Comparison of UV-absorbing Nets in Pepper Crops: Spectral Properties, Effects on Plants and Pest Control

S. Legarrea¹, A. Karniel², A. Fereres¹ and P.G. Weintraub³

¹Departamento de Protección Vegetal, Instituto de Ciencias Agrarias, Centro de Ciencias Medioambientales-CSIC, Madrid, Spain
²Jacob Blaustein Institute for Desert Research, Sede Boker Campus, Ben-Gurion University of the Negev, Israel
³Department of Entomology, Agricultural Research Organization (ARO), Gilat Research Center, D.N. Negev, Israel

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ABSTRACT

In horticultural crops, the use of screens to protect plants is the usual strategy in the Mediterranean area. Screen manufacturers offer a range of netting that vary in their UV-absorbing properties. We compared the photoeffects of seven different screens. Sweet pepper trials were conducted at the Gilat Research Center, Israel, where the spectral properties of the nets and their influence on pest infestation and crop development were evaluated. UV transmittance varied among the materials studied ranging from 40% to 70% of the incident radiation. BioNet white and P-Optinet, which absorbed and reflected the highest amount of UV radiation, performed the best protection against the main pepper pest (thrips, whiteflies and broad mites). Spectral measurements also showed that the photosynthetically active radiation differentially penetrated the nets, which together with the amount of UV absorbed by the screenings, resulted in a range of plant height and chlorophyll content. A global understanding of the UV-absorbing nets’ effect on pepper crops and their pests was evaluated in this work because of the importance of these screening to integrated pest management and sustainable agriculture production.

INTRODUCTION

Over the past centuries various systems have been developed to protect vegetable and ornamental plants from extremes of weather, high winds, insects and airborne diseases, thus creating better growing conditions. Structures can be covered with any of several materials such as glass, plastic or screening/netting. Solid plastic sheets or glass should be used in climates that have relatively cool summers and require heating in the winter. However, in warm climates screening or netting is a necessity to prevent damage to plants as these materials permit the movement of air, cooling the structure and reducing humidity that can enhance plant pathogen development (1), and avoiding insect infestations (2). One of the most important factors that influences plant productivity is the quality and amount of radiation transmitted through the covering material.

Photosynthetically active radiation (PAR, 400–700 nm), the main source of energy for the plants, should be transmitted through the covering material at a high rate to enhance yields. At the same time, red (R, 600–700 nm) and far red (FR, 700–800 nm) photon flux ratio has gained interest to alter stem elongation properties as desired in horticultural crops (3); blocking near-infrared radiation (NIR, 700–1100 nm) (4), and allowing better temperature control inside the structure. In addition, the near-UV spectrum (UV, 200–400 nm)-absorbing qualities that plastics naturally have can be enhanced by the addition of materials (5) that alter the UV and can control vegetable pigments (6) and produce bigger fruit size (7). The UV portion of the spectrum was first subdivided into three regions in the Second International Congress of Light, held in 1932 because its biological effects vary enormously with wavelength. The regions are arbitrary and, according to environmental photobiologists, are normally defined as UV-C (200–290 nm), UV-B (290–320 nm) and UV-A (320–400 nm). The division between UV-B and UV-C of 290 nm was chosen as wavelengths shorter than that are unlikely to be present in terrestrial sunlight (8). UV-B is characterized by inducing a variety of damaging effects in plants while UV-A is the less hazardous part of UV radiation (9) but of great importance in the organisms’ responses to light via cryptochrome (10) or visual photoreceptors (11,12). Changing light quality in the UV-A range of the spectrum affects arthropod pests (13–15) and so it is considered a sustainable tool to reduce losses caused by them. Most insects (14,16) and mites (17) have photoreceptors sensitive to radiation in the UV range which plays an important role in their ecological behavior (13). UV-A radiation is a necessary stimulus for whiteflies (16), aphids (18) and thrips (12) to differentiate between their host plant and the environment so that the lack of it affects orientation and dispersal activity (19,20). Arthropod visual cues are altered in a greenhouse covered by UV-absorbing materials and generally a lower density of harmful arthropods develops (14). There are two possible mechanisms; either by preventing the entrance of insects into greenhouses as a result of a repellent effect by reflecting radiation from the cover (21)
or by affecting population growth, e.g. aphids in pepper (20) or cucumber (22) crops. Finally, success has been achieved in the management of vegetable crops with UV-absorbing nets because of a reduction in the incidence of important viruses vectored by insects: tomato yellow leaf curl virus, cucumber vein yellowing virus and tomato spotted wilt virus (23,24).

