellow colour markedly increased productivity, improved fruit quality of different cultivated vegetables and reduced the crop infestation by pests and diseases. The combined effects resulted in better crop yields and lower susceptibility to decay during post-harvest storage compared to traditional shading methods (Stamps, 2009; Shahak, 2014). Yellow coloured mesh shades increased open field pepper yield and quality compared to traditional black nets (Fallik *et al.*, 2009), while both yellow and pearl coloured nets reduced the occurrence of *Alternaria* and improved post-harvest qualities of the product (Goren *et al.*, 2011).

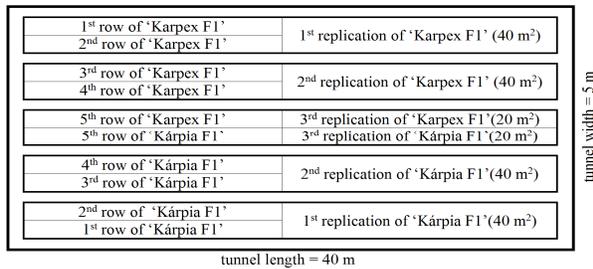


Fig. 1. Layout of the pepper rows and replications in the walk-in tunnels

Although numerous studies focused on the use of shading nets in open field pepper cultivation, less result was obtained from the investigation on the effect of photoselective meshes on greenhouse sweet pepper production. In Almería, Spain, red nets of 30% shading capacity resulted in higher yield in greenhouse pepper production than traditional whitewash (Shahak *et al.*, 2004 *cit. by* Shahak *et al.*, 2008). Red and pearl coloured internal shading nets improved tomato fruit quality and carotenoid content in walk-in plastic tunnels in Serbia (Ilić *et al.*, 2012; Ilić *et al.*, 2015).

The current study aimed to contribute to the knowledge on the effect of different coloured shading nets on the incident radiation and air temperature of walk-in tunnels and on the yield of pepper cultivated in the tunnels.

Materials and Methods

Conditions and methods of the cultivation

The experiment was established in the Southern Great Plain region of Hungary close to Lajosmizse (NL 47°00', EL 19°64') in 2012 in a private vegetable farm. Cultivation experiments were settled in six unheated walk-in plastic tunnels of 2.3 m height, 5 m width and 40 m length. Tunnel ends were designed to be converted and two side vents in each tunnel provided proper ventilation. After sowing on the 15th of March, seedlings were transplanted on the 24th of April distributed in 5 twin rows in each tunnel (10 rows as a total for each tunnel) at a distance of 0.3 m and 0.7 m between the rows. The space between the plants in the row was 0.25 m, resulting in a density of 8 plants per m². Seedlings of 'Kárpia F1' pepper cultivar were planted on the five left rows and 'Karpex F1' peppers on the five right rows, both cultivars of "kapija" type (Fig. 1).

As the general practice for Hungarian small-scale vegetable forcing farms, fertigation, ventilation and mist irrigation were operated manually. Fertigation was daily dosed through a drip irrigation system. Overhead micro spray irrigation was applied each day for 5 minutes when tunnel air temperature exceeded 30 °C. In the daytime the ends of the tunnels and the side vents were open when tunnel air temperature was over 22 °C. At night-time the side vents were continuously open when outside air time temperature exceeded 15 °C. Eight harvests were managed from 2nd July to 27th September collecting only ripened, hard, full-grown fruits of at least 75% red colouration.

Treatments

Tunnels were clad by 180 µm thick and 8.5 m wide Extra S-24 type (Solarker Ltd., Kecskemét, Hungary) light stable polyethylene film in its second cultivation season. Besides the five treatments, unshaded tunnel represented control. In the first

treatment Shadefix shading paint (Royal Brinkman B.V., s-Gravenzande, Holland) was applied at two occasions during the season with a dose of 100 kg/ha. Four tunnels were covered with different coloured shade nets (white, green, yellow and red, each tunnel by one colour) of 34 g/m² weight and of 8.35 m width (Első Magyar Kenderfonó PLC, Szeged, Hungary) at the top of the polyethylene cover for the whole season.

