

Management of Air-Borne Viruses by “Optical Barriers” in Protected Agriculture and Open-Field Crops

Yehezkel Antignus^{*,1}

^{*}Plant Pathology and Weed Research Department, ARO, The Volcani Center, Bet Dagan, Israel

¹Corresponding author: e-mail address: antignus@volcani.agri.gov.il

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Abstract

The incurable nature of viral diseases and the public awareness to the harmful effects of chemical pest control to the environment and human health led to the rise of the integrated pest management (IPM) concept. Cultural control methods serve today as a central pivot in the implementation of IPM. This group of methods is based on the understanding of the complex interactions between disease agents and their vectors as well as the interactions between the vectors and their habitat. This chapter describes

a set of cultural control methods that are based on solar light manipulation in a way that interferes with vision behavior of insects, resulting in a significant crop protection against insect pests and their vectored viruses.



1. INTRODUCTION

Insect-borne plant viruses may cause severe losses to many annual and perennial crops of a high economic value. Insect vectors of plant viruses are found in 7 of the 32 orders of the class Insecta and are therefore responsible for severe epidemics that form a threat to the world's agricultural industry. Insect vectors transmit plant viruses by four major transmission modes that are supported by a number of viral and insect proteins (Raccach & Fereres, 2009). The obligatory parasitism of plant viruses and their intimate integration within the plant cell requires an indirect approach for their control. This chapter will focus on the use of light manipulation to affect insects vision behavior in a way that interferes with their flight orientation, their primary landing on the crop, and the secondary dispersal within the crop. Manipulation of light signals simultaneously diminishes the insect immigration into the crop and reduces feeding contacts between the insect vector and the host plant, thus lowering significantly virus disease incidence.



2. THE INSECTS VISION APPARATUS

Insects perceive light through a single pair of compound eyes which facilitate a wide field of vision. The basic unit of the compound eyes is the ommatidium which rests on a basement membrane. The corneagen cells are located atop a long retinula formed by long neurons and secondary pigment cells. A crystalline cone lies within the corneagen cells. The dorsal surface of the ommatidium is covered with the corneal lens which is a specialized part of insect cuticle. Part of each retinula cell is a specialized area known as a rhabdomere. A nerve axon from each retinula cell projects through the basement membrane into the optic nerve. Ommatidia are functionally isolated because the retinula cells are surrounded by the secondary pigment cells (Diaz & Fereres, 2007).

Vision involves the transduction of light energy into a bioelectric signal within the nervous system. The first events in this process take place in the retinula cells. The fine structure of rhabdomeres consists of thousands of closely packed tubules (microvilli). The visual pigments occur mainly in these

rhabdomeric microvilli. It has been suggested that the small diameter of each microvillus inhibits free rotation of visual pigments. This specific orientation may be the molecular basis of insects' sensitivity to polarized light. Photobiological processes in the insect eye occur in a narrow band of the electromagnetic spectrum between 300 and 700 nm. Visual pigments initiate vision by absorbing light in this spectral region. These pigments are a class of membrane-bound proteins known as opsins that are conjugated with a chromophore. Visual pigments whose chromophore is retinal are called rhodopsins. The visual pigments of all invertebrates, including insects, crustaceans, and squids, are all rhodopsins. According to which parameter of the light is being used or what information is extracted from the primary sensory data, vision is often divided into subcategories like polarization vision (Wehner & Labhart, 2006), color vision, depth perception, and motion vision (Borst, 2009). Polarization arises from the scattering of sunlight within the atmosphere enabling the insect to infer the location of the sun in the sky. The polarization plane is detected by an array of specialized photoreceptors (Heinze & Homberg, 2007). Many insects can discriminate between light wavelength (color) (Fukushi, 1990) its contrast and intensity. Motion signals are also part of vision cues that serve as a rich information source on the environment in which the insect is acting (Borst, 2009; Diaz & Fereres, 2007).

2.1. UV vision and insects behavior

In insects, the different visual pigments (opsins) are segregated into different subsets of cells that form the ommatidium. In the fruit fly *Drosophila*, seven genes encoding different opsins have been identified and sequenced (Hunt, Wilkie, Bowmaker, & Poopalasundaram, 2001). The ability of insects and mites (McEnrone & Dronka, 1966) to perceive light signals in the UV range (300–400 nm) is associated with the presence of specific photoreceptors within their compound eye. UV receptors of the greenhouse whitefly *Trialeurodes vaporariorum* (Westwood) as in other herbivorous insects are present in the dorsal eye region (Mellor, Bellingham, & Anderson, 1997; Vernon & Gillespie, 1990). Many insects have two rhodopsins, one with maximum absorption in ultraviolet wavelengths (365 nm) and one with maximum absorption in the green part of the spectrum (540 nm) (Borst, 2009; Matteson, Terry, Ascoli, & Gilbert, 1992). UV component of the light spectrum plays an important role in aspects of insect behavior, including orientation, navigation, feeding, and interaction between the sexes (Mazokhin-Porshnykov, 1969; Nguyen, Borgemeister, Max, & Poehling,

2009; Seliger, Lall, & Biggley, 1994). The involvement of UV rays in the flight behavior of some economically important insect pests has been studied by several workers (Coombe, 1982; Issacs, Willis, & Byrne, 1999; Kring, 1972; Matteson et al., 1992; Moericke, 1955; Mound, 1962; Vaishampayan, Kogan, Waldbauer, & Wooley, 1975; Vaishampayan, Waldbauer, & Kogan, 1975).

2.1.1 Effect of UV on insects dispersal and propagation

Whiteflies [*Bemisia tabaci* (Gennadius)] dispersal pattern under UV-absorbing films was examined using a release-recapture experiment. In “walk-in” tunnels covered with a UV-absorbing film and an ordinary film, a grid of yellow-sticky traps was established forming two concentric circles: an inner and an external. Under UV-absorbing films, significantly higher numbers of whiteflies were captured on the internal circle of traps than that on the external circle. The number of whiteflies that were captured on the external circle was much higher under regular covers, when compared with UV-absorbing covers, suggesting that filtration of UV light hindered the ability of whiteflies to disperse in a UV-deficient environment (Antignus, Nestel, Cohen, & Lapidot, 2001).

Following artificial infestation of pepper plants with the peach aphid [*Myzus persicae* (Sulzer)] in commercial tunnels, covered with a UV-absorbing film, aphid population growth and spread were significantly lower compared to tunnels covered with an ordinary film. In laboratory experiments, no differences in development time (larvae to adult) were observed when aphids were maintained in a UV-deficient environment. However, propagation was faster in cages covered with the regular film. The numbers of aphids was 1.5–2 times greater in cages or commercial tunnels covered with an ordinary film. In all experiments, the number of trapped winged aphids was significantly lower under UV-absorbing films. It was suggested that elimination of UV from the light spectrum reduces flight activity and dispersal of the alate aphids (Chyzik, Dobrinin, & Antignus, 2003).

Mazza, Izaguirre, Zavala, Scopel, and Ballaré (2002) reported that in choice situations *Caliothrips phaseoli* (Hood) (Thysanoptera: Thripidae), favored areas with ambient UV-A (320–400 nm) radiation compared with areas where this part of the light spectrum was blocked. This type of behavior was explained by the relatively broad gap between the peak sensitivities of the photoreceptors that are responsible for sensing the UV range (365 nm) and the visible light (540 nm). It was assumed that under UV-deficient environment formed by the photoselective film, UV receptors are not

stimulated by the ambient light, lacking the short wavelength (<400 nm) and thus did not trigger the dispersal flight of thrips. Moreover, it was hypothesized that if only the 540-nm receptor is activated, thrips should be unable to discriminate colors but only light brightness because at least stimulation of two receptors is essential for color vision, and blue and UV are of special importance regarding color opponency mechanism (Doring & Chittka, 2007). In large-scale dispersal experiments with *Frankliniella occidentalis* [western flower thrips (WFTs)], plants or blue sticky cards were arranged in concentric circles around a source plant at the release point. Dispersal of the WFT tended to exhibit reduced dispersal from source plants under UV-deficient conditions (Kigathi & Poehling, 2012).

2.1.2 UV stimulated phototaxis of insects

The UV range (360–400 nm) forms a strong stimulus for whiteflies to fly; e.g., the greenhouse whitefly, *T. vaporariorum*, took off more readily and walked faster when exposed to light of wavelengths under 400 nm than when exposed to that between 400 and 500 nm (Coombe, 1981). Similar photosystems and effects of UV light were suggested for aphids and thrips (Kring, 1972; Matteson et al., 1992). Monochromatic UV lamps in a flight chamber served to study the attraction of *B. tabaci* to distinct wave lengths in the UV-A and UV-C parts of the spectrum. Whiteflies were attracted similar to light source emitting at 366 and 254 nm (Antignus, Mor, Ben Joseph, Lapidot, & Cohen, 1996). Preference for richer UV environments has been shown for the whiteflies *B. argentifolii* (Bellows & Perring) and *T. vaporariorum*, when tested in choice situations (Costa & Robb, 1999; Costa, Robb, & Wilen, 2002; Doukas & Payne, 2007b; Mutwiwa et al., 2005). A striking demonstration of the effect of UV phototaxis on aphids and whiteflies occurs in greenhouses with roof arches that are covered alternately, with a UV-transmitting film and a UV-absorbing film. In cases where such greenhouses are invaded by virus born insects, all the plants under the UV-transmitting film become infected, while plants under the UV-absorbing film remain totally virus free (Y. Antignus, unpublished) (Fig. 1.1). This dramatic scenario is a consequence of the fact that when an insect is in a choice situation, it will be attracted always to a UV-rich environment.

