Ultraviolet-Blocking Materials as a Physical Barrier to Control Insect Pests and Plant Pathogens in Protected Crops

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ABSTRACT

New types of ultraviolet (UV)-blocking materials, such as polyethylene films and nets, have been developed in recent years as a very promising tool to control insect vectors of plant disease threatening greenhouse crops. UV-blocking materials have properties to filter the UV radiation (280-400 nm) interfering with the vision of insects and in consequence, their behaviour related with movement, host location ability and their population parameters. The exclusion of part of the UV radiation within the greenhouse environment has a dramatically incidence on insect orientation, movement and on the spread of insect-transmitted viral diseases. In the same way, the impact of UV-absorbing materials on population dynamics of natural enemies, pollinators and crop yield needs further investigation. The level of protection of the different UV-blocking materials may vary among different designs of greenhouses and the geographic location that determines different internal climatic conditions and the amount of UV and visible light absorbed and transmitted within the covered structures. In this review, we will discuss the current knowledge about the impact of UV-absorbing films on insect pests, plant pathogens and beneficial organisms, with special attention to insects acting as vectors of plant disease. Also, the new perspectives, limitations and advantages of using UV-blocking materials together with other control strategies under Integrated Pest Management (IPM) production systems will be discussed.

Keywords: cover materials, greenhouse, insect vectors, Integrated Pest Management, plant diseases

INTRODUCTION

Agriculture has played a major contribution to the maintenance of natural resources and biodiversity and plays an important role in increasing yields and profit of lands and therefore, reduces the withdrawal of agricultural activities.

The contribution of plastic materials to agriculture has been a real evolution to traditional agriculture that has made possible the increases of productive areas of the world with the incorporation of areas with unfavourable climatic conditions.

Protected crops include horticulture and ornamental flower production (cut flower, potted floral and foliage plants). Protected production has increased in the last decade with the development of new types of plastic films which have achieved a high degree of specialization with different applications and properties (anti-dripping, anti-thermal, anti-pest). At present, greenhouses are mainly distributed in two regions of the world; one of these is Asia, especially in China, Korea and Japan, with almost 80% of the total area, and in the Mediterranean region covering about 15% of the world (Espí et al. 2006). This protected production requires the use of 1.000.000 t/year of plastic films to cover all the protected crops grown worldwide (Espí et al. 2006).

In protected agriculture crops suffer important econo-
mic damage from insect pests as well as diseases caused by viruses (e.g. CMV, TSWV, TYLCV) and their vectors (e.g. aphids, thrips, whiteflies), fungi (e.g. Botrytis cinerea, powdery mildew), and bacteria (e.g. Clavibacter michiganensis and Pectobacterium spp.). The most extended and common practice to control insect pests and plant pathogens is the application of large amount of pesticides. However, pesticides have a negative impact on farmers, consumers and the environment (Pimentel and Greiner 1997). Currently the situation is unsustainable and other alternative control measures need to be implemented because many of the active ingredients are being banned in the European Union (DOUCE 2002) and elsewhere, and also pesticide efficacy is also not enough to control many of the key pests and diseases because resistance build-up to insects and pathogens often occurs (Urech et al. 1997). In addition, consumers are very sensitive to environmentally friendly agricultural systems (organic agriculture, integrated production, etc.), and are demanding pesticide-free high quality and low cost food products. All these demands require the investigation of new control tactics for pest and disease control.

Photosensitive plastics are a quite recent development that can block or modify the transmitted light to obtain specific benefits (Catalina et al. 2000). Nakagaki et al. (1982) reported the first evidence of the inhibitory effect of UV blocking materials on the invasion of greenhouses by insects. An environment with a low level of UV light modifies insect vision and in consequence its behaviour. Several studies have been conducted to evaluate the effect of this plastic materials used as nets and films to reduce insect population in protected crops and these will be discussed in this review.

In addition, changing the light spectrum underneath the film cover may alter plant morphogenesis, and consequently produce changes in herbivory responses. In the same way the manipulation of greenhouse light quality was used as a non-chemical alternative method for growth regulation of ornamental crops (Rajapakse and Kelly 1995). Crop yield and quality can be increased at the time that pest and disease damage is significantly reduced by changing the colour physicochemical characteristics of plastic films. Photosensitive plastic barriers have also shown good efficacy in the control of plant pathogenic fungi (Honda et al. 1977). At the same time these types of barriers have proved positive effects by increasing the persistence and viability of the entomopathogenic fungi, Beauveria bassiana (Costa et al. 2001) and of baculoviruses (Lasa et al. 2007) used as biological control agents.

The aim of this review is to update the information available on the use of the UV-blocking plastic materials used in protected environments to control insect pests and diseases, with special attention to their impact on insect vectors of plant diseases, their natural enemies and other beneficial organisms. In addition, the use of the UV blocking materials as a tool in Integrated Pest Management (IPM) programs will be discussed.

RESPONSE OF INSECTS, PATHOGENS AND PLANTS TO UV RADIATION

Effects of UV radiation on insect vision and behaviour

Vision is defined as the ability to perceive spatial patterns. Vision of insects is due to the photoreceptors present in the ocelli and the compound eyes (Fig. 1B, 1C). Compound eyes are formed of aggregations of separate visual elements known as ommatidia, each ommatidium corresponding with a single facet of the cornea (Fig. 1B). The ommatidium is composed by different parts, such as, the cornea, the crystalline cone cells, the primary and secondary iris cells and the retinula (Fig. 1C). The retinula forms the basal portion of an ommatidia and is composed of a group of pigmented cells, each of the latter being continuous with a post-retinal fibre. The visual cells collectively secrete an internal optic rod or rhabdom. The rhabdom forms the central axis of the retinula and is in contact with the extremity of the crystalline cone (Imms 1957). Dorsal ocelli and stemmata (lateral ocelli) are poor image formers relative to compound eyes, detecting mainly the light and dark expanses, the fluctuating light intensity or polarized light (Prokopy and Owens 1983). True image formation in insects is a property solely of the compound eyes, which are able to mediate the discrimination of form with various degrees of visual acuity and to perceive the movement and spatial location of distant objects (Imms 1957). The compound eye is a unique structure with enormous flexibility for selective adaptation. They vary in external (size, shape, color, facet number, surface texture and position) and internal (morphology of innervation and physiology of photoreceptor function) characteristics and these differences determine visual capability (Prokopy and Owens 1983).