Measurements

Measurements of the intensity of incident solar radiation and intensity and spectral distribution of photosynthetically active radiation (PAR) were performed four times during the growing season (26th June, 17th July, 16th August and 26th September) both inside and outside the tunnels. Measurements of three replicates of each treatment were carried out at midday under clear skies with LI-185B type radiometer (LI-COR Inc., Lincoln, Nebraska, USA). Radiation intensity (W m⁻²) was measured by LI-200 pyranometer sensor while photosynthetic photon flux density (PPFD) values (µmol m⁻²s⁻¹) were determined by LI-190 SB type quantum sensor. Relative shading (reduction in radiation) of each treatment was calculated by using the formula of Oren-Shamir *et al.* (2001): relative shading = 100 * (1 - radiation inside/radiation outside the tunnels). Spectral distribution of the PAR was measured by HR2000+ High Resolution type spectroradiometer (Ocean Optics Inc., Dunedin, Florida, USA). Air temperature in the tunnels was determined by Voltcraft DL-120TH type thermometer (Conrad Electronic SE, Hirschau, Germany) at every 30 minutes from 27th April to 27th September. Three data loggers for each tunnel were situated in the centre of the tunnels above the three middle twin rows at the height of plant apex. Data loggers were protected from direct sunlight and irrigation and their situation was adjusted to plant height every second week.

Relative chlorophyll content of leaves was measured by Minolta SPAD 502 type chlorophyll meter (Konica Minolta Inc., Tokyo, Japan) eight times during the season. Measurements were carried out on young, fully developed, unshaded leaves. 3x30 measurements were made for each cultivar and each treatment at one occasion.

Harvest was divided among treatments and cultivars, collecting fruits from the edge-positioned twin rows, from the next inner twin rows and from the half of middle twin rows (Fig. 1). Fruits were classified as marketable and non-marketable (undersized, sunscald, injured, etc.) categories.

Statistical analysis

Air temperature values were evaluated by one-way ANOVA, while PPFD and SPAD values were analysed by two-way ANOVA considering treatment and data collection date as factors. Yield of the whole season was analysed with two-way unreplicated ANOVA with the factors of treatment and position of the rows. Mean separations were performed using Fisher's protected least significant difference test at $P \leq 0.05$. Linear regression analysis was used to reveal relations among different parameters using Microsoft Excel 2007 software (Microsoft Inc., Redmond, Washington, USA).

Results and Discussion

Radiation

Average intensity of incident radiation based on four measurement times was 743 W m⁻², considered medium high with

Table 1. Effect of shading methods on the intensity of incident solar radiation and on photosynthetically active radiation (PAR) based on the average of four measurement times

Treatment	Solar radiation		PAR	
	W m ⁻²	Relative shading (%)	μmol m ⁻² s ⁻¹	Relative shading (%)
Open field	743 a*		1588 a	
Control tunnel	638 b	14	1200 b	17
Shading paint	565 c	24	1175 bc	26
White net	548 cd	26	1063 de	33
Green net	453 e	39	863 f	46
Yellow net	520 d	30	988 e	38
Red net	575 cd	23	1088 d	32

*Mean separation within columns by Fisher's protected least significant difference test at $P < 0.05$

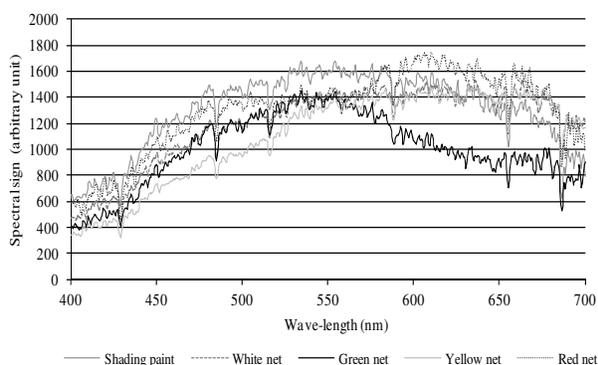


Fig. 2. Effects of the different shading treatments on spectral distribution in the PAR range on 18th July

the highest value of 810 W m⁻² measured on the 16th of June. The polyethylene cover itself, used in its second season, decreased solar radiation by 14% and PAR by 17%. Radiation was reduced the least by shading paint among the treatments (Table 1). Colour of the nets had a significant effect on shading capacity, green being responsible for the highest shading while red and white nets were the most permeable for radiation. In spite that weight and weave density of red and green nets were equal, a difference of 16% in shading effect was measured, affirming the findings of Ilic *et al.* (2015) where different incident radiation and PAR were measured in the case of nets of equal nominal shading capacity but different colour. Nets increased relative shading in the PAR range more (+ 7-9%), than polyethylene alone and shading paint (+ 2-3%) compared to relative shading measured in total solar radiation (Table 1). This finding is in harmony with the result of 9-11% increase, calculated from the data of Ilic *et al.* (2015).

