ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 104, No. 1 (2017), p. 53–62
DOI 10.13080/z-a.2017.104.008

Effect of shading by coloured nets on yield and fruit quality of sweet pepper

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Abstract

The concept of photo-selective netting was studied in a sweet pepper (*Capsicum annuum* L.) cultivar 'Cameleon' from summer cultivation in south Serbia (under high solar radiation 910 W m^{-2}, with a photosynthetic photon flux density of 1661 μmol m^{-2} s^{-1}), under four different coloured shade-nets (pearl, red, blue and black) with 40% relative shading. The aim of the study was to determine how different environmental control technologies, coloured shade-nets as net house or plastic-house integrated with coloured shade-nets, could influence plant parameters, production and quality traits in pepper fruits. Shade-grown leaves generally have higher total chlorophyll and carotenoid content than control leaves. Pericarp fruit thickness was significantly higher in peppers grown under red net house (4637.10 μm) and black net house (4609.32 μm) compared to the open field – control (3116.19 μm). The highest concentration of total soluble solids (TSS) was detected in pepper fruits grown under the open field conditions (8.03%). Pepper fruits grown in plastic tunnels had significantly lower TSS content (6.58%). Total acid (TA) content was 0.19 in the control and 0.25 in pepper fruits grown under red nets. The highest concentration of vitamin C was detected in peppers grown in plastic tunnels integrated with red coloured nets (175.77 mg 100 g^{-1}). These results show that red and pearl photo-selective nets create optimal growing conditions and increase the total fruit yield as well as the number of fruits with fewer physiological disorders and with thicker pericarp. Photo-selective pearl and red nets can be recommended for sweet pepper 'Cameleon' with respect to quality and bioactive compound and can furthermore be implemented in protected cultivation practices.

Key words: *Capsicum annuum*, coloured shade-nets, fruit structure and quality, leaf structure, physiological disorders, yield.

Introduction

High solar radiation, heat stress, drought, desiccating winds and hail storms are some of the major environmental limitations to optimal productivity and nutritional quality of field grown vegetables. In traditional vegetable-producing regions, pepper cultivation in a protected environment has expanded to prevent seasonality in the availability of fruit. Low-cost plastic tunnels are still very commonly used for pepper cultivation in Serbia (Ilić et al., 2015). Overheating could be a serious problem in these tunnels considering high summer temperatures. To control the air temperature, ventilation and mist irrigation (López-Marín et al., 2012), shading paint and external shading nets are generally applied (Ombódi et al., 2016). The application of photo-selective netting technology is gaining popularity around the world. This practice is already popular in Europe, especially in Israel (Fallik et al., 2009; Kong et al., 2013) and other Mediterranean countries (Díaz-Pérez, 2014) as well as in South Africa (Mashabela et al., 2015; Selahle et al., 2015). The use of shading nets has also become very popular in Serbia due to the very high (35~40°C) temperatures in the summer season (Ilić et al., 2011; 2015; Milenković et al., 2012). The netting is either applied by itself over net-house constructions, or combined with greenhouse technologies (Ilić et al., 2015). Temporary shading, applied only during sunny periods, is considered to be less deleterious than constant shading.

Photo-selective shade-nets provide physical protection against hail, wind, bird and insect-transmitted virus diseases (Shahak, 2008). Reducing the transmitted

Please use the following format when citing the article:
Ilić Z. S., Milenković L., Šunić L., Barać S., Mastilović J., Kevrešan Ž., Fallik E. 2017. Effect of shading by coloured nets on yield and fruit quality of sweet pepper. Zemdirbyste-Agriculture, 104 (1): 53–62 DOI 10.13080/z-a.2017.104.008

solar radiation under shading reduces the canopy and air temperatures as well as the transpiration rate in the greenhouses. This consequently reduces the water consumption by about 50%, increases the water use efficiency and enhances the crop productivity up to 40% (Ahemd et al., 2016).

Sweet pepper has been proven to be well-adaptable to a shaded environment (Kitta et al., 2014). Regardless of the stress level, light quality changes could potentially alter the crop's physiological and biochemical processes, metabolite profiles and ultimately growth, development, yield and quality. For instance, photo-selective nettings have been shown to influence the biosynthesis of bioactive compounds in sweet peppers (Mashabela et al., 2015; Selahle et al., 2015). According to the literature, photoselective shading nets of red, pearl and yellow colour markedly increase productivity (Fallik et al., 2009), improve the fruit quality of peppers (Kong et al., 2013) and reduce the crop infestation by pests and diseases (Díaz-Pérez, 2014). Light quality and different wave lengths were reported to affect fruit colour and maturation (Alkalai-Tuvia et al., 2014). Ripening inhibition can be associated with less fruit susceptibility to fungal infection in the field (Goren et al., 2011), produce better crop yields (Ilić et al., 2011) and lower the fruit susceptibility to decay during post-harvest storage (Shahak, 2014; Selahle et al., 2015). Red and pearl coloured shading nets also improve tomato fruit quality (Ilić et al., 2012; 2015) and carotenoid content (Tinyane et al., 2013).

Fruits produced under pearl nets show higher fruit mass, firmness, chlorophyll content, ascorbic acid content and antioxidant scavenging activity (Alkalai-Tuvia et al., 2014; Mashabela et al., 2015). The combined effects result in better crop yields and lower susceptibility to decay during post-harvest storage compared to traditional black nets (Fallik et al., 2009; Stamps, 2009; Goren et al., 2011; Shahak, 2014). Pearl shade-nets may improve not only yield and quality, but also postharvest shelf-life of the bell pepper fruit (Goren et al., 2011; Kong et al., 2013; Díaz-Pérez, 2014). Sensory analysis indicated a preference for red pepper fruits after storage from plants grown under pearl nets (Selahle et al., 2015).