Materials that absorb radiation in the UV-A range of the spectrum usually absorb UV-B radiation as well. The effects of a high UV-B radiation on plants have been studied in order to understand the consequences that the reduction in the ozone layer would have on nature (25); some of these effects are also driven by UV-A (9) and excessive PAR radiation. UV has been determined to damage DNA (26), proteins, phytohormones and membranes in plant cells. In response to damaging solar radiation, plants have developed repair and acclimation responses: changing tissue physiology (27), accumulating secondary metabolites, scavenging active oxygen species or altering the photosynthetic machinery. As UV can be considered an abiotic stress factor for plant development that affects crops by reducing biomass and yields (28), protected crops covered with UV-absorbing films would improve plant production, as was shown for soilless eggplant crops (7). Not only do plants develop better, but also arthropods like thrips (29) and mites (30) are known to strongly avoid the UV-B range of the spectrum. As has been shown, manipulating radiation quality and quantity by means of photosynthetic covers have direct and indirect effects on all elements of the agrosystem and should be studied prior to commercialization of new products for growers (31).

Pepper (Capsicum annuum L.) is one of the main vegetable crops produced in the Mediterranean area in protected systems, and it is usually grown under screened walk-in tunnels (2). As most of the larger pests are excluded from the crops, thrips, whiteflies and mites are the main pests that can cause serious damage to the plants. Scirtothrips dorsalis Hood, which has recently arrived in the Mediterranean area (32), is an especially problematic pepper species that causes serious injuries in early stages, feeding on the young growing plant parts. This niche is shared with the broad mite Tetranychus urticae Koch. T. cinnabarinus (Boisduval), Thrips tabaci Lindeman, T. palmi Karny and Trialeurodes vaporariorum (Westwood) (2).

Among the various materials and products available in the market, UV-absorbing nets combine beneficial optical properties and work as a physical barrier that prevents larger insects from reaching the crop (15,21). Since BioNet®, the first UV-absorbing net developed, several companies have designed new products and are used in the management of different crops (37), but the optical qualities of UV-absorbing screenings have not been compared. The objective of this work was to comparatively describe the optical properties of a range of UV-absorbing nets, their effect on pepper plant physiology and photosynthesis, as well as to test their effectiveness in the control of arthropods that seriously threaten pepper crops.

MATERIALS AND METHODS

Field design and sampling. Seven nets were provided by two plastic manufacturers to test their suitability in pepper crop management. Polysack Plastics Industries, Israel, supplied P-Optinet, P-AntiInsect net and T-AntiInsect net whereas BioNet white, BioNet transparent, Antivirus 50 mesh and SpiderNet Plus were provided by Meteor Agricultural Nets Ltd., Israel. Six of the nets were woven in a 50 mesh pattern (20 x 10 threads per cm), typically commercialized for growing vegetable crops, while in SpiderNet Plus a different material, composed of innovative micro-fibers, was added to fibers in a 50 mesh screen and aims to prevent passage of small insects like thrips by reducing the open area. Yarn diameter was 255–240 µm which resulted in ~480 µm net thickness when an intersection between yarns was considered. Both manufacturers ensured that their products are stable for several years under field conditions (Yossi Ofr, personal communication; Meteor Agricultural nets Ltd., http://www.meteor.co.il/english/comparison-table.htm).