Spectral measurements revealed differences in the penetration of radiation in case of different coloured nets, confirming previous results (Arthurs *et al.*, 2013; Legarrea *et al.*, 2010). Compared to shading paint, white coloured and red coloured nets, measured spectral signs for yellow and green nets were considerably lower in the 450-550 nm range and 550-670 nm range, respectively (Fig. 2). These results could explain the higher shading capacity of yellow and green nets.

Air temperature

Average air temperature of tunnels fell in the optimal 21-23 °C range of pepper cultivation (Wien, 1997) except in the case of the treatment with the yellow net. Shading did not affect considerably average air temperature in the season except in the case of yellow net where temperature was significantly higher than of other

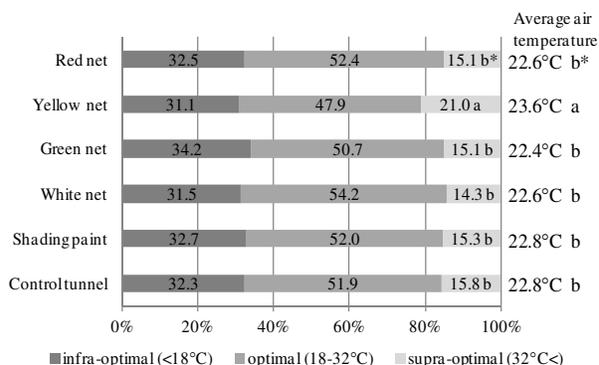


Fig. 3. Average air temperature of the tunnels and the distribution of infra-optimal, optimal and supra-optimal air temperature values for sweet pepper under different shading methods

*Mean separation within parameters by Fisher's protected least significant difference test at $P < 0.05$

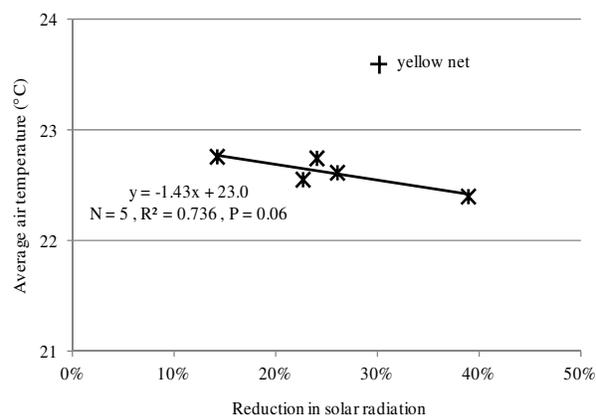


Fig. 4. Relation between reduction in solar radiation caused by the applied treatment and the average air temperature of the plastic tunnel

treatments (Fig. 3). In the yellow net treatment rate of optimal values (18-32 °C; Bosland and Votava, 1997) was lower (although not significantly) and rate of supra-optimal temperatures was significantly higher than those of other treatments. These results indicated that temperature conditions of yellow net treatment were less favourable and other treatments had no considerable difference in this pattern.

Table 2. Effect of shading methods on the total yield and marketable yield ratio of two kápia type sweet pepper cultivars grown in plastic tunnels

Treatment	'Kárpia F ₁ '		'Karpex F ₁ '	
	Total yield (kg m ⁻²)	Ratio of marketable yield (%)	Total yield (kg m ⁻²)	Ratio of marketable yield (%)
Control tunnel	7.07 a*	81.4	8.08 a	81.3
Shading paint	6.95 ab	82.7	7.38 ab	84.4
White net	6.49 ab	82.0	7.65 a	81.3
Green net	6.27 bc	84.6	6.14 c	83.5
Yellow net	5.69 c	81.3	6.55 bc	84.5
Red net	7.13 a	82.3	8.21 a	83.1

*Mean separation within columns by Fisher's protected least significant difference test at P < 0.05