It is known that insects have ocular photoreceptors in a bandwidth of ultraviolet (200-400 nm), visible or photosynthetically active radiation (PAR), 400-700 nm and the far red (700-800 nm) part of the electromagnetic energy spectrum (Fig. 1A). Wavelength in the UV region have incidence on insect behaviour, such as, orientation, navigation, host finding and feeding (Antignus and Ben-Yakir 2004) (Fig. 1D).

However, to optimize detection of ground pattern movement, insect motion detectors in the ventral half of the eye are most sensitive to long wavelengths (greater than 500 nm) which are in the region of earth’s reflecting energy, and are least sensitive to short wavelengths (less than 500 nm), which are in the region of greatest visible sky energy (Prokopy and Owens 1983).

In many herbivorous insects, plant spectral quality appears to be the principal stimulus eliciting alighting on living plants. In this way, special attraction is elicited by foliage-like hues, such as the wavelengths reflecting between 500-580 nm causing maximum reaction of aphids to yellow (Klingauf 1987).

The spectral discrimination requires a minimum of two photoreceptor types located in different parts of the compound eyes. Insects are able to distinguish between vegetation and sky by the presence of two receptor types, one absorbing maximally before ca. 500 nm and one absorbing maximally beyond this point. Discrimination between foliage and bare soil theoretically require one additional receptor for detection differences above 580 nm (Prokopy and Owens 1983). Using the electroretinogram technique Kirchner et al. (2005) determined that alate female summer migratory aphid Myzus persicae has three types of photoreceptive photoreceptor types located in different parts of the compound eye, the first in the green region around 530 nm, the second peak was registered in the blue-green region (490 nm) and the third peak was registered in the near UV (330-340 nm). However, Frankliniella occidentalis showed two peaks of spectral efficiency, the primary in the UV range and a secondary in the visible region around 540 nm (Matteson et al. 1992). Mellor et al. (1997) observed a similar spectral efficiency between the whitefly Trialeurodes vaporariorum and its parasitoid Encarsia formosa, the primary peak is in the blue-green-yellow region (520 nm) and a secondary peak in the UV region. Also, they observed a difference in the response to UV light between the dorsal and the ventral region of the compound eye of T. vaporariorum. Doukas and Payne (2007b) found that compartments clad with films that blocked LTV below 375 nm attracted significantly more whiteflies than the films that blocked LTV below 385 nm, whereas the absorption of LTV wavelengths above 385 nm did not show any further effect on whitefly numbers. Another recent work conducted by Doukas and Payne (2007a) revealed that under UV-blocking films with similar UV-absorbing properties, E. formosa showed preference to disperse into compartments clad with films that had high diffusion properties. However, adults of T. vaporariorum did not discriminate between direct and diffused-light environments. The positive response of the
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parasitoid *E. formosa* to diffuse light could be a result of the better illumination of all ommatidia than in its whitefly host, and the different response between both species to diffused light.

Dispersal difference between *T. vaporariorum* and *E. formosa* under poor UV-light environments could be explained not only by the position of the photoreceptors in the compound eye, but also by the differences in the structure of the compound eye in the two insect species (Doukas and Payne 2007a). Mellor *et al*. (1997) observed that *E. formosa* has more light receptors than its whitefly host, and therefore, the radiance perceived under the same light intensity will be greater for the parasitoid, because more photons will be received by its compound eye (Doukas and Payne 2007a).

Different groups of insects are able to support a different amount of UV light depending on their habits, either nocturnal or diurnal. Antignus *et al*. (1996) suggested that the ability of UV-absorbing plastic sheets to protect crops from *Bemisia tabaci*, *Aphis gossypii* and *F. occidentalis* indicates a common response of diurnally active insects to UV light probably caused by the presence of similar photoreceptors in their compound eyes.

In the same way, the amount and quality of sunlight radiation vary with latitude; the compound eyes of insects have a different capacity to react to UV light exposure. Meyer Rochow *et al*. (2002) studied the UV-induced damage in photoreceptors in four species of insects from higher and lower geographic latitudes. They found two kinds of reaction in the photoreceptive cells of the insect’s eyes. The diurnal butterflies, *Papilio xuthus* (from Japan) and *Pieris napi* (from northern Finland) exhibited changes only in the cell bodies of retinula cells identified as short wavelength receptors, but not their corresponding rhabdomeres, exhibit damage with apoptotic features. The UV-vision in bright sunlight is important to these butterflies for intraespecific communication and for recognizing UV-nectar guides on the petals of flowers. However, rhabdomeres of cells of the adult crickets, *Gryllus bimaculatus* (from Japan) exhibit signs of severe membrane disruption when exposed to UV radiation. These effects can be explained by the nocturnal habits of the crickets and in consequence, their UV receptors could not play a role in communication or food identification. No signs of damage occurred in the photoreceptors of the eyes of the bumble bee, *Bombus hortorum* because their rhabdoms are voluminous and are able to see under relatively low light environments. This fact has implications for this bumble bee species that lives in northern Finland, where they are able to visit flowers 24 h a day during the short summer season.

Within the UV portion is possible to distinguish three types of wavelengths: UV-C (200-290 nm), UV-B (290-320 nm) and UV-A (320-400 nm) (*Fig. 1A*). UV-B radiation reduce the infestation of different species of thrips, such us *F. occidentalis* (Antignus 1996) and *Calliotrips phaseoli* (Mazza *et al*. 1999). Behavioural experiments conducted on *Pieris brassicae* using a monochromatic light as stimuli, demonstrated that the open-space reaction corresponds to UV-A wavelengths, while the feeding, egg laying and drumming reactions correspond to wavelengths higher (420-590 nm) than the UV-radiation (Scherer and Kolb 1987).

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**Fig. 1** Incidence of the different types of wavelengths of the electromagnetic energy spectrum (A) on insect vision organs (B, C) and on insect colonization of a protected crop (D). (A) Wavelengths are expressed in nanometers (nm). (B) Section of the compound eye showing a group of ommatidia and the cornea (a). (C) Diagram of a standard ommatidium showing its different parts, the crystalline cone (b), primary iris cells (c), secondary iris cells (d), retinula (e), rhabdom (f) and nerve fiber (g). (B) UV-blocking materials affecting insect orientation, navigation, host finding and the spread within a greenhouse structure.
Effect of UV radiation on plants and their relationship with insect herbivores

Three photoreceptors have been described that have a direct effect on green plants: Phytochrome, that absorbs visible light in the red or far red interval, 600-800 nm, Cryptochrome, that absorbs light in the blue and ultraviolet A interval, 320-450 nm and, a Photoreceptor that absorbs in the UV-B, 280-320 nm interval. Many microorganisms, plants and animals use UV-B and UV-A radiation as a source of information about their environment affecting many ecological processes (Paul and Gwynn-Jones 2003). Long exposure to UV radiation may damage plants and other living organisms because the UV photons have enough energy to destroy chemical bonds causing phototoxic chemical reaction, that induces structural and biochemical changes (Kovács and Kékesi 2002; Jacobs et al. 2007). A large number of experiments where solar UV-B has been attenuated using wavelengths-selective filters, such as polyester, show a range of significant responses across many plant species and locations (Paul et al. 2005).