Trials were conducted at the Gilat Research Center (31°20′04.58″N, 34°40′03.07″E) where seven walk-in tunnels (6 x 6 x 3 m high) were each covered with a different net. In each tunnel, 40 sweet pepper seedlings Capsicum annuum cv. Red Rock were transplanted to 1 L pots aligned in two fertigation drip rows on 7 September 2008. In addition to the seven tunnels, one plot was not covered and designated as a control because open field production was the main system to cultivate vegetables before netting was used to protect crops from pests (38). Comparisons with the noncovered control allowed us to test the effects of netting in pest incidence and plant development. Neither pesticide nor herbicide treatments were applied; weeds were removed by hand in the tunnels. The trial was carried out for 10 weeks, until 16 November 2008, when plants in the noncovered control, T-Anti Insect net, and Antivirus 50 mesh plots produced neither flowers nor fruit and comparisons in yield would be impossible. Meteorological data were continuously monitored by a local climate station.

Figure 1. Spectral irradiance in UV waveband (300–400 nm) for each plot studied. Measurements were obtained on 5 October 2008 with a spectroradiometer (Li-1800®, Li-Cor) at 2 nm intervals.
on 26 March 2007 at the Li-Cor laboratories.

Net properties concerning radiation were measured by means of a spectroradiometer (LI-1800, Li-Cor®, NE) that measures the 300–1100 nm range of the solar spectrum in 2 nm intervals. Spectral irradiance was measured inside each tunnel and control using a cosine receptor, at midday and under clear-sky conditions on 5 October 2008, when solar irradiance was 776 W m⁻². In addition, the spectrometer was attached to external integrated sphere (LI-1800-12S) for measuring the reflectance and transmittance of the nets. These two measured variables enabled calculation of the absorption property of the nets. The spectroradiometer was calibrated on 26 March 2007 at the Li-Cor® laboratories.

Pest assessment. The primary pepper arthropod pests, thrips, whiteflies and mites were monitored on a weekly basis in each plot. To assess insect populations damaging young growing plant parts, 20 top leaves were selected following a regular sampling schedule and put into containers with 80% EtOH. All insects and mites were recorded by observation with a stereoscopic dissecting microscope. Indirect sampling of flying insects (adult whiteflies and thrips) was performed by placing yellow sticky traps (15 × 17 cm) at the plant canopy level. Two traps were located in the far ends of one row while a third one remained in the middle of the other row in order to trap insects moving from plant to plant. Visual assessment, to record direct damage caused in the top buds of each plant, was performed at four dates during the trial. In this case, damage caused by S. dorsalis and P. latus was globally evaluated as a zigzag in the main leaf vein, thickness increase in top leaves, as well as typical leaf curling upward or downward.

Plant physiology. To record the effect of the light environment under each cover on the pepper crop, chlorophyll content was measured weekly in five selected plants per plot, using a portable chlorophyll meter, SPAD-502 (Minolta Corporation, Ramsey, NJ). In each plant, an unshaded fully expanded leaf was chosen for the study in which the average of three measurements was determined. The relationship between SPAD values (S) and the chlorophyll content (μg cm⁻²) (C), in pepper leaves has been already defined (39) in a linear equation: $C = 16.158 + (1.182S)$, which was applied to these data. To study how light environment affects pepper morphogenesis, the plant height was measured for 3 weeks from the soil to the apex in the same five plants in each plot.

Statistical analysis. Data of arthropods monitored under each cover were compared by the nonparametric methodology, Kruskall–Wallis test, in which differences among several samples were analyzed. When significant differences were found, plots were compared in pairs by applying a Mann–Whitney U-test at $p = 0.05$ (40). The same software was used to perform a linear regression to evaluate the effect that transmitted radiation (independent variable), expressed as a rate (transmitted radiation inside the tunnel/transmitted radiation outside), has on the chlorophyll content and height of the plants (dependent variables). Finally, to differentiate among the proportion of damaged plants in their top buds under each plot, chi-squared tests were performed for each sample date.