In choice situations, *Ceratothripoides claratris* (Shumsher) thrips exhibited a clear preference to fly toward rooms enlightened with higher UV intensities, while it avoids greenhouse constructions with low internal UV radiation, as initially shown by Kumar and Poehling (2006). Costa and Robb (1999)

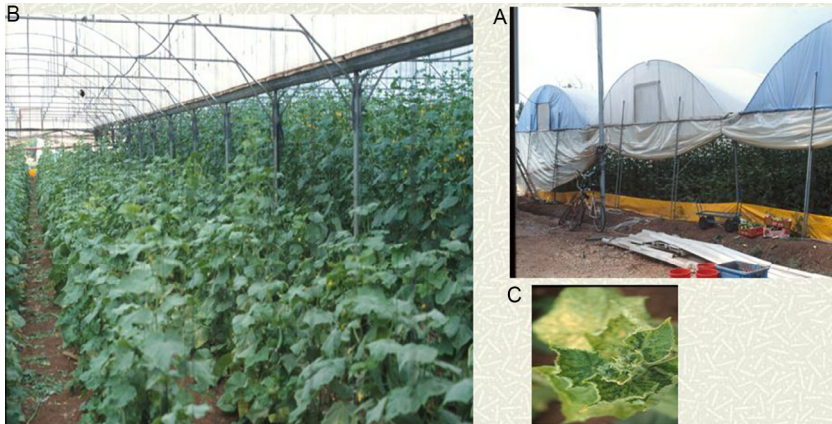


Figure 1.1 A demonstration of aphids phototaxis toward UV irradiation and the formation of the “two-compartment effect” in greenhouses with roof arches covered alternately with UV-absorbing (films with a bluish hue) and ordinary films (A). The massive immigration of aphids into greenhouse sections with a rich UV environment resulted in total infection with the aphid-borne nonpersistent *Zucchini yellow mosaic virus* (ZYMV) (B Left hand). All the stunted plants show the typical mosaic symptoms of the virus (C). None of the plants grown under the UV-absorbing film were infected (A Right hand).

reported a distinct flight preference of the WFT, to higher UV levels in choice experiments carried out in plastic tunnels. Likewise, [Kigathi \(2005\)](#) reported similar findings for WFT in choice experiments, in the laboratory, and in small greenhouses.

2.1.3 Effect of UV reflection

[Moller \(2002\)](#) assumed that UV reflection from plant surfaces plays an important role in making plants visible to herbivorous insects, thus directing their take off and initial orientation. It was assumed that stimulation of UV receptors by incoming UV mainly controls initiation of take off and directs the route of dispersion flight of the thrips *C. claratris* ([Nguyen et al., 2009](#)). However, high reflectance of UV rays seems to disrupt the host-finding behavior of insect pests. For example, in the case of thrips, *F. occidentalis*, the strong reflection of UV caused an attractively colored surface to become repellent ([Vernon & Gillespie, 1990](#)), and the use of UV-reflecting mulches has been proposed to reduce populations of *Frankliniella* spp. and the associated incidence of tomato spotted wilt disease in open-field tomato ([Stavisky, Funderburk, Brodbeck, Olson, & Andersen, 2002](#)).



3. USE OF UV-ABSORBING CLADDING MATERIALS FOR GREENHOUSE PROTECTION AGAINST THE SPREAD OF INSECT PESTS AND VIRUS DISEASES

The first report on the effect of UV-absorbing films on insects came from a Japanese experimental station (Onuma & Nakagaki, 1982). Few years later, this effect was discovered independently by Antignus et al. (1996) through a field experiment in which an anti-Botrytis UV-absorbing film (Raviv & Antignus, 2004; Reuveni & Raviv, 1992) was tested for its ability to protect cucumbers against the spread of downy mildew. Surprisingly, 100% of the plants grown in tunnels covered by an ordinary non-UV-absorbing film were infected by the whitefly-borne *Cucumber yellow stunting disorder virus* (CYSDV), while those that were grown under the UV-absorbing film remained healthy. Further studies have shown the blocking effect of UV-absorbing films on the invasion of a wide range of insect pests into structures covered with different UV-absorbing cladding materials. Since then, an extensive research was carried out in different laboratories worldwide enabling a better understanding of the interactions among UV light, insects, and their host plants.

3.1. Spectral transmission properties of UV-absorbing cladding materials

Improved greenhouse film technology has given growers access to plastic covers that last up to twice as long, allow a better light transmission, and are engineered to lift crop production. Unique among these covering materials are multilayered polyethylene films, often referred to as “smart films” that include UV inhibitors and colorants to filter or enhance light quality, and additives that offer anti-drip and UV blocking, as well as cooling and thermal benefits (Espí, Salmerón, Fontecha, García, & Real, 2006).

Photosynthesis active radiation, 400–700 nm, the main source of energy for plants, should be transmitted through the covering material at a high rate to enhance yields. According to environmental photobiologists, the UV portion of the spectrum is subdivided into three regions, defined as UV-C (200–290 nm), UV-B (290–320 nm), and UV-A (320–400 nm). The near-UV spectrum (200–400 nm)-absorbing qualities that plastics naturally have can be manipulated by the addition of additive materials (Edser, 2002).

The introduction of UV-blocking compounds into polyethylene films determines their UV-absorbing capacity. UV films block the transmission of UV irradiation in the range of 280–380 nm, while most of visible part of the solar light spectrum is transmitted (Fig. 1.2). Only 7% of the solar light spectrum between 250 and 400 nm is transmitted through UV-absorbing films compared to 39% transmission by the ordinary films (Chyzik et al., 2003).

UV-absorbing screens permit the influx of a mixture of filtered and unfiltered light, resulting in transmission of less than 40% of the natural UV radiation. Ordinary nets allow more than 75% of incident light to reach the crop (Legarrea, Karnieli, Fereres, & Weintraub, 2010).

The level of the UV-blocking capacity of the plastic is determined by the level of the UV-blocking additive that it contains or by the molecular properties of the material. Enhanced UV-blocking capability increases the protection efficiency of the cladding material (Antignus et al., 1996; Doukas, 2002). The activity of UV blockers is time limited due to chemical degradation. Polyvinyl chloride (PVC) films on the other hand act as efficient UV filters due to their molecular properties which increase both the UV-absorbing capacity and stability (Antignus et al., 1996).

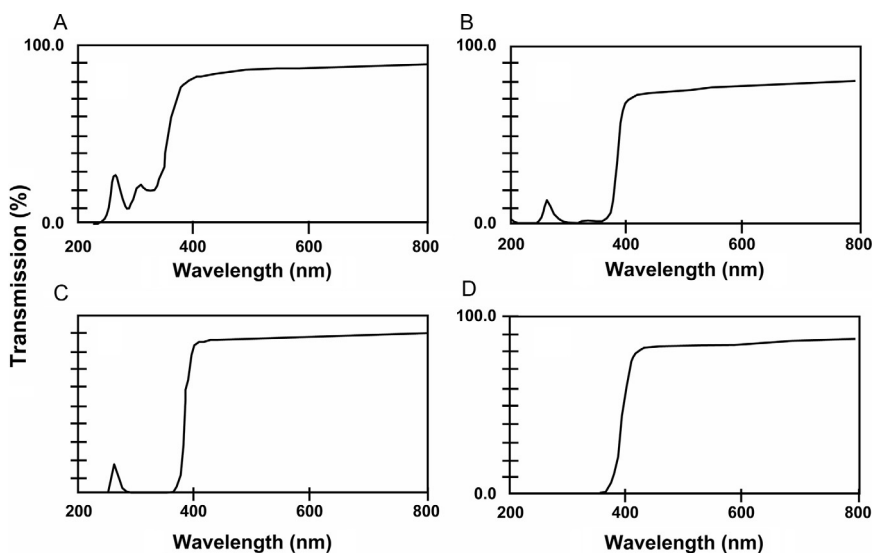


Figure 1.2 Light transmission spectra of ordinary nonabsorbing UV film (A), and different brands of UV-absorbing films: Solarig (B), IR-Veradim (C), PVC sheet, Rav-Hozek (D).

3.2. Effect of UV-absorbing films on the immigration of insect pests into greenhouses

Photoselective greenhouse cladding materials can serve as mega filters to eliminate parts of the UV light spectrum, thus inhibiting insect development and virus epidemics (Antignus et al., 1996). UV-absorbing polyethylene films were highly efficient in protection of greenhouse crops against infestation by different insect pests and viral diseases. Tomato crops grown in “walk-in” tunnels covered with a UV-absorbing polyethylene were highly protected against the immigration of *B. tabaci* (Fig. 1.3). UV-absorbing plastic sheets were also highly efficient in protecting cucumbers from infestation by the WFTs, *F. occidentalis* (Fig. 1.4), and the cotton aphid, *Aphis gossypii* (Glover) (Fig. 1.5) (Antignus et al., 1996; Raviv & Antignus, 2004). Similar results were obtained by other workers showing that these protection effects seem to be universal and are not species specific. UV-absorbing films were found effective against the invasion of thrips *Ceratothripoides claratris* (Kumar & Poehling, 2006), *Thrips tabaci* (Lindenman) (Doukas & Payne, 2007a), the peach aphid *M. persicae* (Chyzik et al., 2003), the whitefly *T. vaporariorum* (Doukas & Payne, 2007a; Gonzales, Rodriguez, Bafion, Franco, & Fernandez, 2001), *Macrosiphum euphorbiae* (Thomas), *Acyrtosiphum lactucae* (Passerini), and *Aphis fabae* (Scopoli) (Diaz, Biurrun, Moreno, Nebreda, & Fereres, 2006; Doukas & Payne, 2007a). Some reports

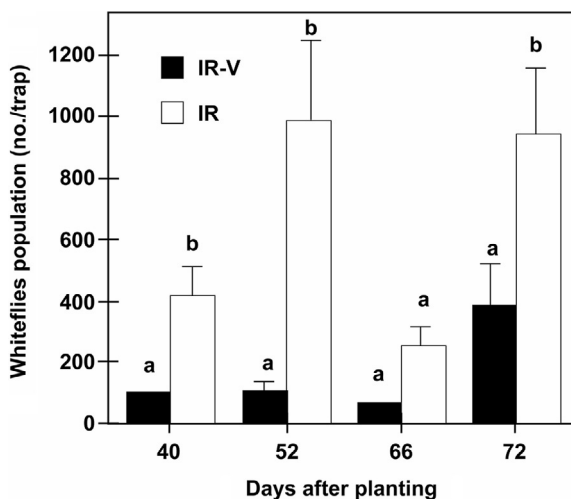


Figure 1.3 Protection of UV-absorbing films from whiteflies immigration. Trapping of *Bemisia tabaci* in “walk-in” tunnels covered with either nonabsorbing polyethylene film (IR) or a UV-absorbing polyethylene film (IR-V).