In this way, responses to UV attenuation by selective filters include increased growth and yield of an eggplant soil-less crop (Kittas et al. 2006). Also, changing in quality, such us pigmentation and taste of lettuce was found when plants were growth under UV-opaque film, which absorbed 50% of UV-A and 95% of UV-B light (Paul et al. 2005).

Plants need UV light for the synthesis of specific pigments such as anthocyanins which are required for colouring of vegetables such as red cabbage. Therefore, UV-blocking films should not be used to protect crops in which anthocyanin pigmentation is a determinant of their quality (Antignus and Ben-Yakir 2004).

Also, in cut flower production flowering is affected by the use of spectral filters. The light quality altered by the use of different colour filters (blue and red absorbing, blue absorbing, two partially blue absorbing and red absorbing) influenced the time of flowering of chrysanthemum (Dendranthema grandiflorum) plants. Time of flowering was affected by a combined action of phytochrome and cryptochrome since filters with blue transmission and high phytochrome photoequilibrium resulted in early flowering (Khattak and Pearson 2006).

Plastic films with different transmission of UV radiation were used to investigate the changes of leaf and flower colours of ornamental plants showing that UV-B causes a decrease of the chlorophyll content of Coleus × hybrida, but no loss of plant quality was recognised as a result of chlorophyll gradation. Therefore yellow pigments of a green cultivar and the red pigments of a red-green cultivar emerged. UV-A induced the synthesis of anthocyanins in flower and leaves of Kalanchoe × hybrida ‘Coforado’ increased by UV-B (Hoffman 1999).

These structural and biochemical changes on plants due to UV radiation affect their relationship with herbivores. Several studies reported that phytophagous insects show direct effects as well as indirect behavioural responses to solar UV-B wavelength induced by changes in plant tissue quality.

The direct effect of the UV-light on insect herbivores was reported by Mazza et al. (1999), who observed a negative effect of the UV-B radiation on the density of the thrips, C. phaseoli and the amount of leaves damage caused by this insect on field-grown soybean crops. Also, in laboratory and field experiments thrips preferred leaves from plants they were not exposed to solar UV-B light than those exposed to supplemental UV-B radiation produced by artificial UV-B bulbs. Using behavioural experiments with C. phaseoli in experimental tunnels Mazza et al. (2002) demonstrated that thrips can sense and respond to solar UV-B under natural background levels of UV-A and human visible radiation. This work provided the first demonstration of a specific behavioural sensitivity to ambient UV-B of an insect.

The indirect responses are mediated by chemical changes in the plant host that are induced by UV-B exposure, which can modify the abundance of a number of secondary metabolites, including phenolic compounds with potential impact on insect herbivores, as shown by Izaguirre et al. (2007). They demonstrated that the anti-herbivore effect induced by UV-B on two wild species of Nicotiana may be mediated at least in part by the accumulation of phenylpropanoid derivatives, such as chlorogenic acid and phenolic compounds that are similar to those induced by the plant in response to insect herbivory.

Hatcher and Paul (1994) showed that leaves of pea (Pisum sativum) exposes to UV-B radiation increases concentration of phenolic compounds and this change had a little effect on the last instar larvae of Autographa gamma. However, tissue nitrogen level also increased with increasing UV-B light and this increase was correlated with an increase in the efficiency of the larvae to utilize their food and on the larval growth rate, but in a reduction in the plant consumption. Similar results were observed in the consumption by the soybean worm Anticarsia gemmatalis, feeding on soybean leaves previously damaged by thrips exposed to supplementary UV-B radiation.

Effect of UV radiation on plant diseases

Diseases are influenced by a range of interacting responses to UV light, including altered plant growth, canopy microclimate, altered host plant resistance and changes in the survival of fungal pathogens (Paul et al. 2005). The effect of the UV-light on pathogens that cause plant diseases are well covered in a recent review by Raviv and Antignus (2004). There are very few new contributions on the relationship between UV-light and plant fungal diseases.

Vakalounakis (1992) has shown that films absorbing infrared radiation increases night temperatures and reduce relative humidity producing a less favourable environment for fungal diseases. Also, the UV-absorbing films may reduce the sporulation of Botrytis cinerea in greenhouse-grown tomato and cucumber plants (Reuveni et al. 1989; Reuveni and Raviv 1992, 1997; Nicot 1996). A dose of 0.88 KJ m⁻² of UV-C light was found to be highly germicidal to B. cinerea conidia in bell pepper (Capsicum annuum L., var. annuum). Also, when pepper fruits were exposed to UV-C 24 hours before inoculation with B. cinerea a lower percentage of infections were recorded, concluding that UV-C radiation was effective for inducing resistance to this fungal pathogen in fruits at various stages of maturity (Mercier et al. 2001).

In addition, Paul et al. (2005) observed that B. cinerea and its biological control agent, the fungus Trichoderma harzianum are both sensitive to UV radiation in experiments conducted on lettuce crops covered with a UV-opaque film (PAR transmission: 95%, UV-A transmission: 10% and UV-B transmission: 0%).

Differences in survival among fungus species was observed when they were exposed to UV-light, varying from 7 days for Sclerotium rolfsii to approximately 50 minutes for Microsphaeraella pinodes and 3 minutes for B. cinerea (Rotem and Aust 1991).

The effect of solar UV-radiation alters phyllosphere bacterial community of peanut leaves in field studies using plants grown under UV-B transmitting or UV-B excluding plastic filters. Other studies using C. michiganensis determined that strains which produce pigments are characterized as UV-tolerant, enhancing the ability of bacterial strains to maintain population size in the phyllosphere (Jacobs and Sundin 2001; Jacobs et al. 2005).