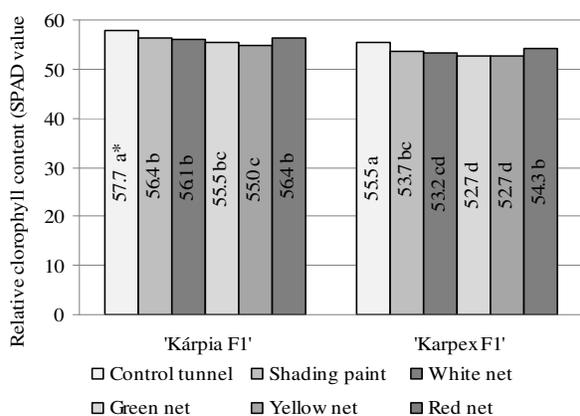


Fig. 5. Effect of shading methods on relative chlorophyll content of sweet pepper leaves

*Mean separation within cultivars by Fisher's protected least significant difference test at P < 0.05

Reduction of radiation by shading nets affect air temperature (Díaz-Pérez, 2013; Stamps, 2009) by strong negative relation, confirmed by the current research except in the case of yellow shading net (Fig. 4).

However, differences among colours of shading nets did not result in considerable air temperature variation (Fig. 3), due to proper ventilation and regular misting. Hence, high temperatures of the yellow shading net treatment could not be explained solely by shading intensity. Unfortunately, based on the measured data we could not explain the unexpectedly high air temperature caused by the yellow shade net. Location of the tunnel, state of mist irrigation and vents were checked, and they were clearly not modifying factors.

Relative chlorophyll content

Based on the average of eight measurements, shading had a significant effect on leaf relative chlorophyll content (SPAD) in both cultivars (Fig. 5). Although all treatments reduced SPAD values, shading paint, white and red nets were responsible for lower, while yellow and green nets for higher reduction. Shading rate and SPAD values resulted in a strong negative relation in both cultivars (Fig. 6). Higher shading reduced SPAD values, in contrast with the findings of López-Marín *et al.* (2012) and Zhu *et al.* (2012) where 60% and 30% shading intensity resulted in the highest SPAD values, respectively. However, our finding harmonizes with those reported by Legarrea *et al.* (2010) and Jang *et al.* (2014) noting that higher PAR resulted in higher SPAD values and higher chlorophyll concentration.

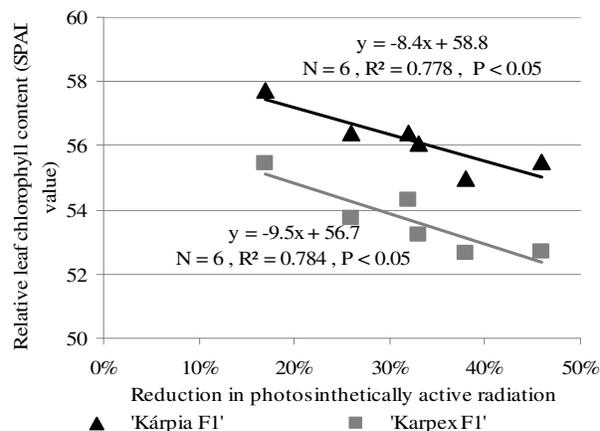


Fig. 6. Relation between shading intensity of the different treatments and average relative leaf chlorophyll content of sweet pepper leaves cultivated in walk-in plastic tunnels

Yield

Yield was not significantly increased by different shading treatments (Table 2). Similar to several previous open field research, red shade net provided good results (Stamps, 2009; Shahak, 2014), having the highest yield, although not significantly higher than those of control, shading paint or white coloured net shading. The lowest yields were recorded in the case of green and yellow nets, being significantly lower than that of control or red net treatments. This result can be explained with a lower penetration capacity of blue and red range radiation causing reduced photosynthetic activity.

Treatments did not affect the rate of marketable fruits significantly (Table 2). Sunscald did not occur more frequently in the control, unshaded tunnel (which itself also had a 14% shading capacity), in contrast with earlier open field researches (Shahak *et al.*, 2008; Shahak, 2014).