Coloured net house pepper production systems must be fine-tuned to the local climatic conditions before the technology can be adopted by growers. This study is the first step in that direction. The aim of the study was to determine how different environmental control technologies (coloured shade-nets as net-house or plastic tunnels integrated with coloured shade-nets) could influence plant growth parameters, production and quality traits in cv. 'Cameleon' peppers cultivated in south Serbia (Balkan region).

Material and methods

Plant material and cultivation. The sweet pepper (*Capsicum annuum* L.) cultivar 'Cameleon' was grown during 2009–2011 in a plastic tunnel (2.2 m high), covered with a polyethylene film 0.15 mm thick (Ginegar Plastic Products Ltd., Israel) and in the open field. The experiments were performed in an experimental plot located in the village of Moravac near Aleksinac (longitude 21°42′ E, latitude 43°87 30′ N, altitude 159 m) in the central area of south Serbia. The plants were grown following the technique usually implemented by the local producers. Before transplanting, 400 kg of NPK fertilizer (15:15:15) was added to the soil together with 2 t of farmyard manure per hectare. During the growing season 100 kg of KAN (calcium ammonium nitrate) fertilizer per hectare was applied as well. Seedlings were transplanted on the 5th of May and arranged in double rows with a distance of 0.8 between beds and 0.3 m between the rows and 0.3 m between the plants. The shading nets were subsequently installed above the crop on the 10th of June (35 days after transplanting) and the measurements were carried out until the 15th of September. All plants were irrigated using drip irrigation. The plants were treated with insecticides Decis 2.5 EC (a.i. deltamethrin) + Calypso 480 SC (a.i. tiakloprid) 0.2% to exclude *Aphididae* during vegetation. The fungicide Ridomil Gold (a.i. mefenoxam) 2.5 kg ha^{-1} was applied shortly after transplanting trought the drip irrigation system to protect plants against disease (*Alternaria*, *Phytophtora capsici*). Mefenoxam needs to be reapplied twice at 30-day intervals after the first application. The sampling was performed randomly by hand at the technological maturity stage of pepper fruits (full grown fruits of at least 75% red colouration). Seven harvests were managed from the 27th of June to mid-September. Each sample consisted of three replicates (n = 3).

Colour shade-nets. The shading nets were combined with greenhouse technologies or mounted on a structure about 2.2 m in height over the plants in a net house. In order to test the effect of shading nets, four different coloured nets (red, blue, black and pearl) were used with shading intensity of 40% relative shading. The coloured shade-nets were obtained from Polysack Plastics Industries, Israel that operates under the trademark ChromatiNet®. The photo-selective net products are based on the incorporation of various chromatic additives, light dispersive and reflective elements into the netting materials during manufacturing. The photo-selective nets (chromati nets or coloured shade-nets) are designed to modify light in either the ultra-violet (UV), visible, or far-red spectral regions. The nets also enhance the relative content of scattered versus direct light and absorb infra-red radiation. The blue shade-nets is designed to absorb UV, red and far-red; while enriching the blue spectral region. The red shade-nets absorbs UV, blue and green, and enriches the red and far-red spectral region. The pearl and grey shade-nets do not enrich or absorb the different wavelengths but the pearl is designed to scatter the light to a greater extent than the other mentioned shade-nets.

Light interception by nets. The effect of nets on the interception of light was measured annually as a percentage of total photosynthetically active radiation (PAR) above canopy, using a ceptometer model Sun Scan SS1-UM-1.05 (Delta-T Devices Ltd., UK) with a 64-sensor photodiode linearly sorted in a 100 cm length sword. Readings are in units of PAR quantum flux (μmol m^{-2} s^{-1}). All measurements were conducted on clear days at noontime. Measurements of global radiation were made every second day, three times during the day. The Solarimeter-SL 100 (KIMO, France) is an easy-to-use portable autonomous solarimeter that measures solar irrigation range from 1 to 1300 W m^{-2}. All spectral data were expressed as radiation intensity flux distribution in W m^{-2} nm^{-1}.

Direct methods for leaf area determination. Paper surface area (P) was calculated from measured length and width of the paper and its mass (G) was measured on the analytical balance. Leaves were picked from the plant, placed on the paper and the contour of each leaf was outlined on the paper with a pencil. The outlined area on the paper was cut with scissors and mass (G_1) was determined. The unknown leaf area (P_1) was calculated from its proportion with measured P, G and G_1 using the formula: $P_1 = G_1 \times P / G$.

Chlorophyll a, b and carotenoids were estimated in fresh leaf samples. One-half gram of fresh leaves was ground in acetone (90% v/v), filtered and made up to a final volume of 50 mL. Pigment concentrations (in mg g^{-1} fresh weight (FW)) were calculated (absorbance (A) of extract at 663, 648 and 470 nm) using the formula of Lichtenthaler (1987):

chlorophyll $a = [(11.75A_{663} - 2.35A_{645}) \times 50] / 500$,
chlorophyll $b = [(18.61A_{645} - 3.96A_{663}) \times 50] / 500$,
carotenoids $= [1000A_{470} - (2.27 \times \text{Chl } a) - (8.14 \times \text{Chl } b) / 227 \times 50] / 500$.