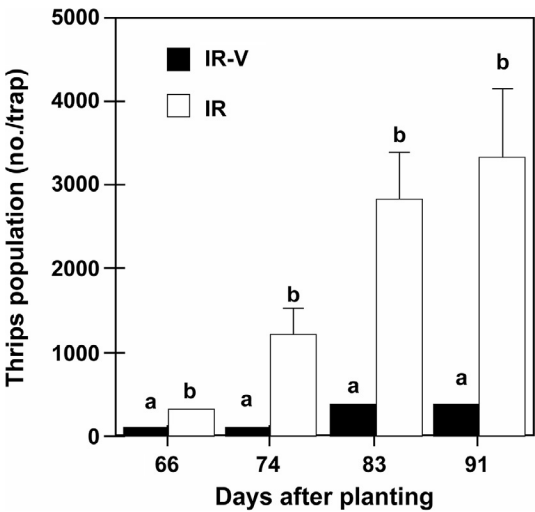


Figure 1.4 Protection of UV-absorbing films from thrips immigration. Trapping of *Frankliniella occidentalis* in “walk-in” tunnels covered with either nonabsorbing polyethylene film (IR) or a UV-absorbing polyethylene film (IR-V).

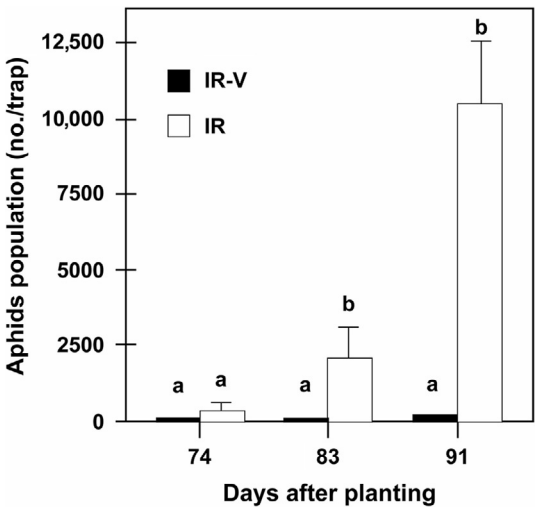


Figure 1.5 Protection of UV-absorbing films from aphids’ immigration. Trapping of *Aphis gossypii* in “walk-in” tunnels covered with either a nonabsorbing polyethylene film (IR) or a UV-absorbing polyethylene film (IR-V).

indicate also inhibiting effects on immigration of the leafhopper *Hauptida maroccana* (Melichar 1907) (Doukas & Payne, 2007a). Lower numbers of *Lyriomyza* spp. were found in structures covered with UV-blocking cladding materials (Antignus, Lapidot, Hadar, Messika, & Cohen, 1998; Costa, Newman, & Robb, 2003). The following mite species were deterred by UV-absorbing films: red mites (*Tetranychus telarius*) (Antignus et al., 1998), the tomato rust mite (*Aculpas lycopersici*), and the broad mite (*Polyphagotarsonemus latus*) (Antignus et al., 1998). Lower numbers of caterpillars of the nocturnal moth *Spodoptera exigua* were found in mint grown in commercial walk-in tunnels covered with a UV-absorbing film (Messika et al., 1999). Population density of the Lepidopteran pest *Autographa gamma* was reduced in lettuce grown in a UV-deficient environment (Diaz et al., 2006). The significant reduction in insect pest populations in commercial greenhouses protected with UV-absorbing films enabled a dramatic reduction in the number of insecticide applications during the growing season. In field experiments carried out in commercial structures (Messika et al., 1999; Messika, Lapidot, & Antignus, 1997; Messika, Nishri, Gokkes, Lapidot, & Antignus, 1998), only three applications were given to the cut flower *Lisianthus* grown in a greenhouse protected by a UV-absorbing film, compared with 20 insecticide applications given to control leafminers, thrips, and whiteflies in the same crop grown under ordinary polyethylene films.

3.3. Effect of UV filtration on the spread of insect-vectored virus diseases

The inhibitory effect of UV-absorbing films on the migration of insect pests into plastic protected structures had a drastic effect on the spread and disease incidence of insect-vectored virus diseases. Thus, TYLCV spread rate and disease incidence under UV-absorbing films were 5- to 10-folds lower compared to that in control structures covered with an ordinary polyethylene film (Fig. 1.6) (Antignus et al., 1996; Kumar & Poehling, 2006; Rapisarda & Tropea-Garzia, 2002). Kumar and Poehling (2006) reported on the attenuation effect of UV-absorbing films on symptoms induced in tomato by *Capsicum chlorosis virus*. Blocking effects on virus spread were reported for potyviruses and the tospovirus *Tomato spotted wilt virus* (Diaz et al., 2006). High protection against the spread of *Zucchini yellow mosaic virus* was recorded in a commercial greenhouse covered with a UV-absorbing plastic (Y. Antignus, unpublished). Cucumber and melon crops grown in commercial “walk-in” tunnels or greenhouses covered with UV-blocking films were highly protected against the whitefly-borne CYSDV. CYSDV

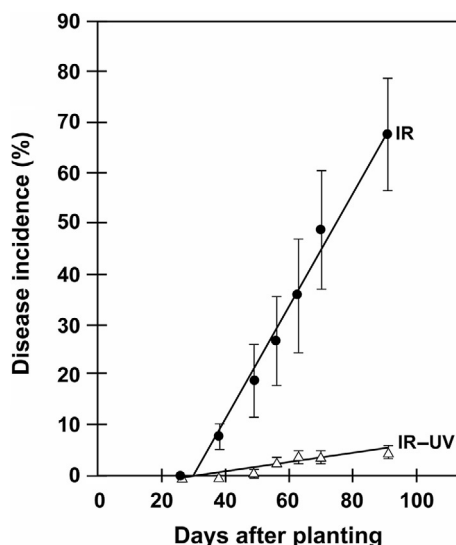


Figure 1.6 The spread dynamics of Tomato yellow leaf curl virus (TYLCV) in tomato plants grown in “walk-in” tunnels covered with either regular (IR) or UV-absorbing films (IR-UV).

incidence under the UV-absorbing films was 2% compared to 14% under an ordinary film (Mizrahi et al., 1998). Infection rates of the nonpersistent viruses *Cucumber mosaic virus* (CMV) and *Lettuce mosaic virus* were lower under UV-absorbing screens, probably due to the lower population density and dispersal rate of the aphid vector *M. euphorbiae* (Legarra, Betancourt, et al., 2012; Legarra, Weintraub, Plaza, Viñuela, & Fereres, 2012).

3.4. Effect of UV filtration on crop plants

The effect of UV filtration on plants was reviewed in the past (Antignus & Ben-Yakir, 2004; Raviv & Antignus, 2004). Although UV-A radiation (315–400 nm) is less potent per photon than UV-B (280–315 nm), its damaging and inhibiting effects on growth and photosynthesis of aquatic and terrestrial plants can also be considerable, since its flux rate is higher than that of UV-B radiation. UV-A radiation may also induce increased amounts of UV-absorbing pigments (Rozema et al., 2002). UV-exclusion studies on cucumber (Krizek, Mirecki, & Britz, 1997) and a red-pigmented lettuce (Krizek, Britz, & Mirecki, 1998) indicate that ambient UV-A radiation greatly inhibits leaf enlargement, stem elongation, and biomass production. UV-B radiation is known to affect the secondary metabolism of plants via

the activation of UV-B photoreceptor, the upregulation of genes of the phenylpropanoid pathway, and the accumulation of flavonoids, anthocyanins, alkaloids, waxes, and polyamines (Marcel, Jansen, Gaba, & Greenberg, 1998). UV-B may also have a negative impact on the plant including damage to DNA, reduction in the activity of several enzymes, reduction in the levels of chlorophyll and carotenoids, downregulation of photosynthetic genes, and changes in the chloroplast ultra structure. It is obvious that elimination of the UV-B from light by greenhouse cladding material may affect plants in different ways (Fiscus, Philbeck, & Britt, 1999; Marcel et al., 1998; Robson et al., 2003). In some species (e.g., cucumber, mung bean, New Zealand spinach, and “New Fire” lettuce), growth is inhibited by solar UV-B (Adamse, Reed, Krizek, Britz, & Mirecki, 1997; Krizek et al., 1998, 1997). In some plants (e.g., tomato), growth is promoted (Cybulski & Peterjohn, 1999; Krizek et al., 1997), whereas others (e.g., cotton, oats) remain unaffected (Adamse et al., 1997; Krizek et al., 1997). No significant differences were found in growth, yield, maturing time, fresh, or dry weights of plant parts in tomatoes grown in greenhouses under standard and UV-blocking films. The yield and quality of pepper and cucumbers were not affected by blocking UV (Onuma & Nakagaki, 1982). No differences were found in pigment intensity and total soluble sugars of tomato and pepper fruits grown under regular and UV-blocking films (Pressman, Moshkovitz, Rsenfeld, & Shaked, 1996). The type of polyethylene film covering did not affect the percentage of viable pollen grains of tomato and pepper plants (Pressman et al., 1996) or on the firmness and shelf life of tomato fruits (Antignus et al., 1999). UV blocking caused an improper pigmentation in the violet cultivar of *Lisianthus* flowers, thus reducing its marketing quality (Messika et al., 1998). Changes in quality, such as pigmentation and taste, were observed in lettuce when plants were grown under UV-opaque film, which absorbed 50% of UV-A and 95% of UV-B light (Paul, Jacobson, Taylor, Wargent, & Moore, 2005). These effects on pigmentation may be explained by the requirement of UV irradiation for the synthesis and accumulation of anthocyanins and flavonoids (Marcel et al., 1998). Therefore, UV-blocking films may not be used to protect crops in which anthocyanin pigmentation is a determinant of quality. The implementation of UV-blocking cladding materials in greenhouses is feasible only if it will not affect negatively plant development, yield level, and quality. Experimental results indicate that UV-absorbing films can be used safely in most crop plants. UV-absorbing films were successfully used to protect tomato (*Lycopersicon esculentum*;