**PHYSICAL AND SPECTRAL CHARACTERISTICS OF UV-BLOCKING MATERIALS**

Plastic films used in agriculture and horticulture have been modified over the years to enhance their performance and useful lifespan by the incorporation of different additives that alter the physical and spectral properties of these mate-
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### Table 1 Different types of UV-absorbing plastic films used for controlling insect vectors and virus diseases under enclosed environments.

<table>
<thead>
<tr>
<th>Type of UV-plastic film and manufacturer</th>
<th>Spectral absorption of UV light</th>
<th>Type of greenhouse</th>
<th>Country</th>
<th>Crop</th>
<th>Insect pests and natural enemies</th>
<th>Virus diseases</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR-Veradim (6)</td>
<td>some light transmittance between 250-400 nm</td>
<td>walk-in tunnel</td>
<td>Besor (Israel)</td>
<td>tomato</td>
<td>B. tabaci, F. occidentalis, A. gossypii, A. colemani, D. isaea, E. mundus</td>
<td>TYLCV</td>
<td>Antignus et al. 1996</td>
</tr>
<tr>
<td></td>
<td>walk-in tunnel</td>
<td>Besor (Israel)</td>
<td>tomato</td>
<td>sweet pepper</td>
<td>B. argentinfoli, A. matricariae</td>
<td>---</td>
<td>Antignus et al. 1998</td>
</tr>
<tr>
<td></td>
<td>walk-in tunnel</td>
<td>Arava Valley (Israel)</td>
<td>tomato</td>
<td>sweet pepper</td>
<td>---</td>
<td>Chyzik et al. 2003</td>
<td></td>
</tr>
<tr>
<td></td>
<td>greenhouse</td>
<td>Besor (Israel)</td>
<td>tomato</td>
<td>sweet pepper</td>
<td>---</td>
<td>Chiel et al. 2006</td>
<td></td>
</tr>
<tr>
<td>Solarig (2)</td>
<td>some light transmittance between 250-400 nm</td>
<td>walk-in tunnel</td>
<td>Besor (Israel)</td>
<td>tomato</td>
<td>B. tabaci, F. occidentalis, A. gossypii</td>
<td>TYLCV</td>
<td>Antignus et al. 1996</td>
</tr>
<tr>
<td>Rav-Hozek (3)</td>
<td>some light transmittance between 200-370 nm</td>
<td>walk-in tunnel</td>
<td>Besor (Israel)</td>
<td>tomato</td>
<td>B. tabaci, F. occidentalis, A. gossypii</td>
<td>TYLCV</td>
<td>Antignus et al. 1996</td>
</tr>
<tr>
<td>DuraGreen-Insulator F1 (4)</td>
<td>&lt;380nm+IR component</td>
<td>small scale experimental tunnels</td>
<td>San Diego County (USA)</td>
<td>no plants</td>
<td>B. argentinfoli, F. occidentalis</td>
<td>---</td>
<td>Costa et al. 1999</td>
</tr>
<tr>
<td>DuraGreen-Custom F1</td>
<td>&lt;380nm component</td>
<td>commercial greenhouse</td>
<td>San Diego County (USA)</td>
<td>cut-flowers</td>
<td>aphids, thrips and whiteflies</td>
<td>---</td>
<td>Costa et al. 2002</td>
</tr>
<tr>
<td>Klerk’s Rose (6) (K-Rose)</td>
<td>&lt;380nm component</td>
<td>small scale experimental tunnels</td>
<td>San Diego County (USA)</td>
<td>no plants</td>
<td>B. argentinfoli, F. occidentalis</td>
<td>---</td>
<td>Costa et al. 1999</td>
</tr>
<tr>
<td>Klerk’s Kool-lite 380</td>
<td>&lt;380nm component</td>
<td>small scale experimental tunnels</td>
<td>San Diego County (USA)</td>
<td>no plants</td>
<td>B. argentinfoli, F. occidentalis</td>
<td>---</td>
<td>Costa et al. 1999</td>
</tr>
<tr>
<td>High UV-absorbing plastic film (7)</td>
<td>&lt;380nm component</td>
<td>small enclosed tunnels</td>
<td>San Diego County (USA)</td>
<td>cut-flowers</td>
<td>M. euphoriae</td>
<td>TSWV</td>
<td>Diaz et al. 2006</td>
</tr>
<tr>
<td>Klerk’s Plastic Product AD-IR AV clear (1)</td>
<td>&lt;360nm +IR component</td>
<td>commercial greenhouse</td>
<td>Navarra (Spain)</td>
<td>lettuce</td>
<td>---</td>
<td>Potyvirus</td>
<td>---</td>
</tr>
<tr>
<td>Sun Selector diffused Antivirus (1)</td>
<td>&lt;380 nm component</td>
<td>greenhouse</td>
<td>Bangkok (Thailand)</td>
<td>tomato</td>
<td>B. tabaci, C. claratris</td>
<td>CaCV</td>
<td>Kumar and Poehling 2006</td>
</tr>
<tr>
<td>Luminance U/VX (7)</td>
<td>&lt; 370 nm component</td>
<td>choice-chambers United Kingdom</td>
<td>cucumber</td>
<td>cucumber</td>
<td>T. vaporariorum</td>
<td>---</td>
<td>Doukas and Payne 2007a, 2007b</td>
</tr>
<tr>
<td>Antibotrytis (7)</td>
<td>&lt; 400 nm component</td>
<td>choice-chambers United Kingdom</td>
<td>cucumber</td>
<td>cucumber</td>
<td>T. vaporariorum</td>
<td>---</td>
<td>Doukas and Payne 2007a, 2007b</td>
</tr>
<tr>
<td>XL Sterilite ver. 2 (XL-385LD) (8)</td>
<td>&lt; 385 nm component</td>
<td>choice-chambers United Kingdom</td>
<td>cucumber</td>
<td>cucumber</td>
<td>T. vaporariorum</td>
<td>---</td>
<td>Doukas and Payne 2007a, 2007b</td>
</tr>
<tr>
<td>XL Sterilite ver. 3 (XL-385) (8)</td>
<td>&lt; 385 nm component</td>
<td>choice-chambers United Kingdom</td>
<td>cucumber</td>
<td>cucumber</td>
<td>T. vaporariorum</td>
<td>---</td>
<td>Doukas and Payne 2007a, 2007b</td>
</tr>
</tbody>
</table>

Plastic films supplied by:
- Ginegar Plastic Products Co., Ginegar, Israel
- Palrig, Neot Mordecha, Israel
- Erez, Thermoplastic Products, Erez, Israel
- DuraGreen Marketing USA, Mount Dora, Fl, USA
- Klerk’s Plastic Product Manufacturing, Richburg, SC, USA
- Hyplast Ltd., Hoogstraten, Belgium
- BPI Agri., Uk
- Plastika Kritis, Greece

Virus abbreviations: Tomato Yellow Leaf Curl Virus (TYCLV), Tomato Spotted Wild Virus (TSWV), Capsicum Chlorosis Virus (CaCV).