Anatomical analyses were performed on ten fruits of each treatment. The segments 5 × 2 cm were cut from the middle part of each fruit and fixed and preserved in 60% ethanol. Cross-sections were made using a hand microtome and a razor blade. Observations and measurements were made using light microscope and image analyzing system Motic Images Plus (Hong Kong). Relative proportions were calculated for cuticle, collenchyma, exocarp, mesocarp and endocarp in relation to total pericarp thickness. The cross-section area of ten exocarp, endocarp and large vesicular mesocarp cells was measured on each cross-section. Mesocarp cells were measured in consecutive layers, the cells under the exocarp being assigned as the first layer, and the cells above the giant cells as the last.

Fruit quality. Pepper samples (20 fruits) were collected each year from June until August. Each fruit was cut into pieces and homogenised in a conventional blender in order to obtain the fruit juice. Thereafter, the fruit juice was filtered using a Whatman No. 4 filter paper and the filtrate was used to determine the total soluble solids (TSS) and titrable acidity (TA). TSS were determined for each fruit sample in two replications using an Atago DR-A1 digital refractometer (Atago Co., Japan) at 20°C and expressed as %. TA was measured with 5-mL aliquots of juice that were titrated at pH 8.1 with Hanna GLP pHmeter HI 111 (Clarkson Laboratory & Supply Inc., USA) with 0.1 mol L^{-1} NaOH (required to neutralise the acids of pepper in the presence of phenolphthalein) and the results were expressed as grams of citric acid per 100 g of fresh pepper weight.

Ascorbic acid was quantitatively determined according to 2,6-dichlorophenol indophenol-dye method as described by Jones and Hughes (1983) with slight modifications.

Statistical analysis. All data were subjected to one-way statistical analysis at $P = 0.05$ using software *JMP* (SAS Institute Inc., USA) and the mean values for all data are presented.

Results and discussion

Microclimate conditions. The microclimates were similar under the nets, with slightly lower values of temperature and air humidity than in the open air. The air temperature on an average day in July under different coloured shade-nets was between 0.9°C (pearl) and 3.0°C (black) lower when compared to the open field air temperature (Fig. 1). Coloured shade-nets benefit in temperature control; they improve productivity by alleviating temperature extremes. Since air movement is restricted, wind damage to the crop is reduced. The air beneath the shade cloth remains humid, which is of further benefit to the plant.

Shade-nets are often deployed over crops to reduce heat stress. Our studies show that in July and August, at high insolation and reduced air circulation (13–15 h), the temperature in shade-nets was 1°C lower (pearl and red) and up to 3°C lower (black), in comparison to the open field (Fig. 1). Shading technology on a number of locations in Israel confirmed a general decrease of maximum daily temperature (Tmax) by 1–5°C, followed by an increase in maximum daily relative air humidity by approximately 3–10%. Shahak (2008) reported that the maximum daily temperature under shade-nets (30% PAR) was up to 3°C lower than the control, similar to what Iglesias and Alegre (2006) have stated, and that larger differences are recorded during bright and sunny days. Relative humidity is often higher under netting than outside, as a result of water vapour being transpired by the crop and reduced mixing with drier air outside the netted area.

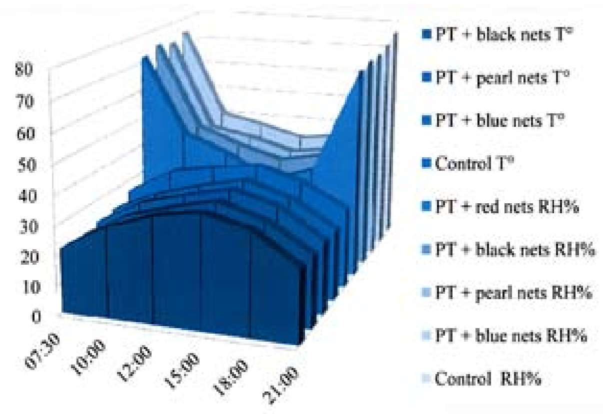

Figure 1. Temperature and relative humidity levels as affected by plastic tunnels and coloured shade-nets

The PAR of a day in July (13–14 h) had a value of 1661 µmol m^{-2} s^{-1} (average of 3-years). By shading with shade nets, the PAR was lowered to 962 µmol m^{-2} s^{-1} in the red shade-net and to 771 µmol m^{-2} s^{-1} in the black shade-net. The sun's rays in the tunnels are intercepted not only by nets but also by a foil which is 150 µm thick. PAR is highest in the tunnel with a red net of the shade index 40% PAR, 832.3 µmol m^{-2} s^{-1}. In July, around 1 pm, the sun radiation in the tunnel without nets during cloudy day is 692 W m^{-2}, which is 24.8% less in comparison to the open field radiation (920 W m^{-2}). Reduction in solar radiation over pepper canopy measured under shade-nets of different colours is represented in Table 1.