### RESULTS

Comparative measurements of spectral irradiance in the UV region under the seven different net types are shown in Fig. 1. The lack of photons and sensitivity of the spectroradiometer resulted in noisy data in the very short end of the spectrum which explains the high variability in transmission and reflection data in the UV-B range. However, comparisons were possible because differences in transmittance and reflectance were found among the nets. Spidernet Plus, BioNet white and P-Optinet transmitted less than 40% of UV radiation whereas Antivirus 50 mesh and T-Anti Insect net allowed more than 75% of incident light to reach the crop. BioNet transparent and P-Anti Insect net fell in between transmitting 40% and 50% of UV radiation. Differences in transmittance and reflectance properties are maintained along the visible and infrared light spectrum among the net types, as shown in Fig. 2. It is noteworthy that 30% of visible light was reflected by observation with a stereoscopic dissecting microscope. Indirect

Table 1. Light quality parameters under each cover studied referred to photon flux ratios of different wavebands: blue (B: 400–500 nm), red (R: 600–700 nm), far red (FR: 700–800 nm), photosynthetically active radiation (PAR: 400–700 nm), near-infrared (NIR: 700–1100 nm), total (T: 300–1100 nm).

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<tr>
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<td>Polyethylene</td>
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<td>0.17</td>
<td>0.18</td>
<td>0.40</td>
<td>0.67</td>
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<tr>
<td>Spidernet Plus</td>
<td>Polyethylene + microfibers</td>
<td>1.08</td>
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by BioNet white and P-Optinet, 20% by Spidernet Plus, while the other materials reflect 10% of incident radiation. Light quality ratios calculated for each plot show little variation among the screens (Table 1). T-Anti Insect net and Antivirus 50 mesh are characterized by the same ratios in all cases. Comparing these nets, blue⁄red ratio is slightly reduced in P-Anti Insect net and BioNet transparent. BioNet white and Optinet show rates vaguely lowers for red⁄far red, blue⁄red, PAR⁄total and blue⁄far red, whereas PAR⁄Near-infrared ratio is 4 points lower. Spidernet Plus has the same parameters to P-Anti Insect net.

As shown in Fig. 3, the chlorophyll content in pepper leaves increases linearly with increasing PAR radiation. This relationship is statistically significant ($F = 23.967, P < 0.001$) although weak ($R^2 = 0.079$). Similar results were obtained when chlorophyll content is plotted against the rate of UV radiation that penetrates the net ($R^2 = 0.089, F = 27.15, P < 0.001$). The height of the plants was significantly dependent on the amount of PAR radiation that reached the crop in weeks 2 ($F = 16.16, P < 0.001$), 3 ($F = 20.24, P < 0.001$) and 4 ($F = 14.18, P < 0.001$) after transplanting (Fig. 4). The same relationship was observed for UV radiation in weeks 2 ($F = 11.82, P = 0.001$), 3 ($F = 15.32, P < 0.001$) and 4 ($F = 10.34, P = 0.003$).

The percentage of arthropod-damaged plants varied among the treatments (Fig. 5): day 36 ($\chi^2 = 158.8$, d.f. = 7, $P < 0.001$), day 43 ($\chi^2 = 170.3$, d.f. = 7, $P < 0.001$), day 63 ($\chi^2 = 181.8$, d.f. = 7, $P < 0.001$), day 77 ($\chi^2 = 170.3$, d.f. = 7, $P < 0.001$). In the noncovered plot, the highest proportion of damaged plants appeared from the first assessment. Screening materials that did not filter the vast majority of UV radiation, Antivirus 50 mesh and T-Anti Insect net, also had hundred percent of plants affected by serious arthropod damage on their apex by the end of the trial. On the other hand, little damage was noticed in the crop grown under P-Optinet and BioNet white, which absorbs and reflects the highest UV radiation. The rest of the screening materials offered an intermediate protection level against pests that affect apical growing parts. Also, differences among the

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**Figure 3.** Regression plot where photosynthetically active radiation (PAR) and UV-transmitted radiation, expressed as a rate (Radiation transmitted in the tunnel/Radiation outside), are the independent variables and the plant chlorophyll content (mg cm$^{-2}$) is the dependent variable. The equation, coefficient of determination ($R^2$) and test probability are also shown.