Results indicated that with the increase of shading intensity, yields decreased considerably, being significant in the case of 'Karpex F₁' cultivar (Fig. 7). Shahak *et al.* (2008) reported yield increase due to modification of radiation components solely by different coloured shading nets under open field circumstances. Rylski and Spigelman (1986) noted that when temperature and water availability were optimal, pepper yield was positively affected by light intensity. According to Díaz-Pérez (2014) optimal shading intensity could be reached by reducing the infrared range in order to maximize cooling effect and, in the meantime, minimize the decrease in PAR, thus, photosynthetic activity. Zhu *et al.* (2012) reported that effect of shading on pepper yield and quality was

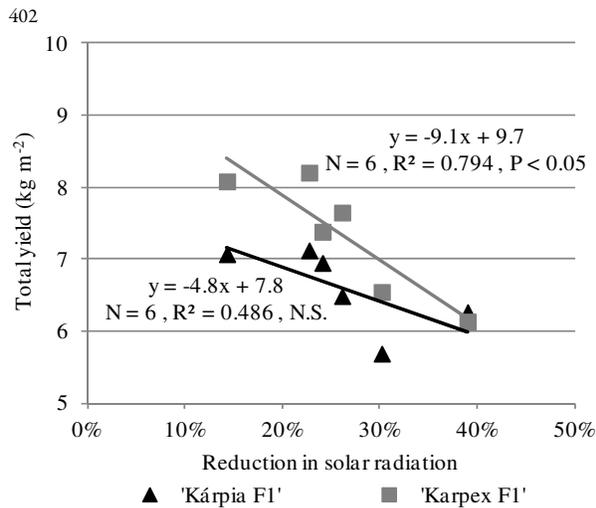


Fig. 7. Relation between reduction in solar radiation and total yield of two kapija type sweet pepper cultivars grown in walk-in plastic tunnels

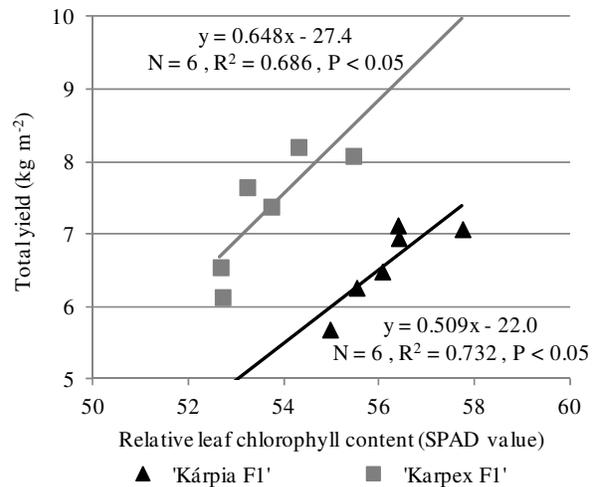


Fig. 8. Relation between relative leaf chlorophyll content and total yield of two kapija type sweet pepper cultivars grown in walk-in plastic tunnels

highly dependent on geographic area and cultivation technology.

In the current research control treatment also provided optimal temperatures (Fig. 3), hence decrease of radiation and hereby temperature did not improve yield. Therefore, PAR intensity and photosynthetic activity were declared as limiting factors. Madeira *et al.* (2003) found strong positive relation between SPAD value and chlorophyll content of pepper leaves. Hence, lower SPAD values indicate lower chlorophyll concentration and hereby reduced potential photosynthetic activity. This finding was confirmed by the significant strong positive relation between leaf SPAD values and yield in both cultivars included in the experiment (Fig. 8). In contrast with our findings Zhu *et al.* (2012) did not find significant correlation between SPAD values and yield, but they reported linear positive relation between net photosynthetic rates and fruit yield.

Conclusions

Shading net colours affected considerably the intensity and spectra of incident radiation. Nevertheless, applied shading methods did not affect positively the yield of the two examined pepper cultivars compared to those of the unshaded tunnel. Therefore, it can be concluded that when temperature of the tunnels can be maintained within optimal circumstances by proper ventilation and misting, shading can be considered unnecessary under Hungarian climatic conditions, even in the case of relatively high radiation as recorded in the research. Additionally, yellow and green shading nets reduced PAR to such an extent (38-46%), which even decreased fruit yield. Hungarian pepper producers generally use green nets to shade plastic tunnels which should be avoided based on our research experience.

Acknowledgments

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