Antignus et al., 1996; Kumar & Poehling, 2006; Rapisarda & Tropea-Garzia, 2002), pepper (*Capsicum annuum*; Chyzik et al., 2003; Mizrahi et al., 1998), cucumbers (*Cucumis sativus*; Antignus et al., 1996), melons (*Cucumis melo*; Antignus, unpublished), chive (*Allium schoenoprasum*), sage (*Salvia fruticosa*), basil (*Ocimum basilicum*), mint (*Mentha* sp.), chervil (*Anthriscus cerefolium*; Messika et al., 1997, 1999), lettuce (*Lactuca sativa*; Diaz et al., 2006), and eggplant (*Solanum melongena*; Kittas, Tchamitchian, Katsoulas, Karaïskou, & Papaioannou, 2006). The growth and performance of the following organic crops were tested in tunnels covered with UV-blocking films compared to non-UV-blocking films: chard, chicory, winter parsley, endive, winter lettuce, winter spinach, winter radish, rocket, Chinese cabbage, and spring cabbage. The crops under the UV-blocking film appeared to grow quicker and also reached a greater final size (Leigh, 2004).

3.5. Effect of UV filtration on pollinators

Pollination improves the yield and increases the quantity of most crop species, thus contributing to one-third of global crop production. More than 75% of the 115 leading crop species worldwide are dependent on or at least benefit from animal pollination, whereas wind and self-pollination are sufficient for only 28 crop species (Klatt et al., 2014).

UV-poor environments might have an influence on pollinator behavior in two ways: first, the overall flight activity may be diminished due to deficient light conditions, and second, the light conditions might change the color perception of the crop flowers by the pollinators so that they will have difficulty in localizing the flowers among the leaf mass (van der Blom, 2010).

Bumblebees [*Bombus terrestris* (Linnaeus)] are important pollinators of angiosperms. The pollination of tomato flowers requires the agitation of flower anther cones to enable an efficient pollination, and bumblebees are widely used in tomato greenhouses (Kevan, Straver, Offer, & Laverty, 1991). Studies carried out under laboratory conditions have shown that bumblebees perceive when ultraviolet radiation is either removed or added to an illumination source, and are capable of using their visual system to forage efficiently in a UV-deficient environment. Thus, their forage efficiency is not affected by the type of greenhouse covering (Dyer & Chittka, 2004). A delay in the hive start up of the bumblebee *B. terrestris* (Bio-Bee, Ltd., Israel) was observed in experimental mini greenhouses covered with UV-blocking films (Steinberg et al., 1997; van der Blom, 2010). Later, this

problem was solved by placing the hives near the greenhouse walls, where they were exposed to unfiltered light (Y. Antignus, unpublished). In a field study, no significant differences were found in bumblebee activity or in the numbers of flowers visited, under standard or UV-blocking films (Fig. 1.7) (Antignus & Ben-Yakir, 2004). Studies in commercial tomato greenhouses have demonstrated that biomass and size of hives were not significantly affected, whether the greenhouses were covered with standard or UV-blocking films (Antignus & Ben-Yakir, 2004; Hefez, Izikovitch, & Dag, 1999; Seker, 1999). No differences were found in the numbers of workers that foraged nor in the final harvest in field trials where the pollination activity of bumblebees, under UV-absorbing and -ordinary films, was compared in both tomato and watermelon crops (van der Blom, 2010). Contrary to the bumblebees, honeybees did show significant behavioral changes under the UV-blocking plastic. Two trials were carried out in watermelon, and one in melon using honey bees for pollination. In all three cases, a reduced foraging activity was observed under the UV-blocking material, resulting in a significantly lower fruit yield. This reduction was seen in the number of workers leaving and entering the hive, so it seems to be the result of deficient general light conditions, more than of the difficulty to localize the flowers once foraging (van der Blom, 2010).

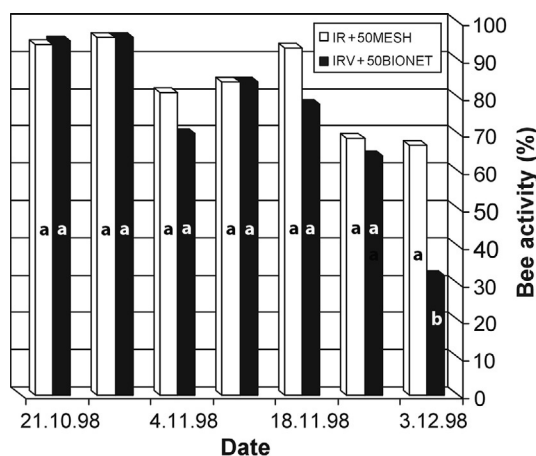


Figure 1.7 Bumblebee (*Bombus terrestris*) pollination activity in tomatoes grown in a greenhouse with ordinary cladding materials (polyethylene film + 50 mesh screen) versus a greenhouse covered with UV-absorbing cladding materials (polyethylene film + 50 mesh “Bionet” screen). Pollination activity is expressed as percentage of visited flowers identified by typical brown ring on the flower stamens cone.

In Canada, bumblebees' activity was 94% greater under standard films than under UV-blocking films (expressed as the number of entrances and exits to and from the hive). No relationship was found there between bumblebees' activity and the amount of solar radiation or the humidity in the greenhouse (Morandin, Laverty, Kevan, Khosla, & Shipp, 2001). The differences between the results from Canada and Israel may be explained by the differences in sun light intensities and temperatures between these two locations. A positive correlation exists between the rate of bumblebees' activity and temperature. Higher temperatures (in the range 5–25 °C) may compensate for the inhibitory effect of reduced UV radiation (Morandin et al., 2001; Morandin, Laverty, Kevan, Khosla, & Shipp, 2002). Areas within the greenhouse that have relatively high levels of UV radiation (normally the southern wall side) were found as optimal sites for placing bumblebees' hives in greenhouses covered with UV-blocking films (Y. Antignus, unpublished).

3.6. Effect of UV filtration on insect natural enemies

The effect of UV-absorbing plastic sheets on the host location ability of three commercially available parasitoids—*Aphidius colemani* (Viereck), *Diglyphus isaea* (Walker), and *Eretmocerus mundus* (Mercet)—was tested in the laboratory as well as in field trials. The parasitoids preference for natural versus UV-filtered light was tested under laboratory conditions using Y-tube system. Approximately 90% of the tested insects, regardless of species, chose natural light. The parasitoid's ability to locate a host-infested plant from a distance (~10 m) was also tested in field trials (Chiel, Messika, Steinberg, & Antignus, 2006). Host location by *A. colemani* (Fig. 1.8) and *D. isaea* as monitored by parasitism rates was not affected by greenhouse covering plastic type whether standard or UV-absorbing plastic was used. *E. mundus*, on the other hand, was unable to locate the host-infested plant when the latter was placed in the center of the UV-absorbing plastic covered greenhouses. Also, parasitism rates were lower under UV-absorbing plastic than under regular plastic when the host-infested plants were located in the corners of the greenhouse and the wasps were released in the center. It was therefore recommended that the number of release points must be increased to facilitate host location when releasing *E. mundus* in greenhouses covered with UV-absorbing plastic, whereas no modification was necessary for *D. isaea* and *A. colemani* (Chiel et al., 2006). Kajita (1986) found that parasitism of whiteflies by *Encarsia formosa* (Gahan) was similar under both standard and UV-blocking films. In choice experiments, significantly more

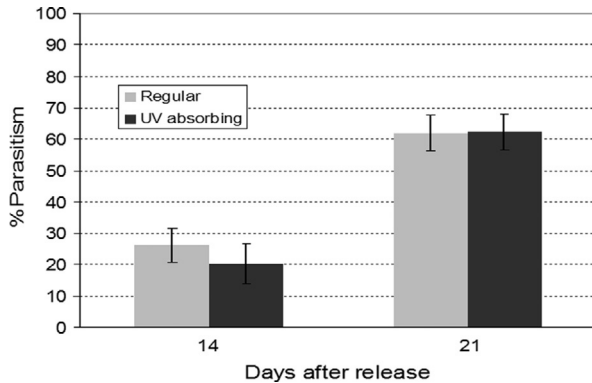


Figure 1.8 Parasitism level of the green peach aphid (*Myzus persicae*) by *Aphidius col-emani* in greenhouses covered with regular cladding materials (plastic film roof and 50 mesh wall screens) or with UV-absorbing cladding materials (plastic film roof and 50 mesh Bionet® screened walls). Parasitoids were released in the center or at the greenhouse perimeter.