**Figure 4.** Regression plots where photosynthetically active radiation (PAR) and UV-transmitted radiation, expressed as a rate (Radiation transmitted in the tunnel/Radiation outside), are the independent variables and the plant height is the dependent variable. The equation and coefficient of determination ($R^2$) are also shown.

**Figure 5.** Percentage of damaged pepper plants in its apex assessed by visual inspection in four dates of crop development. Different letters indicate statistical differences among the nets ($\alpha = 0.05$).
tunnels were found in the weekly sampling of apical leaves performing the Kruskall–Wallis analysis for the variables studied; broad mites ($\chi^2 = 36.129, \text{d.f.} = 7, P < 0.001$) and total number of thrips ($\chi^2 = 34.689, \text{d.f.} = 7, P < 0.001$). As shown in Table 2, a significantly lower number of broad mites was found in tunnels covered by P-Optinet and BioNet white whereas a significantly higher number of thrips was encountered in the outside Control, T-Anti Insect net and Antivirus 50 mesh. Intermediate values were obtained in the rest of the covers, aside from Spidernet Plus where the highest numbers of $F. latus$ as well as a considerable high infestation by thrips were found. Yellow traps caught statistically different numbers of insects under the different nets, ($B. tabaci$: $\chi^2 = 26.215$, d.f. = 7, $P < 0.001$; $S. dorsalis$: $\chi^2 = 34.193$, d.f. = 7, $P < 0.001$; $F. occidentalis$: $\chi^2 = 19.310$, d.f. = 7, $P < 0.001$). Based on the number of whiteflies captured in yellow traps, all of the screens excluded the pest from the pepper plants at a rate higher than 90%. Significantly fewer whiteflies were caught inside tunnels in which screening filtered at least 50% of the UV light, as shown in Table 2. The same trend was obtained for $S. dorsalis$, a species caught in very low numbers under Spidernet Plus, P-Optinet, BioNet white and BioNet transparent. The number of $F. occidentalis$ was greater in the yellow sticky traps placed in the outside control than in all tunnels, although in all cases the number of insects was low.

**DISCUSSION**

The different nets studied altered the quantity and quality of the light in the pepper crop. Compared to solid plastic sheeting/films, these screens tend to transmit a lower percentage of PAR radiation (not higher than 80%) that could affect crop development and should be taken into account when studying the light necessary to obtain optimum yield. Light passing through the screen is a mixture of filtered and unfiltered light (37), so the UV radiation is not completely blocked inside the tunnels (a maximum of 70% UV radiation absorbed in Spidernet Plus), compared to the UV-absorbing solid plastic sheeting that in some cases have the ability to block nearly all UV radiation (16). However, light quality parameters under the screens studied do not differ highly when compared with polyethylene films (31). When considering only the blue waveband, the ratio of B/R and B/FR shows lower values than the plastic polyethylene covers.

Little variation was observed in the chlorophyll content of the leaves (0.065–0.075 mg cm$^{-2}$), and its relationship to the rate of PAR and UVR that penetrates the net was weak. In fact, as shown in previous work, the effect of UV radiation on chlorophyll varies depending on experimental conditions and when the solar UV radiation is blocked by films, the amount of chlorophyll in the leaves may be increased (41) or, it may not change (42), as we also observed.