Table 1. Reduction in solar radiation and incident photosynthetically active radiation (PAR) over pepper canopy measured under different coloured nets (average of 3-years)

Coloured nets	Reduction in solar radiation %		PAR µmol m^{-2} s^{-1}	
	plastic tunnels + coloured nets	only coloured nets	plastic tunnels + coloured nets	only coloured nets
Red	22.9	32.5	832.3	962.0
Black	52.4	55.9	703.1	771.8
Pearl	25.1	33.9	813.9	993.6
Blue	32.9	43.9	756.6	889.7
Control	100 ◘	100 ◙	1199.5 ◘	1661.3 ◙

Control: ◘ – plastic tunnel, solar radiation 761 W m^{-2}; ◙ – open field, exposure to full sunlight 910 W m^{-2}

The sun radiation in July and August is high. It can reach 1700 µmol m^{-2} s^{-1} and it is most frequently followed by temperatures above 35°C. During a sunny day in July (with solar radiation at 920 W m^{-2}) the reduction did not exceed 1°C in plastic tunnels with shade. With every 100 W m^{-2}, the solar radiation increased the temperature by 1°C. The net radiation is strongly correlated to the incoming solar radiation, in analogy to what is known to occur over open ground. Under high solar radiation (in conditions of south Serbia in July and August) PAR values exceed 1650 µmol m^{-2} s^{-1}, resulting in unshaded plants being exposed to high heat stress throughout the growing season (Table 1).

The PAR values varied between 1661 µmol m^{-2} s^{-1} on sunny days and 700–920 µmol m^{-2} s^{-1} on cloudy days. Similarly, Jaimez and Rada (2006) state that the PAR at full insolation (1519 µmol m^{-2} s^{-1}) is lowered to 931 µmol m^{-2} s^{-1} when shaded to 40% PAR and to below 550 µmol m^{-2} s^{-1} when shaded to 60% PAR. Producers from Brazilian tropical regions using reflective shading nets (40% shading rate) obtained reductions in incident solar radiation and PAR by 46.3% and 48.3%, respectively (Ferreira et al., 2014). In addition to light intensity and quality (Shahak, 2008; 2014), shade-nets may modify environmental variables such as temperatures, wind speed, or relative humidity inside the canopy (Arthurs et al., 2013).

Wind speed can be reduced from 6 m s^{-1} in the open field (control) to 1.0–1.9 m s^{-1} under different coloured nets (Fig. 2). The effect varies according to the porosity (knitting density) of different net cover. Nettings also reduce wind speeds and wind run, which can affect temperatures, relative humidity and gas concentrations resulting from reductions in air mixing. These changes can affect transpiration, photosynthesis, respiration, and other processes. The effects on air movement depend on the porosity and physical location of the netting in relation to the plants and can be affected by time of day, season, and other factors.

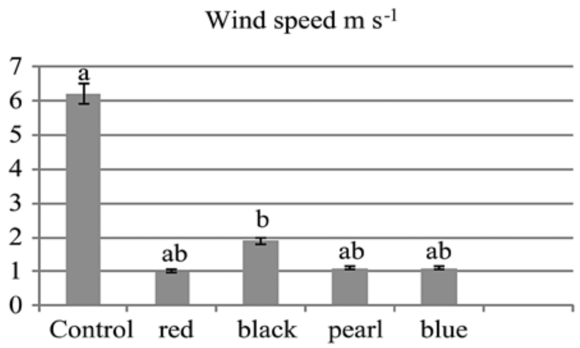

Figure 2. Influence of colour shade-nets on wind speed

In this study we have found that all shade-nets significantly increase the leaf area index (LAI), compared to the LAI values obtained from control plants (plastic tunnel). Generally, pepper under plastic tunnels integrated with coloured shade-nets have a lower LAI in comparison to the plant LAI obtained under net house (only coloured nets). Among the coloured nets, pepper plants under black nets produce crop with the lowest LAI value. Leaf area indices ranged from 1.2 in open field crop (control) to maximum LAI values of 2.9 in plants under plastic tunnel cover with pearl nets (Table 2).

Santana et al. (2012) reported minor differences in LAI value of pepper plants under shading net comparing with plants from open field. Thus, the red screen (40%) promotes slight increase in the LAI values (1.13–1.15) compared to the field conditions (0.94–1.04). Plants grown in the shade tend to have a larger leaf area because cells expand more under low light intensities in order to receive light for photosynthesis. Lower light intensities increased the stem elongation, leaf blade area and leaf area index (Tinyane et al., 2013).

Chlorophyll content. Shaded leaves generally have larger total chlorophyll (chlorophyll *a* and *b*) content than leaves from control plants (from plastic house or open field). Leaves of pepper plants, cultivated under black and blue shade-nets have the highest chlorophyll

Table 2. Leaf area index (LAI) in sweet pepper as affected by light intensity using coloured shade-nets

Coloured nets	Red	Black	Pearl	Blue	Control
Plastic tunnel + coloured nets	2.8 a	2.6 a	2.9 a	2.6 a	2.0 b◘
Only coloured nets	2.3 a	1.3 b	2.1 a	1.7 ab	1.2 b ◙

Note. Control: ◘ – plastic tunnel, ◙ – open field; different letters in the same column indicate statistically significant differences (significance level $P = 0.05$).

content in comparison with plants cultivated under other coloured shade-nets (Table 3). An increase in biomass (vegetative and reproductive) coincides with increases in leaf area and chlorophyll content. Shade-grown leaves harvest lower levels of light and thus contain more chlorophyll than leaves exposed to direct sun. Although shade-grown leaves are not directly exposed to sunlight, they produce additional chlorophyll to capture diffuse radiation to produce the carbohydrates needed for the plant to grow. Chlorophyll content of pepper fruits grown under pearl net was significantly higher than that of fruits grown under the black net (Alkalai-Tuvia et al., 2014).