The first additives incorporated into polyethylene films were UV stabilizers to protect them from fast degradation. Later, thermal stabilizers were also incorporated and the introduction of antifog and antidrip agents were applied to diminish the negative effects of the condensation which reduce the amount of light transmission into the greenhouse and reduce the risk of fungal diseases (Cemek and Demir 2005). Nowadays a new family of additives for agricultural films has been developed to manipulate their optical properties. Optical properties include the manipulation of different regions of the light spectrum that are necessary for photosynthesis and in consequence to enhance the process of plant growth and crop yield (Winsel 2002). The same principle was used to manipulate the light spectrum in the UV
region to improve pest and disease management. These types of materials act as a photoselective barrier by blocking the transmission of the UV radiation (280-400 nm) to the interior of the greenhouse (Espi et al. 2006). The lack of UV radiation has a positive effect on plant growth and contributes to reduce the damage caused due to insect pests and plant diseases.

The name “UV-blocking materials” includes different plastic films and nets available in the market provided by various manufacturers with different capacities to absorb UV wavelength below 380 nm and with a proved action for reducing the damage caused by insect pests.

Different types of UV-blocking plastic films and types of structures have been tested under different climatic conditions and regions of the world mainly against the three main groups of insect vectors of virus diseases (aphids, whiteflies and thrips) (Table I). Also, there are some studies on the impact of these types of films on the natural enemies of insect vectors and other beneficial organisms (reviewed in the Section COMPATIBILITY OF UV-BLOCKING MATERIALS WITH BENEFICIAL ORGANISMS). Krizek et al. (2005) compared the spectral properties of UV-selecting and UV-transmitting plastic materials by means of a UV-VIS spectroradiometer or a UV-VIS spectrophotometer to provide growers some guidelines for selecting appropriate covering materials, showing that plastics have different spectral transmittance capacity. For example, cellulose diacetate (CA) excludes UV-C wavelength, but transmits UV-B and UV-A wavelengths.

Polyester films block the transmission of UV-B, but are able to transmit UV-A wavelengths, and are commonly used in UV-enhancement studies as a control when using CA to exclude UV-B radiation. Also, Teflon transmits radiation at 245 nm and above. When using these three types of plastics, CA should be used with caution in UV exclusion studies because it may have a phytotoxic effect on sensitive plants such as cucumber (Krizek and Mirecki 2004).

The kind of UV-blocking plastic used in a structure determines the level of protection and can affect the population levels of some insect species. In this way, Costa et al. (2002) found that UV-absorbing components that block the majority of UV-light at wavelengths below 380 nm had more influence in reducing insect numbers than those that blocked light at wavelengths below 360 nm. Antignus et al. (1996) found a positive correlation between the level of protection and the capacity of the sheets to absorb UV light.

In addition, the design of the greenhouse and the amount of unfiltered light that enters the system appear to be an important component in determining the level of protection provided by UV-blocking films (Costa et al. 2002). It is important to consider that most works have been conducted in enclosed greenhouses or tunnels obtaining in some cases contradictory results compared with those obtained from open-side greenhouse structures (Table I). For example, UV-blocking materials were not able to reduce the population density of T. vaporariorum in open-side greenhouses, while a positive effect of the film in reducing insect density was observed in enclosed tunnels (Costa et al. 2002; Mutwiwa et al. 2005; Diaz et al. 2006). In this last case, it was not possible to evaluate the effect of UV films on the attraction to insect invasion into the protected structure which is the first phase in the process of infestation by insects in a greenhouse crop (Fig. 1D).

Habitats with significant UV levels can be found at high altitudes, where solar radiation has penetrated a thinner layer of the atmosphere. Consequently, UV-blocking films will be more adequate to use under these types of high intensity UV-light conditions and in geographical locations closer to the equator, where UV-light differences within the greenhouse and the outside light environment are greater (Doukas and Payne 2007b).

As shown in Table 1, most of the pioneer experiments to evaluate the efficacy of UV-blocking plastic films were done in desertic areas from southern Israel (mainly in the Negev desert), but the latest works on this subject were conducted in other Mediterranean and temperate regions, with higher relative humidities which demands a different design of greenhouses structure and specific management tactics, such as strategies to increase ventilation over the crop canopy.

In general, physical barriers such as plastic films or nets reduces the efficiency of natural ventilation with the consequent increase of temperature inside the covered structure, although this principle is not applicable to UV-plastic films, because the heat load depends on the overall energy transmittance and not on the different spectral properties of the films (von Elsner and Xie 2003). However, the specific external climatic conditions of a given region determines the need for ventilation inside the cover structure as has been described by Kumar and Poehling (2006) in studies conducted in the humid tropics (Thailand). These high humidity external conditions reduced the efficiency of UV-plastic films to mitigate insect immigration because side wall ventilation is a pre-requisite under such climatic conditions. Conversely, the efficiency of UV-absorbing barriers is much higher in dry regions of Germany where crops can be grown under closed tunnels, as shown by Mutwiwa et al. (2005).

**TYPES OF PHOTOSELECTIVE BARRIERS USED FOR INSECT PEST MANAGEMENT**

Habitat manipulation is an insect pest management strategy that provides an unfavourable environment for insect pests and more favourable habitat to their natural enemies. In this way, physical barriers are one of the oldest tactics used to control insect pests and had a significant role in Integrated Pest Management Programs in the last few decades (Boiteau and Vernon 2001). Different kinds of physical barriers have been used in the past to exclude insects, modify their behaviour and provide a deleterious environment for their development and population increase. For example, insect screens act as an exclusion physical method between the plants and the pest and have been successfully adopted by many growers around the world.

Vision and olfaction are the primary cues used by insects to orient to their host plants; sometimes the two cues work in concert (Prokopy and Owens 1983). Some physical barriers are often based on manipulating insect vision dependent behaviours by using UV-blocking or UV-reflective materials to interfere with host finding, landing and orientation (Antignus 2000). These materials have been used commonly in three different forms, such as mulches for open-grown crops, and as plastic sheets or screen/nets for protected crops.