(two to three times) *E. formosa* individuals were trapped under standard rather than under UV-blocking films. It seemed that the parasitoids—like their hosts—oriented more toward an environment with high UV radiation. However, when they had no other choice, they performed well in a UV-deficient environment (Doukas & Payne, 2007c). Results from experiments carried out in cages covered with UV-absorbing nets showed that visual cues in *Orius laevigatus* (Fieber) (Hemiptera: Anthocoridae) may be disturbed under UV-absorbing covers, inducing a reduction in dispersal. UV-deficient environments formed under photoselective screens seem to be attractive for *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) (Legarrea, Weintraub, et al., 2012). It was suggested that the predatory mite attempts to avoid UV-B radiation that may reduce survival, egg laying, and hatching, as has been found for other predatory mite species (Onzo, Sabelis, & Hanna, 2010).

3.7. Effect of UV-absorbing screens on the immigration of insect pests into greenhouses

Fifty-mesh screens installed as greenhouse walls were implemented in Israeli greenhouses as a protection mean against the spread of the whitefly-borne TYLCV (Berlinger et al., 1991; Cohen & Berlinger, 1986). However, these dense screens prevent adequate ventilation, especially during summer when temperatures are high. The negative effect of the resulting heat stress can be

decreased, however, by using different types of cooling systems. The protection efficiency of 50 mesh screens was dramatically increased by introduction of a UV-absorbing additive into the polyethylene used for the production of the screens. The first UV-absorbing screens (BioNet[®]) were developed and reported by Antignus et al. (1998). These screens are characterized by a double insect-exclusion mechanism based on both their physical and optical properties. When compared to ordinary 50 mesh screens, the UV-absorbing screens reduced whitefly penetration and spread of TYLCV by a factor of 4 (Antignus et al., 1998). The “Bionets” were significantly more effective than the conventional 50-mesh screens in protecting tomato from infestation with *B. tabaci*, red spider mites, and leafminers [*Lyriomyza trifolii* (Burgess)]. “Bionets” also protected cucumbers against aphids (*A. gossypii*) (Antignus et al., 1998) and leafhoppers (Weintraub, Pivonia, & Gera, 2008). However, 50-mesh “Bionet” screens failed to prevent the ingress and build up of *F. occidentalis* in the protected structures and these results were later confirmed by others (Ben-Yakir, Hadar, Offir, Chen, & Tregerman, 2008; Diaz & Fereres, 2007; Legarrea, Betancourtb, et al., 2012; Legarrea, Diaz, Morales, Vinuela, & Fereres, 2008; Legarrea et al., 2010; Legarrea, Weintraub, et al., 2012; Weintraub et al., 2008). However, later, a different brand of photoselective screens designated OptiNet[®] were developed which were also able to protect against thrips. Forty and fifty mesh OptiNet[®] screens reduced thrips infestations on cucumber, tomato, and chive plants by three- to fourfolds compared with standard 50 mesh screen (Ben-Yakir et al., 2008).

3.8. Mode of action of UV-absorbing greenhouse cladding materials

A putative twofold mechanism is suggested to explain the defense impact of UV filtration on the immigration and spread of insect pests and virus diseases in greenhouses covered with UV-absorbing cladding materials. Initially, insects are excluded from the greenhouse wall due to the lack of UV emission from the inner space of the greenhouse. This effect was well demonstrated by Antignus et al. (2001) and Nguyen et al. (2009) who monitored lower numbers of whiteflies and thrips, respectively, on sticky traps placed on the outer sidewalls of greenhouses covered with UV-absorbing cladding materials. Hypothetically, a “two-compartment effect” is formed by the photoselective cladding materials: the greenhouse ambient environment has a normal level of UV irradiation, thus representing a UV-rich compartment, while a second UV-deficient compartment is formed within the greenhouse due to UV filtration. Insects that approach

the greenhouse wall from the external environment exhibit a positive UV phototactic behavior, and as they lose contact with UV, near the walls of the protected greenhouse, they become diverted toward the UV-rich environment, away from the UV-deficient greenhouse compartment (Antignus, 2010).

While the first step of the defense mechanism is interfering with the primary infestation of the crop, the second step is involved in the secondary spread by altering the insects' normal behavior paradigm. As described in paragraphs 2.1.1, 3.2 and 3.3, the reduced flight activity that was observed in greenhouses covered with UV-absorbing cladding materials is leading to a lower rate of secondary spread of the invading insect and as a consequence insect-vectorized virus diseases are hindered (Antignus, 2010; Antignus et al., 2001; Chyzik et al., 2003; Diaz & Fereres, 2007).



4. STICKY TRAPS FOR MONITORING AND INSECTS MASS TRAPPING

Mound (1962) suggested that *B. tabaci* is attracted by two groups of wavelengths of transmitted light, the blue/ultraviolet, and the yellow parts of the spectrum. He correlated the reaction to ultraviolet to the induction of migratory behavior, whereas yellow radiation induces vegetative behavior, which may be part of the host selection mechanism. The attraction of whiteflies to yellow has been utilized as an important instrument in sampling and monitoring of whiteflies populations (Gerling & Horowitz, 1984; Gonzalez & Rawlin, 1968). Aphid-landing preference is determined by the color of the background, mainly by the degree of contrast between the green plant and the color of the soil (background color) (A'Brook, 1968). When horizontal sticky yellow traps are installed on stands at different heights above ground, their whitefly (*B. tabaci*) trapping efficiency is directly correlated to the distance between the trap plane and soil level. A gradient of number of trapped insects is obtained, with a maximum on traps that are placed directly on soil providing the highest contrast between the yellow plate and the soil background (Fig. 1.9). However, when the yellow-sticky cards are placed on a large yellow plate which drastically diminish contrast, very few insects are trapped (Fig. 1.9) (Y. Antignus, unpublished).

This vision cue was used by Cohen & Marco (1973) to protect pepper (*C. annuum*, L.) from nonpersistently transmitted aphid-borne viruses in the open field. A "protection belt" consisting of polyethylene sheets, 2–3 m long, hung on stakes 70 cm above ground and covered with transparent glue, was erected around the field 6–7 m beyond the end rows. Disease incidence in the

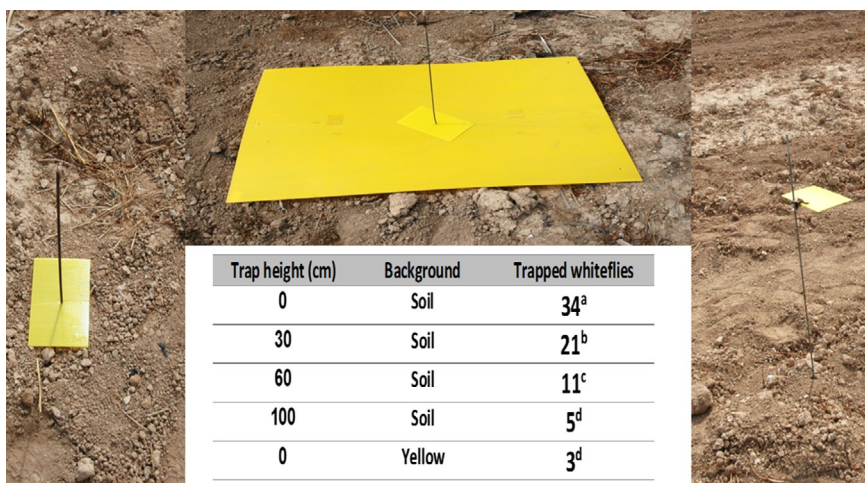


Figure 1.9 The contrast effect on whiteflies (*Bemisia tabaci*) trapping by yellow-sticky cards. The highest trapping efficiency was obtained when traps were placed directly on bare soil. A gradient of numbers of trapped insects was formed according to the distance of the yellow cards' plane from ground level. Lower trapping numbers are correlated with lower levels of contrast between the yellow color and background formed by the brown soil. When the yellow cards were placed over a large yellow "poligal" plate trapping was zero or near zero, indicating again the importance of high contrast between the trap and its background.

protected plots was one-half that in unprotected ones, where the incidence reached 52%. This method was used to protect seed potato crops against the persistently transmitted *Potato leafroll virus* (PLRV) (Zimmerman-Gries, 1979). However, such success cannot be assumed for other systems as there have been failures using this practice (Harpaz, 1982; Raccach, 1986). A predominance of olfactory and gustatory cues over those of vision may explain some of the failures. Mass trapping of insects in greenhouses by yellow-sticky cards was reported by Van de Veire & Vacante (1984). Vertical sticky traps consisting of blue and yellow plastic strips (Poly-traps) are used routinely in Israeli greenhouses and they are positioned around the lower part of the inner walls of greenhouses to trap invading insects.



5. SOIL MULCHES

Mulching consists of spreading a thin plastic film directly over the ground. Mulching films usually have a thickness between 12 and 80 mm and a

width of up to 3 m. Usually, they are designed for a lifetime of 2–4 months. In order to avoid the expense of collection after use, they are sometimes photo- or biodegradable. The insulating effect of the mulching film helps to maintain or increase temperature and humidity of the ground, minimizing the seed time and enhancing crop growth. Mulching also helps to maintain the structure of the ground, avoiding the erosion and improving the management of water, an important issue in areas with limited water resources. Mulching films can be transparent or pigmented: black films minimize the growth of weeds, reducing the use of agrochemicals; aluminized or white films increase the reflection of light toward the low parts of the plants. Light reflection affects plant physiology as well as attracts or repels certain insects (Espí et al., 2006). The use of soil mulch to protect tomato plants from infestation by whiteflies was reported by Avidov (1956), who used sawdust or whitewash spray to mulch the crop seedbeds. Similar results were obtained from straw mulches that not only markedly reduced whitefly population but also delayed the spread of *Cucumber vein yellowing virus* and TYLCV both vectored by *B. tabaci* (Cohen, 1982). Later on, Cohen and Melamed-Madjar (1978) tested yellow, aluminum, and blue polyethylene film, demonstrating the high efficiency of the yellow polyethylene in delaying infection of tomatoes by TYLCV. Loebenstein, Alper, Levy, and Menagem (1975) found that aluminum foil was highly efficient in protecting pepper crops from aphid-transmitted viruses such as CMV and PVY. Corn plants grown in early spring on transparent polyethylene mulch to obtain an early yield were highly protected from *Maize dwarf mosaic virus* due to repelling effect of the reflected light on winged aphids that vector the virus (Y. Antignus, unpublished). Transparent polyethylene mulches reduced both whitefly and aphid populations and virus incidence (Orozco-Santos, Perez-Zamora, & Lopez-Arriaga, 1995). Similar protective effects against whiteflies, aphids, and their vectored viruses were reported later by others (Csizinszky, Schuster, & Kring, 1995; Summers, Mitchell, & Stapleton, 2005; Suwwan, Akkawi, Al-Musa, & Mansour, 1988). Yellow and silver polyethylene mulches efficiently protected zucchini plants from the spread of the whitefly-borne Squash leaf curl virus (SLCV). A delay in SLCV spread was observed 2 weeks after planting, when disease incidence was 10–20% in plants grown over yellow or silver mulches, respectively, compared with 50% disease incidence in the unmulched plots (Fig. 1.10). The landing rate of whiteflies on plants grown over silver and yellow soil mulches was five- to sevenfolds lower than that on plants grown over bare soil (Antignus, 2012; Antignus, Lachman, et al., 2004).