Table 3. Photosynthetic pigments (mg g^{-1}) in the leaves of sweet pepper plants in response to light intensity using coloured shade-nets

Coloured nets	Chl *a*	Chl *b*	Car	Chl *a* + *b* / Car	Chl *a*	Chl *b*	Car	Chl *a* + *b* / Car
	plastic tunnels + coloured nets				only coloured nets			
Red	1.885 ab	0.824 a	0.518 ab	5.229	1.745 ab	0.879 ab	0.505 a	5.198
Black	1.943 a	0.742 ab	0.582 a	4.613	1.845 a	0.728 a	0.865 ab	5.587
Pearl	1.809 b	0.731 ab	0.488 b	5.206	1.690 ab	0.814 b	0.473 ab	5.293
Blue	2.101 b	0.815 a	0.566 a	5.240	1.799 a	0.919 a	0.507 a	5.360
Control	1.423 c ◘	0.542 b	0.413 c	4.750	1.406b ◙	0.680 c	0.423 b	4.943

Note. Chl – chlorophyll, Car – carotenoids; control: ◘ – plastic tunnel, ◙ – open field; different letters in the same column indicate statistically significant differences (significance level *P* = 0.05).

Carotenoid content ranged from 0.423 mg g^{-1} in plants from open field (control) to maximum carotenoid values (0.865 mg g^{-1}) in leaves of plants cultivated under net houses with black nets (Table 3). A similar trend was observed in plastic tunnels integrated with coloured shade-nets where the lowest carotenoid content (0.413 mg g^{-1}) was recorded in leaves of plants cultivated under plastic tunnels (control). The highest content of carotenoids in the leaves of pepper plants cultivated under plastic tunnels was observed in the plots integrated with black nets (0.582 mg g^{-1}). Carotenoids serve to protect chlorophyll from too much light or the wrong wave lengths thereof, and so act as a selective filter. Carotenoids are able to absorb energy that may otherwise lead to singlet oxygen formation from excited chlorophyll molecules. Carotenoids may also scavenge any singlet oxygen that forms during photosynthesis (Bergquist, 2006). The excess radiation generates reactive oxygen species that may cause photo inhibition if not scavenged, for example, by carotenoids (Bergquist et al., 2007). A strong and negative relation was noted between the intensity of shading and the relative chlorophyll content of leaves. Strong positive linear relation was declared between the chlorophyll content of the leaves and the yield (Ombódi et al., 2016).

Leaf structure and thickness. Bell peppers present leaf and stem morphological and physiological adaptations in response to shade. The bell pepper plant height, plant leaf area, individual leaf area, individual leaf dry weight, and leaf weight ratio (fraction of total above-ground biomass allocated to leaves) have been found to increase, whereas the specific leaf weight (leaf dry weight per unit leaf area, an estimator of leaf thickness) decreases with increased shade level (Díaz-Pérez, 2013). The capsicum species studied showed a dorsiventral mesophyll leaf blade. The palisade parenchyma consisted of one layer of elongated cells and the spongy parenchyma showed 4–5 layers of cells with varying shapes and noticeable intercellular spaces. Results indicate that the spongy parenchyma leaf thickness is higher in control plants from open field (160.19 µm) and significantly higher in plants from plastic tunnels (160.91 µm) compared to other treatments. Similarly, palisade parenchyma leaf thickness is significantly higher from control plants from open field (123.76 µm) and plastic tunnels (108.15 µm) compared to other treatments of coloured nets (Table 4). No significant differences were found in upper and lower epidermis leaf thickness between plants from open field and plants under coloured nets.

Fruit yield. Bell pepper yields depend on the total number of fruits and fruit size. The number of fruits produced declined with increasing shade level. Thus, increased total fruit yield under moderate shading was caused by increased fruit size. Increased marketable fruit yield was also caused by increased fruit size, but it was also strongly determined by reduction in number of cull fruit, which resulted in increased percent of marketable fruit relative to total fruit number. Depending

Table 4. The structural characteristics (µm) of sweet pepper leaves conditioned by coloured shade-nets

Coloured nets	Plastic tunnels + coloured nets				Only coloured nets (net house)			
	upper epidermis	palisade parenchym	spongy parenchym	lower epidermis	upper epidermis	palisade parenchym	spongy parenchym	lower epidermis
Red	20.93 a	85.32 b	123.32 b	15.68 a	20.46 a	115.82 ab	155.24 a	17.59 a
Black	22.32 a	87.48 b	114.50 b	14.29 a	24.05 a	103.09 b	152.45 a	16.09 a
Pearl	22.89 a	95.13 ab	145.97 a	16.07 a	21.77 a	102.87 b	150.87 a	17.12 a
Blue	23.93 a	98.47 ab	130.48 ab	15.30 a	22.23 a	111.09 ab	146.46 ab	17.97 a
Control	21.99 a	108.15 a	160.91 a	16.01 a	23.14 a	123.76 a	160.19 a	17.18 a

Note. Different letters in the same column indicate statistically significant differences (significance level *P* = 0.05).

on the shading level, the total fruit yield (t ha^{-1}) under the coloured shade-nets were increased by 7.5% to 30%, relative to the equivalent black shade-net. The highest fruit yield resulted mostly from enhanced fruit production rates, namely the number of fruits produced per plant, while average fruit size was not significantly affected in most cases (Table 5).

Plants grown under black coloured nets with 40% shadow had a 10.3% higher yield of than control plants grown without nets. Red and pearl shade-nets significantly increased the total yield by 30% which was associated with both higher productivity per plant and larger fruits. Pepper plants under 50% shadow achieved lower fruit yield in comparison with the yield obtained from 40% coloured shade-nets, especially under combination with plastic tunnels and black shade-nets where the achieved yield was lower than the control (plastic tunnels) as shown in Table 5.