**Reflective mulches**

Plastic mulches act among other purposes as deflecting insect pest populations. Depending of the mulch colour they may also have repellent effects on insects. Therefore different types of plastic mulches have been used to control insect vectors, such as aphids, thrips and whiteflies.

Plastics mulches are now being manufactured either as with a high absorption or with a high reflection for certain wavelengths of light (Weintraub and Berlinger 2004).

One of the first reports on the use of reflective mulches and plastic sheets to control plant viruses transmitted by insect vectors is the work by Lobenstein et al. (1975). They found that aluminium mulches have been used specifically to control insect vectors such as *Cucumber mosaic virus* (CMV) and *Potato virus Y* (PVY).

UV-reflective plastic mulches combined with the insecticide spinosad reduced early season abundance of adult thrips, *F. occidentalis*, in field-grown pepper and the consequent primary infection of *Tomato spotted wild virus* (TSWV) compared to plots covered with a black mulch (Reitz et al. 2003). Similar results were obtained by Sta-
visky et al. (2002) using UV-reflective mulches on the population of F. occidentalis, Frankliniella tritici and Frankliniella bispinosa and TSWV in field-grown tomato as a unique control measure, or when UV-reflective mulch was combined with a plant activator (acibenzolar-S-methyl) and insecticides to control the same species of thrips (Momol et al. 2004).

Other works X-bomb that UV-reflective plastic mulches are ideal tools for reducing silverleaf whitefly, Bemisia argentifolii populations and the incidence of silverleaf in cucurbits (Summers and Stapleton 2002; Summers et al. 2004). Also, UV-reflective mulches provided a higher reduction in the incidence of Tomato mosaic virus (ToMoV) when compared with wheat straw mulch in fresh-market tomato (Csizinsky et al. 1999).

No effects were observed on the number of leafminers and mite colonies on tomato foliage from field-grown commercial tomato covered with aluminium-painted plastic mulch compared to non-painted mulch (Kring and Schuster 1992).

Aphid landing preference is determined by the colour of the background, mainly by the degree of contrast between a green target (e.g. the plant) and the colour of the soil (background colour) (A’Brook 1968).

In an experiment using water traps located on soil covered by different coloured plastic sheets, aphid catches were highest in the traps placed on the uncovered background and lowest in the traps placed on white or silver backgrounds (Doring et al. 2004). Similar trends were observed by Kring and Schuster (1992) capturing lower number of aphids in water dish traps and on tomato foliage when a tomato field crop was covered with an aluminium-painted plastic film. As a consequence, fewer tomato plants infected with aphid-transmitted viruses were recorded.

Also, a significant reduction in the incidence of aphid-borne viruses was obtained in a zucchini squash crop (Cucurbita pepo L.) using plastic UV reflective mulches (metalized mulch) as a crop cover (Summers et al. 2004).

**UV-blocking insect nets or screens**

Insect exclusion screens (50 mesh) were first used against B. tabaci to prevent primary infestation of this pest and the spread of whitefly-transmitted viruses in fresh-market tomato production in Israel. Later, a new product was developed by combining the physical barrier provided by the conventional insect-proof net with optical properties, developing a new screen that is able to absorb UV-radiation in the UV-A and UV-B range (Bionet®) (Antignus et al. 1998). Experiments conducted in Israel showed that Bionet® screen with a density of 50-mesh was effective to protect the invasion of B. argentifolii and the spread of Tomato Yellow Leaf Curl Virus (TYLCV), red spider mites (Tetranychus telarius), and leafminers (Liriomyza trifolii) in tomato greenhouses. Also, the 50-mesh screen was able to protect cucumber from aphids very effectively.

However, this positive effect disappeared when the hole size was reduced to 16-mesh and 16-mesh, because a considerable amount of UV-light was transmitted through the screen compared with that of the 50-mesh screen (Antignus et al. 1998). However, due to the small size of the holes of the 50-mesh screens, they do not provide a good solution for regions that require high ventilation such as those with hot and humid climate.

Greenhouses (“parral type”) in southeastern Spain (Almeria) covered with Bionet® and to the control and their sides provided good control of B. tabaci and reduced the incidence of TYLCV of tomato crops with similar results to those obtained in Israel (Ticó Malauque et al. 2002).

However, in all of the experiments carried out in Israel and Spain, Bionet® screen failed to prevent the invasion of F. occidentalis into the protected structures (Antignus 1998; Tico Malauque et al. 2002). In a recent work, Kumar and Poehling (2006) combined the use of UV-blocking nets and plastic films to study the movement of the whitefly, B. tabaci, the thrips, Ceratothripsoides claratus and the aphid, A. gossypii in tomato protected crops located in a humid tropic region in southeastern Asia. Results showed that a greenhouse structure completely covered with UV-blocking materials (plastic and nets) significantly reduced the entry and attraction of whiteflies, winged aphids and thrips into the greenhouse interior and the outside sidewalls compared with those made from UV-transmitting materials, and this protection was independent of the length of the time that greenhouses gates were opened for ventilation.

**UV-blocking plastic films**

Pest invasion is the first phase in the process of host plant infestation by insects in a greenhouse crop (Fig. 1D). In greenhouses and walk-in tunnels conditions, the first level of protection provided by UV-plastic films is determined by the reduction in the number of invading insects through the opening of the structures from the covered environment, as was observed by Costa and Robb (1999) on B. argentifolii and F. occidentalis in small scale experimental tunnels (0.5 by 0.5 by 1.8 m). Also, Costa et al. (2002) found a significant reduction in the number of aphids and thrips captured on yellow sticky traps (YST) in greenhouses covered with UV-reflective plastic films (see Fig. 1D). UV-blocking materials (plastic and nets) significantly reduced the entry of protection provided by UV-blocking materials (plastic and nets) significantly reduced the entry into the greenhouse covered with UV-blocking plastic films (Kumar and Poehling 2006). Once the invading insects entry into the protected crop, they must recognize and locate their host plants. As a result, insects begin the second phase of the process of host plant infestation, which is primary infestation (Fig. 1D). Studies conducted by Antignus et al. (1996) show that B. tabaci is attracted by 254-366 nm when exposed to monochromatic UV-A and UV-B sources as well as full-spectrum light, thus exploiting the inability of this whitefly to recognize the host plants under UV-blocking materials. Also, Antignus et al. (1996) observed that walk-in tomato tunnels covered by UV-absorbing plastics reduce the landing rate of B. tabaci, F. occidentalis and A. gossypii. The same effect was observed on the landing rate of, M. euphorbiae and F. occidentalis on lettuce plants grown under a UV-light deficient environment.