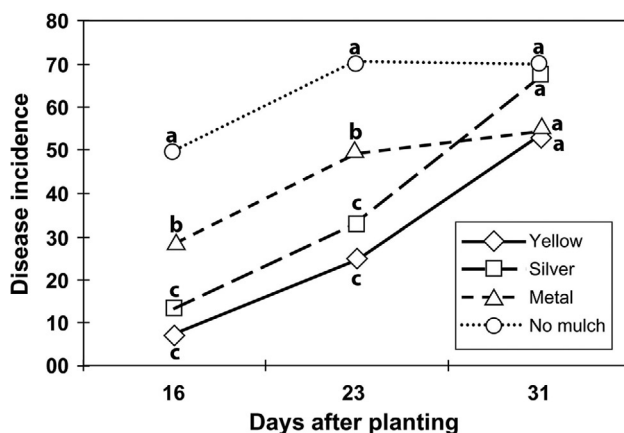


Figure 1.10 Delay in the spread of *Squash leaf curl geminivirus* (SLCV) infection in zucchini crops grown on different polyethylene mulches. A disease incidence of 70% was found 20 days after planting when plants grew on bare soil, while 25%, 32%, and 50% disease incidence was recorded in zucchini plots grown on yellow, silver gray, and metal polyethylene mulching films, respectively. SLCV disease delay by reflective mulches resulted in a double increase of high-grade fruit.

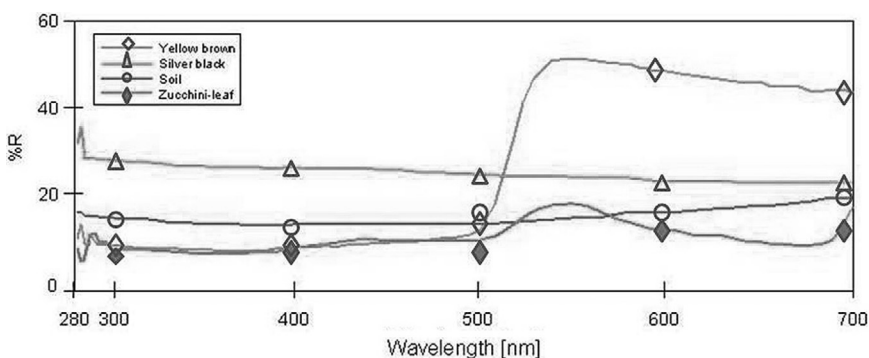


Figure 1.11 Spectrophotometric analysis of light reflection ($R\%$) from colored polyethylene films, soil surface, and leaf surface. A reflection peak at 540 nm (50 $R\%$) measured from yellow mulching polyethylene film (Ginegar Plastic, Israel) (\diamond). A constant reflection level at 30 $R\%$ at both the UV and visible light ranges measured from silver black mulching polyethylene film (Ginegar Plastic, Israel) (∇). A constant reflection level at ca.18 $R\%$ at both the UV and visible light ranges measured from bare soil (\circ). A reflection peak at 540 nm (19 $R\%$) measured from zucchini leaf (\blacklozenge). The contrast between the plant canopy and soil is highest when plants are grown on bare soil. Plant image is less visible for landing insects when plants are grown on highly reflective yellow or silver black mulches blurring the plant image.

Spectrophotometric analysis of light reflection from yellow and silver polyethylene mulches, soil surfaces, and plant canopy (Fig. 1.11) has demonstrated a relatively high level of light reflection from the plastic mulches in the range of 300–700 nm, compared with low levels of light reflection from bare soil. The plant foliage had a distinct reflection peak at 550 nm, considerably higher than that of the reflection from the bare soil. Under these circumstances, the contrast between the soil background and the plant canopy was maximal, enabling insects to detect the crop for landing. On the other hand, when the background of the plant was formed by yellow or silver mulches, the amount of reflected light in the visible range was considerably higher than the reflection of the soil and plant canopy. The poor contrast resulting from the reflection of the plastic interfered with the ability of the insect to detect the plant image and perceive a landing signal (Antignus, 2012; Antignus et al., 2005).



6. REFLECTIVE AND COLORED SHADING NETS

Cohen (1981) used white coarse nets to get a highly efficient protection of pepper crops from aphids and their vectored viruses: CMV and PVY. Recently, photoselective shade nettings were designed to screen various light spectral components of the solar radiation and/or transform direct light into diffused light. These spectral manipulations are utilized to promote desired physiological responses in ornamental plants, vegetables, and fruit trees. Thus, growing vegetables, fruits, and ornamental crops under certain colored shading nets can increase their yields and improve their quality (Shahak, Gal, Offir, & Ben-Yakir, 2008; Shahak et al., 2009).

Although shading nets permit free passage of small size pests, the infestation levels of aphids and whiteflies in “walk-in” tunnels covered by either the yellow or pearl nets were consistently two- to threefolds lower than in tunnels covered by the black or red nets. The reduced level of insect infestation resulted in 2- to 10-folds lower infection rates of pepper plants by CMV under yellow or pearl nets compared to disease incidence under black or red nets, where infection level ranged between 35% and 89%. Similarly, the incidence of necrotic PVY in tomato grown under black or red nets ranged between 42% and 50%, two- to threefolds higher than under the yellow or pearl nets. Yellow or pearl nets also provided efficient protection against the whitefly-borne, TYLCV in tomato. Disease incidence under these nets was two- to fourfolds lower compared to tomato plants grown under the black or red nets

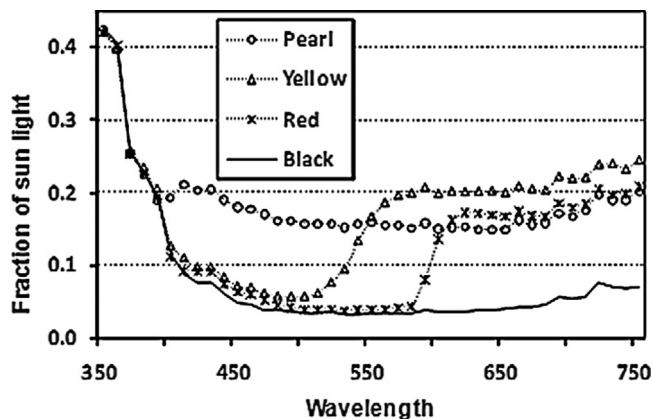


Figure 1.12 Sunlight reflectance profile from colored 35% shading nets in the UV and visible ranges.

where disease incidence ranged between 15% and 50% (Antignus et al., 2009; Ben-Yakir, Antignus, Offir, & Shahak, 2012; Shahak et al., 2008).

Apparently, the protection mechanism of shading nets is associated with insect repellence by the intensive light reflection from the nets. Indeed, spectral analysis of the reflection profiles of the different nets showed clearly the high light reflection by the yellow and pearl nets, in the visible range of the spectrum, compared to the low reflection characteristics the ordinary black net and the red one (Fig. 1.12) (Ben-Yakir et al., 2012). The protection against nonpersistent viruses (PVY and CMV) is probably a result of both the deterring effect on invading aphids due to light reflection and the mechanical effect formed by the nets in delaying aphid landing on the crop beyond the relatively short retention time of these viruses.



7. REFLECTIVE FILMS FORMED BY WHITEWASHES

Whitewash spray has been shown to be effective in preventing the colonization of plants by aphids (Bar Joseph & Frenkel, 1983) and preventing vector-borne virus and spiroplasma diseases (Yokomi, Bar-Joseph, Oldfield, & Gumpf, 1981). Marco (1986) showed that weekly sprays with 15% whitewashes of Loven and Yalbin reduced the number of landing aphids on field grown potatoes by 30–50%. PLRV and PVY incidence in tubers harvested from whitewashed plants was 0–61% and 0–68% lower, respectively, compared to untreated plots. However, whitewashes reduced the tuber yield by about 30%.