Table 5. Effects of shading on the fruit mass, number of fruit per plant and total sweet pepper yield

Coloured nets	Fruit mass g		Number of fruits / plant		Total yield t ha^{-1}	
	only coloured nets	plastic tunnels + coloured nets	only coloured nets	plastic tunnels + colour nets	only coloured nets	plastic tunnels + coloured nets
Red	95.7 a	107.2 a	7.7 a	9.3 b	40.2 a	54.2 a
Black	75.0 c	100.1 a	6.5 b	8.0 c	27.8 b	44.8 b
Pearl	94.9 a	102.1 a	7.5 a	10.8 a	40.3 a	60.4 a
Blue	86.1 b	97.8 a	6.1 b	8.0 c	29.6 b	43.6 b
Control	78.1 c	89.5 b	5.6 b	8.3 c	25.2 b	41.3 b

Note. Different letters in the same column indicate statistically significant differences (significance level $P = 0.05$).

The major response to the photoselective filtration was the production of more fruits per plant, with essentially no reduction of fruit size or quality. Increased fruit size was likely the result of reduced transpiration and improved plant water status and net photosynthesis under shaded conditions. According to the available literature, it is evident that shading is one of the promising methods to control the plant growth characteristics in order to increase yield and quality of pepper. Moderate shading (30% to 47%) increased total and marketable yields probably as a result of amelioration of heat stress (reduction in canopy and root zone temperatures) compared with unshaded plants (Díaz-Pérez, 2014). The number of fruit produced per plant throughout the growing season was 30–40% higher, and the yield (t ha^{-1}) 20–30% higher under these photoselective nets, in all tested cultivars, while fruit size was comparable with the black shade-net (control) (Shahak, 2008).

In Serbia, bell pepper grown under coloured nets with 40% or 50% shade had higher total yields compared with unshaded plants (Ilic et al., 2011). Santana et al. (2012) achieved greater yield and higher fruit quality for sweet pepper hybrids grown under photo-selective (red and blue) shading net houses compared with those obtained from open field. According to the authors, the loss of commercial fruit by solar blight is significant in open crops. Peppers grown in an arid region under red and yellow shade-nets (30% relative shading in PAR) had a significantly higher yield compared with black nets of the same shading factors, with no reduction in fruit size (Fallik et al., 2009).

Shahak (2008) reported that the production of three cultivars of bell pepper increased by 16% to 32% under pearl and red compared with black netting. With roughly 50% shade, commercial production was greater than in full sunlight, although less than with 26% (Rylski, Spigelman, 1986). Shade can increase total and marketable yields of pepper grown in the open field in hot climates, but shade is far more deleterious in a cool and cloudy environment. These studies suggest that shade is more beneficial under high compared with low sunlight intensity on both a daily and a seasonal basis.

Fruit physiological disorders. High temperatures can be detrimental to bell pepper, resulting in reduced fruit yield and increased incidence of fruit disorders such as sunscald and blossom-end rot. The intensive sunlight can cause severe damage, because sunscald fruits do not meet industry standards and their nutritional value is reduced. Sunscald was eliminated under shading while pepper cracking, blossom-end rot and pericarp lignification were reduced to about 50% compared to open field conditions. Cracks are due to strong variation in water content likely due to increased leaf transpiration followed by strong water influx. Fruit cracking not only reduces fruit appeal and marketing, but can also increase fruit susceptibility to decay and shorten shelf life. Shading reduced the appearance of pepper cracking and eliminated sunscald on pepper fruits and accordingly, increased the marketable pepper production by about 25% compared to non-shading conditions (Table 6).

Table 6. Effects of shading on the percentage of physiological disorders of sweet pepper fruits

Coloured nets	Marketable fruit	Blossom-end rot	Cracking	Irregular shape	Pericarp lignification	Sun scald
Red	88 a	5 bc	1 c	4 c	2 bc	–
Black	83 b	6 b	3 ab	6 b	3 b	–
Pearl	89 a	4 c	1 c	5 bc	1 c	–
Blue	83 b	6 b	2 b	6 b	3 b	–
Control	68 c	8 a	4 a	9 a	5 a	6

Note. Different letters in the same column indicate statistically significant differences (significance level $P = 0.05$).

The number of sunscalded fruit decreased with the shade level (Díaz-Pérez, 2014). Like with sunscald, blossom-end rot and fruit decay declined with shade level. Beneficial effects (increased marketable yield and reduced incidence of sunscald) of shading are probably associated with a reduction in irradiation, air temperature and soil temperature under shaded conditions resulting in amelioration of heat stress in the plants.

Due to high temperatures during the vegetative period it was expected that intense sunlight would damage, to a considerable extent, the colour of the pepper fruit (Ambrózy et al., 2016). Sunscald injury of pepper fruit increased with irradiance and air temperature. Peppers at the mature-green stage are especially susceptible. Sunscald is a solar radiation injury that causes fruit tissue necrosis or browning and is accompanied by changes in fruit pigments (Schrader, 2011). Bell pepper yellow fruit cultivars displayed greater incidence of sunscald than red fruit cultivars. This could be attributed to a likely increased concentration of carotenoids in red fruit cultivars. Carotenoids protect leaves and fruit tissues from photo-oxidative processes associated with sunscald disorder.