The third phase of greenhouse infestation by insects consists in the secondary spread of the insects within the greenhouse, by the movement of insects by walking or flying from plant to plant (Fig. 1D). UV-blocking materials have a positive effect on the movement of insects within the protected environment, not only by reducing the secondary spread of the pest, but also by reducing the incidence of insect-transmitted virus diseases. In this way a positive effect of the UV-light deficient environment was observed in the population growth and spread of M. persicae (Chyzik et al. 2003) and on the movement of M. euphorbiae and F. occidentalis across lettuce plants, reducing the percentage of lettuce plants affected with Potyviruses and TSWV, respectively (Diaz et al. 2006). In addition, a delay of Capsicum chlorosis virus (CaCV) symptoms on tomato plants was observed in a greenhouse covered with UV-blocking plastic films and nets (Kumar and Poehling 2006). Other works ex-
plain a reduction on virus spread not only because a reduc-
tion of insect movement, but also due to changes in insect
physiology under deficient UV-light environments (Antig-
nus et al. 2001). They suggested that feeding behaviour of
insect vectors change in a way that reduces their transmis-
sion ability under UV-blocking plastic films (IR-Veradim),
and in consequence a dramatic reduction in virus disease
incidence was observed (Antignus et al. 1996).

COMPATIBILITY OF UV-BLOCKING MATERIALS
WITH BENEFICIAL ORGANISMS

Photosensitive plastic films should be compatible with natu-
ral enemies of pests and other beneficial organisms such as
pollinators because biological control is one of the most
widely used strategies in vegetable production due to its
well known environmental benefits (Vithuela 2005).

Impact of UV-light on parasitoids

Parasitization mechanisms begin with the host habitat loca-
tions by the female parasitoids, and then followed by its
host location. In each of these steps, different cues are per-
ceived from the natural habitat (shape, color, texture) and
from the target host itself (Willis 1987). These stimuli may
be visual, olfactory, gustatory, or chemosensory. Some spe-
cies of parasitoids locate their host through very specific
cues making a unique host-parasitoid relationship (Harris
and Bautista 2003). These considerations should avoid any
generalization made about any possible effects of UV-
blocking materials on parasitoids, and therefore each specif-
c host-parasitoid relationship must be considered in any
given environment. In this way, Chiel et al. (2006) studied
the effects of UV-absorbing plastic sheets on the host loca-
tion ability of three parasitoids that are available commer-
cially and commonly released by the growers under green-
house conditions, such as, Aphidius colemani a parasitoid of
M. persicae, Diglyphus isaea a parasitoid of Lyriomyza
bryoniae, and Eretmocerus mundus, a parasitoid of B.
tabaci. Two types of experiments were carried out, under
laboratory choice conditions and in greenhouse trials. In
laboratory experiments, in which only the visual stimuli
were evaluated, the three species showed a strong attraction
to environments with high levels of UV-light. However,
greenhouse trials showed significant differences in their
host location ability among the three species under the UV-
blocking cover. A. colemani and D. isaea were not affected
by UV-low light environment to find their hosts, because
apparently they do not use visual stimuli for host finding or
there is no significant change in the visual stimuli under the
deficient light. For E. mundus UV wavelengths were neces-
sary for long range host location, because this process is
driven by visual stimuli, but were not essential for the close
range host location probably because they use non-visual
stimuli (Chiel et al. 2006). These results provide practical
information for growers about the release of these parasit-
oids in greenhouses covered by UV-blocking materials. For
example, it is known that E. mundus should be introduced
in multiple release points or as close as possible to the B.
tabaci infected plants.

Chyzik et al. (2003) showed that UV-blocking films
suppressed both the propagation and flight activity of M.
persicae within walk-in tunnels, without effects on the host-
finding activity and fecundity of it parasitoid Aphidius
mataricariae. The mechanisms of the inhibitory effect on the
aphid host are not yet under study, whereas, the parasitoid be-
haviour under UV-deficient environment may be explained
by the hypothesis that the attraction of this wasp to its aphid
host is controlled by olfactory rather than by visual cues.

Doukas and Payne (2007a) confirmed that E. formosana
dispersal is not affected by environments with low UV-light,
while this wavelength radiation is necessary for their white-
fly host flight activity and dispersal. From a practical point
of view, these authors concluded that the number of para-
sitoids to be released could be lowered under UV-blocking
films to achieve the same level of protection against T.
vaporariorum.

Impact of UV-light on predators

To date no experiments were carried out to evaluate the ef-
efects of the UV-blocking greenhouse covering materials on
the predators commonly released by growers. Reitz et al. (2004)
carried the impact of different plastic soil mulch on insect
insecticides and predator releases for the control Frankli-
niella thrips in field-grown pepper. The results showed that
the abundance of the predator Orius insidiosus was signifi-
cantly reduced in UV-reflective mulch compared to a black
mulch treatment.

Effects of UV-light on pollinators

Most of the flower-visiting Hymenoptera are trichromatic,
with photoreceptor spectral sensitivity peaks in the UV, blue
and green regions of the spectrum (Skorupski et al. 2007).

The effects of enhanced UV-B radiation on reproductive
and pollination success were investigated in the Mediterr-
anean annual Malcomia maritima. Plants were exposed in
the field to ambient or ambient plus supplemental UV-B
radiation. UV-B radiation had no effect on stem and fruit
biomass, anthesis time and duration and flower number.
However, flower diameter, nectary volume and nectar
amount per flower (but not nectar concentration) were sig-
nificantly increased by supplemental UV-B radiation. In
addition, UV-B treated plants showed higher reproductive
success and a trend to higher pollination success (i.e. in-
creased number of seeds per fruit). As a result, the seed
yield was increased. This work suggests that the UV-B in-
duced changes in flower attributes might have affected pol-
inators’ behaviour in a way that improved the fitness of M.
maritima (Petropoulou et al. 2001).