Kaolin particle film technology has been proposed as a new measure against several arthropod and disease pests (Glenn, Puterka, van der Zwet, Byers, & Feldhake, 1999). Hydrophilic processed kaolin, composed mainly of kaolinite ($\text{Al}_2 [(\text{OH})_2, \text{Si}_2\text{O}_5]$), was developed as a commercial product named “surround WP” crop protectant (Engelhard Corporation, Iselin, NJ, USA). It was approved by the US Food and Drug Administration (FDA) as a human food additive. “Surround WP” was registered by the US Environmental Protection Agency (EPA) in 2000. Additionally, the Organic Materials Review Institute (OMRI) in the United States has listed it for use in organic production. This processed kaolin is a nonabrasive, non-toxic sprayable particle barrier which effectively controlled psyllid *Cacopsylla pyricola* (Foerster) on pear; *Diaphorina citri* (Kuwayama) on citrus (Hall, Lapointe, & Wenninger, 2007; Puterka, Glenn, & Pluta, 2005); codling moth *Cydia pomonella* (L.) on pear (Unruh, Knight, Upton, Glenn, & Puterka, 2000); the oblique banded leafroller moth *Choristoneura roseana* (Knight, Unruh, Christianson, Puterka, & Glenn, 2000) Mediterranean fruit fly *Ceratitidis capitata* (Wiedemann) on apple (Mazor & Erez, 2004); thrip *T. tabaci* (Lindeman) on onions (Larentzaki, Shelton, & Plate, 2008); aphids *M. persicae* on peach (Karagounis, Kourdoumbalos, Margaritopoulos, Nanos, & Tsitsipis, 2006); and the spirea aphid *Aphis citricola* (van der Goot) (Bar Joseph & Frenkel, 1983). Kaolin has also horticultural benefits of reducing sunburns and heat stress in fruit trees (Glenn, Prado, Erez, McFerson, & Puterka, 2002). Kaoline film also affects some biological characteristics of the insect, as oviposition rate of *T. tabaci* and hatch rate in onions were significantly reduced on kaolin-treated plants. The time required for development of larval stages was significantly increased, and mortality was significantly higher on kaolin than on water-treated onion leaves. Feeding choice was influenced by the presence of the kaolin treatment and in choice assays both larvae and adults fed significantly less on kaolin-treated than on water-treated leaves. In a field study, significantly more adults were captured in the beginning of the season on control than on kaolin-treated plots, and at population peaks, significantly more larvae and adults were harbored in control plots (Larentzaki et al., 2008).

The mode of action of whitewashes can be explained by the increased light reflectance from the leaf surface, 130–250% higher for leaves sprayed by Loven and Yalbin whitewashes (Marco, 1986). Interestingly, different aphids responded differently to the whitewashes treatment. *A. citricola* (van der Goot) was repelled to a greater extent compared to other aphid species, while *A. gossypii* was attracted to treated leaves (Marco, 1986). Another

mechanism that may work in insect repellency by whitewashes is the contact between the insect and the whitewash particles that are present on the leaf surface. The whitewash film or powder may irritate the sensilla located at the insects' tarsus and induce a takeoff response from the treated plant canopy (Glenn et al., 1999). The use of whitewashes is relevant only to dry climates where the whitewash film is not washed off by frequent rains.



8. PROSPECTS AND OUTLOOKS

This review summarized the research and international efforts to develop and implement alternatives for chemical control of insect pests and virus diseases. The array of optical barriers described are based on insects ability to perceive light signals that drastically affect their flight orientation and landing as well as their interaction with the host plants in terms of feeding and propagation rates. Light plays also a central role in the metabolism, physiology, and development of plants. A comprehensive study is required to shed light on how different parts of the solar light spectrum affect the physiology of plants and insects and how it affects their interaction. More research should be directed to understand how light manipulation is affecting the ecology of other organisms that occupy the crop habitat. A better understanding of these parameters may help to design light filters and reflectors to manipulate light signals in order to improve crop yields and better environmental friendly, plant protection technologies.

REFERENCES

- A'Brook, J. (1968). The effect of plant spacing on the numbers of aphids trapped over the groundnut crop. *Annals of Applied Biology*, 61, 289–294.
- Adamse, P., Reed, H. E., Krizek, D. T., Britz, S. J., & Mirecki, R. M. (1997). An inexpensive setup for assessing the impact of ambient solar ultraviolet radiation on seedlings. *Journal of Natural Resources and Life Science Education*, 26, 139–144.
- Antignus, Y. (2010). Optical manipulations block the spread of *Bemisia tabaci* in greenhouses and the open field. In P. A. Stansly, & S. E. Naranjo (Eds.), *Bemisia: Bionomics and management of a global pest* (pp. 349–356). Dordrecht Heidelberg London New York: Springer Science+Business Media BV.
- Antignus, Y. (2012). Control methods of virus diseases in the Mediterranean Basin. In G. Loebenstein, & H. Lecoq (Eds.), *Advances in virus research. Viruses and virus diseases of vegetables in the Mediterranean Basin* (pp. 349–356). Oxford, UK: Elsevier.
- Antignus, Y., & Ben-Yakir, D. (2004). Greenhouse photosensitive cladding materials serve as an IPM tool to control the spread of insect pests and their vectored viruses. In R. Horowitz, & Y. Ishaya (Eds.), *Insect pest management* (pp. 319–335). Berlin: Springer.

- Antignus, Y., Ben-Yakir, D., Offir, Y., Messika, Y., Dombrovsky, A., Chen, M., et al. (2009). Colored shade nets form optical barrier protecting pepper and tomato crops against aphid-borne non-persistent viruses. *Sade Va'Yerek*, 12, 60–62 (in Hebrew).
- Antignus, Y., Lachman, O., Leshem, Y., Matan, E., Yehezkel, H., & Messika, Y. (1999). Protection efficiency of UV-absorbing films in greenhouses with vertical walls. In O. Zeidan (Ed.), *Bulletin of the Israeli extension service. Summary of research projects and field experiments in tomato crops for 1999* (pp. 29–39). Bet Dagan: Israeli Ministry of Agriculture.
- Antignus, Y., Lachman, O., Pearlsman, M., Koren, A., Matan, E., Tregerman, M., et al. (2004). Development of an IPM system to reduce the damage of squash leaf curl begomovirus in zucchini squash crops. (Abstract), *Compendium, 2nd European Whitefly Symposium*, Cavtat, Croatia.
- Antignus, Y., Lapidot, M., Hadar, D., Messika, Y., & Cohen, S. (1998). UV absorbing screens serve as optical barriers to protect vegetable crops from virus diseases and insect pests. *Journal of Economic Entomology*, 91, 1401–1405.
- Antignus, Y., Mor, N., Ben Joseph, R., Lapidot, M., & Cohen, S. (1996). Ultraviolet-absorbing plastic sheets protect crops from insect pests and from virus diseases vectored by insects. *Environmental Entomology*, 25, 919–924.
- Antignus, Y., Nestel, D., Cohen, S., & Lapidot, M. (2001). Ultraviolet-deficient greenhouse environment affects whitefly attraction and flight behavior. *Environmental Entomology*, 30, 394–399.
- Antignus, Y., Lachman, O., & Pearlsman, M. (2005). Light manipulation by soil mulches protect crops from the spread of Begomoviruses. In *Abstracts of the IX International Plant virus Epidemiology Symposium*. Lima: Peru.
- Avidov, Z. (1956). Bionomics of the tobacco whitefly (*Bemisia tabaci* Gennad.) in Israel. *Ktavim*, 7, 25–41.
- Bar Joseph, M., & Frenkel, H. (1983). Spraying citrus plants with kaoline suspensions reduces colonization by the Spirea aphid (*Aphis citricola* van der Goot). *Crop Protection*, 2, 371–374.
- Ben-Yakir, D., Antignus, Y., Offir, Y., & Shahak, Y. (2012). Colored shading nets impede insect invasion and decrease the incidences of insect-transmitted viral diseases in vegetable crops. *Entomologia Experimentalis et Applicata*, 144, 249–257.
- Ben-Yakir, D., Hadar, M. D., Offir, Y., Chen, M., & Tregerman, M. (2008). Protecting crops from pests using OptiNet[®] and ChromatiNet[®] shading nets. *Acta Horticulturae*, 770, 205–212.
- Berlinger, M. J., Dahan, R., Mordechi, S., Liper, A., Katz, J., & Levav, N. (1991). The use of nets to prevent the penetration of *Bemisia tabaci* into greenhouse. *Hassadeh*, 71, 1579–1583 (in Hebrew).
- Borst, A. (2009). *Drosophila's view*. *Insect Vision Current Biology*, 19, 36–47. <http://dx.doi.org/10.1016/j.cub.2008.11.001>, Elsevier Ltd All rights reserved.
- Chiel, E., Messika, Y., Steinberg, S., & Antignus, Y. (2006). The effect of UV-absorbing plastic sheet on the attraction and host location ability of three parasitoids: *Aphidius colmani*, *Diglyphus isaea* and *Eretmocerus mundus*. *Biocontrol*, 51, 65–78.
- Chyzik, R., Dobrinin, S., & Antignus, Y. (2003). Effect of a UV-deficient environment on the biology and flight activity of *Myzus persicae* and its hymenopterous parasite *Aphidius matricariae*. *Phytoparasitica*, 31, 467–477.
- Cohen, S. (1981). Reducing the spread of aphid transmitted viruses in peppers by coarse-net cover. *Phytoparasitica*, 9, 69–76.
- Cohen, S. (1982). Control of whitefly vectors of viruses by color mulches. In K. F. Harris, & K. Maramorosch (Eds.), *Pathogens, vectors and plant diseases, approaches to control* (pp. 45–56). New York: Academic Press.
- Cohen, S., & Berlinger, M. J. (1986). Transmission and cultural control of whitefly-borne viruses. *Agriculture and Ecosystem Environment*, 17, 89–97.