These results agree with those reported by Santana et al. (2012). The authors found less sunscald fruits under photo-selective shading (5%) than under the control (35%) in sweet pepper. In the case of all shading nets, a positive effect was experienced against sunscald except for the white net. Several studies (Stamps, 2009; Ilić et al., 2012; 2015) have demonstrated improvement in fruit quality and an increase in commercial fruit production due to the use of coloured shading screens. In addition to protection against direct solar radiation avoiding damage to the fruit epidermis, these screens promote better solar radiation distribution within the plant canopy, improving the size, ripeness, colour and taste of the fruits.

Fruit structure and pepper quality. The yield is determined by the formation and development of the fruit. Fruit size depends on the development of the plants, mainly leaf mass and the number of seeds in the fruit. The fruits from the plants growing under coloured nets contain about 20% more seeds per fruit and as much as 29% of the fruit has more than 400 seeds per fruit compared to fruit that develop on plants from open field conditions (data not shown). The pericarp consists of the exocarp, mesocarp and endocarp. The mesocarp is made from large thin wall cells and vascular tissue. Results indicate that the pericarp fruit thickness is significantly higher in plants from plastic tunnels covered by pearl and red coloured net compared to other treatments and control (plastic tunnel). The pericarp fruit thickness (exocarp 139.00 µm, mesocarp 4740.99 µm and endocarp 20.88 µm) is significantly higher in the plants from plastic tunnels cover by red (4921.14 µm) and pearl (4522.83 µm) coloured nets compared to other treatments and control (plastic tunnel 3918.86 µm) (Table 7).

Table 7. Sweet pepper fruit structural characteristics (µm) in plastic tunnels covered by coloured shade-nets

Coloured nets	Exocarp	Mesocarp	Giant cells	Endocarp	Perikarp
Red	139.00 b	4740.99 a	441.06 bc	20.88 ba	4921.14 a
Black	178.86 a	4291.54 a	492.70 ba	30.53 a	4495.72 a
Pearl	135.02 b	3729.65 a	387.60 cb	31.98 a	4522.83 a
Blue	146.26 b	4072.39 a	515.65 ab	28.68 ab	4363.34 a
Control	148.88 b	3760.77 a	613.56 a	24.59 ab	3918.86 a

Note. Different letters in the same column indicate statistically significant differences (significance level $P = 0.05$).

Results indicate that high temperature tolerance of coloured shade applied plants is primarily linked to improved growth and fruit quality parameters. Although some reports show improvement in plant growth by colour shade-nets (Milenković et al., 2012), no report is available on the enhancement of the pepper fruit composition in shade-grown plants. In this study, we found that coloured shade-nets improved the fruit structural parameters.

Results indicate that the pericarp fruit thickness is significantly higher in plants from plastic tunnels covered by coloured nets compared to pericarp fruit thickness in plants from net house and open field (control). The pericarp fruit thickness (exocarp 124.00 µm, mesocarp 4467.52 µm and endocarp 30.26 µm) is significantly higher in the plants from red net house (4637.10 µm) and black net house (4609.32 µm) compared to other treatments and control – open field (3116.19 µm) (Table 8).

Therefore, the mechanical properties of pepper tissues (exocarp, mesocarp and endocarp) were determined in this paper, and the obtained data can be used to create optimal growing conditions to achieve fruits with thicker pericarp, firmness and better tolerated transport and

Table 8. Sweet pepper fruit structural characteristics (µm) as affected by coloured shade-nets

Coloured nets	Exocarp	Mesocarp	Giant cells	Endocarp	Perikarp
Red	124.87 a	4467.52 a	347.13 a	30.26 a	4637.10 a
Black	146.04 a	4373.34 ab	408.61 a	26.19 a	4609.32 ab
Pearl	140.29 a	3455.58 ab	393.68 a	29.14 a	3649.13 ab
Blue	138.17 a	3094.85 bc	329.39 a	26.82 a	3237.60 ab
Control	124.68 a	2972.91 ca	389.67 a	23.42 a	3116.19 ba

Note. Different letters in the same column indicate statistically significant differences (significance level $P = 0.05$).

storage. Decreases in fruit dry weight percent with shade level indicate that fruit had reduced specific fruit weight (fruit dry weight per unit fruit surface area) or a thinner pericarp or that fruit may have undergone changes in cell structure or cell size under shade.

The highest concentration of TSS (8.03%) was detected in pepper fruits grown under open field conditions. Pepper fruits from plastic tunnels had significantly lower TSS content (6.58%). No significant differences were observed in the TSS values of fruits grown under control conditions (plastic house) and fruits grown in integrated plastic tunnels with different shade-nets. Results from Table 9 show that significant differences in vitamin C contents were observed in peppers grown in plastic tunnels (151.37 mg 100 g^{-1}) compared to the open field conditions (171.27 mg 100 g^{-1}). The highest concentration of vitamin C (175.77 mg 100 g^{-1}) was detected in peppers grown in plastic tunnels integrated with red coloured nets, while peppers grown only under red nets had the lowest levels of vitamin C (148.50 mg 100 g^{-1}).