Another study was carried out to study the response of
insect pollinators to the UV-reflectance of flowers indepen-
dently of other wavelengths. Flower corollas of Hypoxis
hemerocallidea were painted with human sunscreen able to
absorb UV wavelengths. The results showed that honey-
bees (Apis mellifera scutellata) foraged on the strongly UV-
reflecting flowers of H. hemerocallidea, rejected flowers
that had UV reflectance eliminated by the sunscreen coating,
but continued to visit control flowers painted with sun-
screen solution that did not contain the UV absorbing com-
 pound. The sunscreen technique could be useful for deter-
mining the response of a wide range of pollinators to the
UV component of spectral reflectance in flowers and could
be used to test the functional significance of UV-contrasting
“nectar guide” patterns (Johnson and Andersson 2002).
The incorporation of the bumblebee (Bombus terrestris)
hives into the greenhouses is a usual practice by growers in
many regions, because they play an important role on the
yield of high-value crops, such as tomato and cucurbits. For
this reason, the effects of UV-light blocking materials on
pollinator’s behaviour must be carefully considered. In
this way, Morandin et al. (2001) observed that the activity of
B. terrestris measured in commercial tomato greenhouses
was higher (94%) under UV-transmitting covering materials
than under UV-blocking films. However, there was no dif-
ference in bumblebee activity based on different types of
covering, when measured in small experimental green-
houses (Morandin et al. 2002). In both, commercial and ex-
perimental greenhouses bumblebee activity had a positive
linear relationship with the internal greenhouse temperature.
In the same experiments, the authors observed that under
UV-transmitting plastics there was a lower loss of bumble-
bees throughout the greenhouse ventilation systems, showing
that bees were more attracted to UV-transmitting than to
UV-blocking materials.

It is known that ultraviolet-sensitive photoreceptors
have an important role in a variety of visual tasks per-
formed by bees, such as orientation, colour and polarization
vision. Ultrastructural studies have shown that the bumble
bee (B. hortorum) eye is similar to that of the honeybee Aphis mellifera concluding that bumble bee, like honeybees, make use of shapes and colours of flowers, the polarization pattern of the sky in navigation and retain fine details of their environment (Meyer Rochow 1981). A recent work conducted by Spaethe and Briscoe (2005) have shown the location of UV-pigments bumblebee brains by molecular characterisation and expression of the UV opsin from Bombyx mori. They found UV-circadian expression in the retina of omatidia, ocelli and various brain parts, particularly in the optic and antennal lobes, the regions that process vision and olfaction. They also found that bumblebees express a circadian clock protein, in the optic and antennal lobes. Since period and the UV opsin are both expressed in the optic and antennal lobes, they concluded that UV light might play a role in bumblebee circadian rhythm regulation, mediated through these two brain regions.

**Impact of UV-light on entomopathogens**

The low survival and persistence of microbial organisms used for pest control exposed to UV radiation is one of the limitations for its wider use as microbial insecticides in field or greenhouse conditions.

Several works showed the detrimental effects of UV radiation on germination and survivorship of different entomopathogenic fungi genera. Fargues et al. (1997) observed that UV-B light appeared to be the most detrimental part of the natural radiation on the survival of conidia of Paecilomyces fumosoroseus. Similar results showing a strong delay in germination of conidia of Metarhizium anisopliae (Braga et al. 2001), Verticillium lecanii and Aphalocladium album strains were obtained after exposure to UV-B radiation (Braga et al. 2002).

New formulations of entomopathogenic fungi are available commercially or in experimental phase that provide UV protectant agents to enhance the survival of conidia exposed to high levels of UV radiation. Among several montmorillonites-containing formulations of V. lecanii, the SCFX-1374 (hydrogenated tallow and trimethyl quaternary ammonium) protects spores with a survival rate >90% after 30 min exposure to UV-C light versus no conidia survival without this type of clay (Lee et al. 2006). Also this selected V. lecanii formulation was tested against A. gossypii in a greenhouse with natural sunlight reducing cotton aphid density to 60% of the initial level, while the cotton aphid densities increased 3-fold in 15 d for the untreated spores of V. lecanii.

Under field conditions, Costa et al. (2001) found that the persistence of viable spores from a commercial formulation of the entomopathogenic fungi Beauveria bassiana was significantly increased under a plastic that blocked UV-light wavelengths below 380 nm compared to that with plastics that blocked UV-light wavelengths below 360 nm.

Other microbial organisms used for pest control, such as the bacteria Bacillus thuringiensis or baculoviruses, need formulations to protect them from the negative effects of sunlight ultraviolet radiation that reduce their persistence in the field (Behle et al. 1997). Lasa et al. (2007) observed that the mixture of Spodoptera exigua multiple nucleopolyhedrovirus (SeMNPV) with an optical brightener increased the prevalence of infection in larvae of S. exigua during the first two days post-application of the baculovirus formulation in grown sweet pepper greenhouse covered with UV-B (280-315 nm) absorbing films. The use of microbial insecticides combined with UV-blocking materials could be an effective and very promising strategy to enhance pest control in protected crops.

**CONCLUDING REMARKS**

We can conclude that UV-blocking plastic materials are a very effective tool to reduce the incidence of pests and diseases, especially under organic and integrated production. But due to the fact that all the strategies to be developed are based on films or nets made out of polyethylene, it is important to have a technology for the correct disposal of such material to avoid its accumulation in the environment. In this way, biodegradable and photodegradable plastics will be developing and will become more important in the near future. The result of photochemical degradation is the production of small film fragments that can disappear from the soil surface due to the activity of soil inhabitant organisms. Another important effect of the other hostile factors exposure in the retina of omatidia, ocelli and various brain parts, particularly in the optic and antennal lobes, the regions that process vision and olfaction. They also found that bumblebees express a circadian clock protein, in the optic and antennal lobes. Since period and the UV opsin are both expressed in the optic and antennal lobes, they concluded that UV light might play a role in bumblebee circadian rhythm regulation, mediated through these two brain regions.

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**REFERENCES**


Cemeck B, Demir Y (2005) Testing of the condensation characteristics and light transmission of different plastic film covering materials. *Polymer Testing* 24,


Summers CG, Stapleton JJ (2002) Use of UV reflective mulch to delay the colonization and reduced the severity of Bemisia argentifolii (Homoptera: Aleyrodidae) infestations in cucurbits. *Crop Protection* 21, 921-928


Vakalounakis DJ (1992) Control of fungal disease of greenhouse tomato under long-wave infrared-absorbing plastic film. *Plant Disease* 76, 43-46


Willis JK (1997) Strategies for successful parasitism. *Insect Behavior* (EN507). Review Articles, Colorado State University, Colorado USA, 5 pp