The longer length stems observed in plants grown under nets that absorb a higher amount of PAR and UV radiation can be explained by several causes. Etiolation can be induced under those covers generating taller plants as a consequence of a lower PAR rate penetration. Also, in P-Optinet and BioNet white, the effect of a slightly lower R/FR ratio could be added to the modification of morphogenesis causing stem elongation, as it has been described for photoselective covers that transmit a higher amount of red than far red (mediated by the phytochrome) (37,43). This characteristic also produces an increase in yield in pepper crops, so this special feature would be a useful tool in obtaining high yields. Plants grown without protection or in an environment with high UV-B, that also are exposed to a higher UV-A and PAR rate, are known to develop lower yields and biomass because they need to develop strategies to overcome UV-B damage (28). In the case of the UV-blocking covers, this stress is greatly reduced, so a higher amount of energy can be utilized to produce higher biomass. Finally, the effect of UV radiation altering plant growth regulators (i.e. photo-oxidation of indole-3-acetic acid) results in shorter stems in irradiated plants (9). All four causes, etiolation, the R/FR ratio, the lack of harmful UV-B and the degradation of phytohormones can explain the tendency of increased height observed in the screens tested. The enhancement of vegetative growth that is induced under UV-blocking nets could be the reason why photosynthetic pigments (chlorophyll) are greater as the amount of transmitted radiation increases. In such case, the plant promotes tissue growth instead of increasing the pigment contents in chloroplasts.

In these trials, pest damage was a determinant factor inhibiting proper crop development because no control strategies were used aside from covering with photoselective screens in some of the plots. Physical control by screens is standard pest management in the Mediterranean area (38,44), and it is necessary, as we have shown, due to high whitefly populations coming from open fields. As whiteflies have been shown to phoretically transport broad mites (45), the infestation of $P. latus$ is higher in the outside plot than in all 50 mesh screens tested. However, this strategy cannot work by itself...
when we refer to thrips that can move freely through 50 mesh screens.

Direct sampling in the crop by evaluation of pests on leaves and monitoring damage in the apex of the plant showed that pest establishment was poorer in the plots covered by photoselective screens, lower numbers of affected plants were found and density of insects and mites was lower. Even a partial blockage of UV radiation (50–70%) has been proved to be effective in preventing pest immigration not only for whiteflies but also for thrips in these trials. The mechanism by which low pest infestation rates inside UV-absorbing covers is found concerns modification of insect behavior by changing color perception, a process in which UV light is needed to find their host plant (23). Several studies have shown that whiteflies (12,15), thrips (21), aphids (20) and leafhoppers (15) either choose environments where UV radiation is present or disperse less where there is no UV radiation. It has been shown that thrips have maximum visual acuity in the UV range (12) and move toward UV-A radiation source (29). Thus, these physiological data and recent reports (21) strengthen our results, where thrips invasion is limited in UV-absorbing covers. The general effect of UV-absorbing covers that we observed, the reduction in the immigration rate of insects, is in agreement with other studies (14,21).

Spidernet Plus needs a special mention because even though it has UV-absorbing properties, higher populations of broad mites and thrips were found under it. The low numbers of whiteflies and thrips adults captured in the yellow traps demonstrate that the microfibers prevent the entrance of small animals. In this case, the physical properties seem to be more relevant than the optical properties in pest incidence. Once pests reach the plant, the environment that may be generated by Spidernet Plus (higher humidity due to reduction in air flow and limited entry of beneficial predators or parasitoids) would allow harmful insect populations to build up when no chemical or biological control strategies are used.

Several interactions among light, pepper and pest have been described in this study. Solar radiation was partially blocked by all the covers studied because screening results in a mix of filtered and unfiltered light penetrating into the structure. Generally, 50 mesh screens that reflect and absorb the highest amount of UV radiation reduce pest infestation and increase the height of the plants which could lead to higher yields. As the use of 50 mesh screens is a current technique in IPM programs in the Mediterranean area, it is recommended to use UV-absorbing materials in order to reduce damage of insects like thrips or whiteflies in pepper crops.

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REFERENCES


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<td>Transpose</td>
<td>≪ ≳ ≪ ≳ linking characters</td>
<td>≪ ≳</td>
</tr>
<tr>
<td>Close up</td>
<td>#</td>
<td>#</td>
</tr>
<tr>
<td>Insert or substitute space between characters or words</td>
<td>▼</td>
<td>▼</td>
</tr>
<tr>
<td>Reduce space between characters or words</td>
<td>▼</td>
<td>▼</td>
</tr>
</tbody>
</table>