Table 9. Sweet pepper fruit quality as affected by coloured shade-nets

Coloured nets	Total soluble solids (TSS) %		Total acidity (TA) %		Vitamin C mg 100 g^{-1}	
	plastic tunnels + coloured nets	only coloured nets	plastic tunnels + coloured nets	only coloured nets	plastic tunnels + coloured nets	only coloured nets
Red	6.39 a	6.95 b	0.23 ab	0.22 a	175.77 b	148.50 b
Black	6.44 a	7.19 b	0.20 b	0.19 b	145.26 a	166.39 a
Pearl	6.54 a	6.64 c	0.25 a	0.23 a	151.28 a	162.02 a
Blue	6.47 a	7.12 b	0.21 b	0.19 b	136.50 a	168.80 a
Control	6.58 a ◘	8.03 a ◙	0.19 b ◘	0.18 b ◙	151.37 a ◘	171.27 a ◙

Note. Control: ◘ – plastic tunnel, ◙ – open field; different letters in the same column indicate statistically significant differences (significance level $P = 0.05$).

Only limited or no data can be found in the literature dealing with the contents of vitamin C in pepper fruits as a response to growing conditions, particularly variations in solar radiation and temperature. The vitamin C content of pepper was affected by cultural practices (genotype and agronomic technique) on the one hand (Topuz, Ozdemir, 2007) and abiotic factors (light and temperature) on the other hand (López-Marín et al., 2011). Vitamin C development in pepper is related to glucose metabolism and light exposure, and concentrations of both vitamin C and reducing sugars typically increase as the fruit matures. Fruits produced under the pearl nets contain more ascorbic acid at harvest and retain more of it after postharvest storage, perhaps through delayed ripening (Mashabela et al., 2015).

The complexity and variability of natural radiation on the one side and the multiple reactions of plant response on the other side make it difficult to predict how a given manipulation of natural solar radiation will affect vegetative responses (Stamps, 2009). Thus, this study confirms the need for further exploration regarding the use of photoselective screens in Serbian regions as the mid-south of Balkan, especially regarding the most appropriate rate of shading and colour interaction between the screens and the different cultivars.

Conclusion

Our results show that shade application of coloured nets to sweet pepper (*Capsicum annuum* L.) plants was effective in substantially improving vegetative growth parameters (leaf area index and leaf pigments) under excessive solar radiation during the summer period. In the light of this investigation, it is evident that the modification of crop microclimate spectral quality and quantity using physiological tools such as pearl and red photo-selective shade-nets can increase the total yield and improve fruit quality (mass, pericarp thickness and vitamin C content). Shading reduced the appearance of sweet pepper cracking and eliminated sunscalds on sweet pepper fruits and accordingly, increased the marketable sweet pepper production by about 25% compared to non-shading conditions. Overall, photo-selective shade seem to be a cost-effective approach for manipulating crop microclimate properties that regulate not only yield, but also the retail/eating quality as well as functional or bioactive properties that are associated with human health and wellbeing.

Acknowledgements

This study, which was part of the TR-31027 project, was financially supported by the Ministry of Science and Technological Development, Republic of Serbia.

Received 10 08 2016
Accepted 30 11 2016

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ISSN 1392-3196 / e-ISSN 2335-8947
Zemdirbyste-Agriculture, vol. 104, No. 1 (2017), p. 53–62
DOI 10.13080/z-a.2017.104.008

Užpavėsinimo spalvotais tinklais įtaka saldžiųjų paprikų vaisių derliui ir kokybei

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Santrauka

Tirta fotoselektyvinio tinklo panaudojimo koncepcija pagal komercinio auginimo praktiką veislės 'Cameleon' saldžiąsias paprikas auginant Pietų Serbijoje (saulės radiacija – 910 W m^{-2}, fotosintezės fotonų srauto tankis – 1661 µmol m^{-2} s^{-1}) ir naudojant keturis skirtingos spalvos (melsvai pilkos, raudonos, mėlynos ir juodos) užpavėsinimo tinklus su 40 % santykiniu užpavėsinimu. Tyrimo tikslas – nustatyti, kaip įvairios aplinkos kontroliavimo technologijos: spalvoti užpavėsinimo tinklai arba plastikinis šiltnamis su integruotais spalvotais užpavėsinimo tinklais, galėtų daryti įtaką paprikos augalų rodikliams ir vaisių produktyvumo bei kokybės požymiams. Pavėsyje augę lapai dažniausiai turi didesnį suminį kiekį chlorofilų ir karotenoidų, lyginant su kontroliniu variantu. Nustatytas žymiai didesnis vaisių, augusių po raudonos (4637,10 µm) ir juodos (4609,32 µm) spalvos tinklinėmis priedangomis, perikarpio storis, palyginus su kontroliniu variantu – augusiais atvirame lauke (3116,19 µm). Didžiausia suminė tirpių kietųjų dalelių koncentracija nustatyta paprikų vaisiuose, augusiuose atvirame lauke (8,03 %). Paprikų vaisiai, auginti plastikiniuose tuneliuose, turėjo žymiai mažiau tirpių kietųjų dalelių – 6,58 %. Suminis rūgščių kiekis buvo 0,19 kontrolinio varianto ir 0,25 paprikų vaisiuose, augusiuose po raudonu tinklu. Vitamino C didžiausia koncentracija nustatyta paprikų vaisiuose, augusiuose plastikiniuose tuneliuose su raudonais tinklais (175,77 mg 100 g^{-1}). Tyrimo rezultatai rodo, kad raudoni ir melsvai pilki fotoselektyviniai tinklai sukuria optimalias augimo sąlygas ir padidina vaisių derlių bei vaisių skaičių su mažiau fiziologinių sutrikimų ir storesniu perikarpiu.

Reikšminiai žodžiai: *Capsicum annuum*, derlius, fiziologiniai sutrikimai, lapų struktūra, spalvoti užpavėsinimo tinklai, vaisių struktūra ir kokybė.