- Cohen, S., & Marco, S. (1973). Reducing the spread of aphid transmitted viruses in pepper by trapping the aphids on sticky yellow polyethylene sheets. *Phytopathology*, 63, 1207–1209.
- Cohen, S., & Melamed-Madjar, V. (1978). Prevention by soil mulching of the spread of tomato yellow leaf curl virus transmitted by *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae). *The Israeli Bulletin of Entomological Research*, 68, 465–470.
- Coombe, P. E. (1981). Wave length specific behaviour of the whitefly *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). *Journal of Comparative Physiology*, 144, 83–90.
- Coombe, P. E. (1982). Visual behavior of the greenhouse whitefly, *Trialeurodes vaporariorum*. *Physiological Entomology*, 7, 243–251.
- Costa, H. S., Newman, J., & Robb, K. L. (2003). Ultraviolet blocking greenhouse plastic films for management of insect pest. *HortScience*, 38, 465.
- Costa, H. S., & Robb, K. (1999). Effects of ultraviolet-absorbing greenhouse plastic films on flight behavior of *Bemisia argentifolii* (Homoptera: Aleyrodidae) and *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Journal of Economic Entomology*, 92, 557–562.
- Costa, H. S., Robb, K. L., & Wilen, C. A. (2002). Field trials measuring the effects of ultraviolet-absorbing greenhouse plastic films on insect populations. *Journal of Economic Entomology*, 95, 113–120.
- Csizinszky, A. A., Schuster, D. J., & Kring, J. B. (1995). Color mulches influence yield and insect pest populations in tomatoes. *Journal of the American Society of Horticultural Science*, 120, 778–784.
- Cybulski, W. J. I., & Peterjohn, W. T. (1999). Effects of ambient UV-B radiation on the above-ground biomass of seven temperate-zone plant species. *Plant Ecology*, 145, 175–181.
- Diaz, B. M., Biurrun, R., Moreno, A., Nebreda, M., & Fereres, A. (2006). Impact of ultraviolet-blocking plastic films on insect vectors of virus diseases infecting crisp lettuce. *HortScience*, 41, 711–716.
- Diaz, B. M., & Fereres, A. (2007). Ultraviolet-blocking materials as a physical barrier to control insect pests and plant pathogens in protected crops. *Pest Technology*, 1, 85–95.
- Doring, T. F., & Chittka, L. (2007). Visual ecology of aphids—A critical review on the role of colors in host finding. *Arthropod-Plant Interactions*, 1, 3–16.
- Doukas, D. (2002). Impact of spectral cladding materials on the behavior of glasshouse whitefly *Trialeurodes vaporariorum* and *Encarsia formosa*, its Hymenopteran parasitoid. In *British crop protection conference, pests and diseases 2002, Brighton* (pp. 773–776).
- Doukas, D., & Payne, C. C. (2007a). The use of ultraviolet blocking films in insect pest management in the UK; effect of naturally occurring arthropod pest and natural enemy populations in a protected cucumber crop. *Annals of Applied Biology*, 151, 221–231.
- Doukas, D., & Payne, C. C. (2007b). Greenhouse whitefly (Homoptera: Aleyrodidae) dispersal under different UV environments. *Journal of Economic Entomology*, 100, 389–397.
- Doukas, D., & Payne, C. C. (2007c). Effects of UV-blocking films on the dispersal behavior of *Encarsia formosa* (Hymenoptera: Aphelinidae). *Journal of Economic Entomology*, 100, 110.
- Dyer, A. G., & Chittka, L. (2004). Bumblebee search time without ultraviolet light. *Journal of Experimental Biology*, 207, 1683–1688.
- Edser, C. (2002). Light manipulation additives extend opportunities for agricultural plastic films. *Plastic Additive Compounds*, 4, 20–24.
- Espí, E., Salmerón, A., Fontecha, A., García, Y., & Real, A. I. (2006). Plastic films for agricultural applications. *Journal of Plastic Film and Sheeting*, 22, 85–101.
- Fiscus, E. L., Philbeck, R., & Britt, A. B. (1999). Growth of *Arabidopsis* flavonoid mutants under solar radiation and UV filters. *Environmental and Experimental Botany*, 41, 231–245.
- Fukushi, T. (1990). Colour discrimination from various shades of grey in the trained blowfly, *Lucilia cuprina*. *Journal of Insect Physiology*, 36, 69–75.

- Gerling, D., & Horowitz, A. R. (1984). Yellow traps for evaluating the population levels and dispersal patterns of *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae). *Annual Meeting of the Entomological Society of America*, 77, 753–759.
- Glenn, D. M., Prado, E., Erez, A., McFerson, J., & Puterka, G. J. (2002). A reflective, processed-kaolin particle film affects fruit temperature, radiation reflection, and solar injury in apple. *Journal of the American Society of Horticultural Science*, 127, 188–193.
- Glenn, D. M., Puterka, F., van der Zwet, J. T., Byers, R. E., & Feldhake, C. (1999). Hydrophobic particle films: A new paradigm for suppression of arthropod pests and plant diseases. *Journal of Economic Entomology*, 92, 759–771.
- Gonzales, A., Rodriguez, R., Bafion, S., Franco, J., & Fernandez, J. A. (2001). The influence of photosensitive plastic films as a greenhouse cover on sweet pepper yield and on insect pest levels. *Acta Horticulturae*, 559, 233–238.
- Gonzalez, D., & Rawlin, W. A. (1968). Aphid sampling efficiency of Moericke traps affected by height and background. *Journal of Economic Entomology*, 61, 109–114.
- Hall, D. G., Lapointe, S. L., & Wenninger, E. J. (2007). Effects of a particle film on biology and behavior of *Diaphorina citri* (Hemiptera: Psyllidae) and its infestations in citrus. *Journal of Economic Entomology*, 100, 847–854.
- Harpaz, I. (1982). Non-pesticidal control of vector-borne viruses. In K. F. Harris, & K. Maramorosch (Eds.), *Pathogens, vectors, and plant diseases: Approaches to control* (pp. 1–21). New York: Academic Press.
- Hefez, A., Izikovitch, D., & Dag, A. (1999). Effects of UV-absorbing films on the activity of pollinators (honey bees and bumble bees). *A report to the chief scientist. Israeli Ministry of Agriculture*, Bet-Dagan ID code 891-0117-96.
- Heinze, S., & Homberg, U. (2007). Map like representation of celestial E-vector orientations in the brain of an insect. *Science*, 315, 995–997.
- Hunt, D. M., Wilkie, S. E., Bowmaker, J. K., & Poopalasundaram, S. (2001). Vision in the ultraviolet. *Cellular and Molecular Life Sciences*, 58, 1583–1598.
- Issacs, R., Willis, M. A., & Byrne, D. N. (1999). Modulation of whitefly take-off and flight orientation by wind speed and visual cues. *Physiological Entomology*, 28, 311–318.
- Kajita, H. (1986). Parasitism of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) by *Encarsia Formosa* (Hymenoptera: Aphelinidae) in a greenhouse covered with near-ultraviolet absorbing vinyl film. *Proceedings of Plant Protection, Kyushu*, 32, 155–157 (in Japanese).
- Karagounis, C., Kourdoumbalos, A. K., Margaritopoulos, J. T., Nanos, G. D., & Tsitsipis, J. A. (2006). Organic farming-compatible insecticides against the aphid *Myzus persicae* (Sulzer) in peach orchards. *Journal of Applied Entomology*, 130, 150–154.
- Kevan, P. G., Straver, W. A., Offer, O., & Laverty, T. M. (1991). Pollination of greenhouse tomatoes by bumblebees in Ontario. *Proceedings of the Entomological Society of Ontario*, 122, 15–19.
- Kigathi, R. (2005). Effect of UV absorbing greenhouse covering materials and UV reflecting mulches on the immigration and dispersal of Western flower thrips. *IPP Int. Msc*, 18.
- Kigathi, R., & Poehling, H. M. (2012). UV-absorbing films and nets affect the dispersal of western thrips, *Frankliniella occidentalis*. *Journal of Applied Entomology*, 136, 761–771.
- Kittas, C., Tchamitchian, M., Katsoulas, N., Karaïskou, P., & Papaïoannou, C. H. (2006). Effect of two UV-absorbing greenhouse-covering films on growth and yield of an egg-plant soilless crop. *Scientia Horticulturae*, 110, 30–37.
- Klatt, B. K., Holzschuh, A., Westphal, C., Clough, Y., Smit, I., Pawelzik, E., et al. (2014). Bee pollination improves crop quality, shelf life and commercial value. *Proceedings of the Royal Society*, 281, 2013–2440. <http://dx.doi.org/10.1098/rspb.2013.2440>.
- Knight, A. L., Unruh, T. R., Christianson, B. A., Puterka, G. J., & Glenn, D. M. (2000). Effects of a kaolin-based particle film on oblique banded leafroller (Lepidoptera: Tortricidae). *Journal of Economic Entomology*, 93, 744–749.

- Kring, J. B. (1972). Flight behavior of aphids. *Annual Review of Entomology*, 17, 461–492.
- Krizek, D. T., Britz, S. J., & Mirecki, R. M. (1998). Inhibitory effects of ambient levels of solar UV-A and UV-B radiation on growth of cv. New red fire lettuce. *Plant Physiology*, 103, 1–7.
- Krizek, D. T., Mirecki, R. M., & Britz, S. J. (1997). Inhibitory effects of ambient levels of solar UV-A and UV-B radiation on growth of cucumber. *Plant Physiology*, 100, 886–893.
- Kumar, P., & Poehling, H. M. (2006). UV-blocking plastic films and nets influence vectors and virus transmission on greenhouse tomatoes in the humid tropics. *Environmental Entomology*, 35, 1069–1082.
- Larentzaki, E., Shelton, A. M., & Plate, J. (2008). Effect of kaolin particle film on *Thrips tabaci* (Thysanoptera: Thripidae), oviposition, feeding and development on onions: A lab and field case study. *Crop Protection*, 27, 727–734.
- Legarra, S., Betancourt, M., Plaza, M., Fraile, A., García-Arena, F., & Fereres, A. (2012). Dynamics of nonpersistent aphid-borne viruses in lettuce crops covered with UV-absorbing nets. *Virus Research*, 165, 1–8.
- Legarra, S., Diaz, B. M., Morales, I., Vinuela, E., & Fereres, A. (2008). Effect of UV absorbing nets in the spread and population growth of the potato aphid. *HortScience*, 43, 1249.
- Legarra, S., Karnieli, A., Fereres, A., & Weintraub, P. G. (2010). Comparison of UV absorbing nets in pepper crops: Spectral properties, effects on plants and pest control. *Photochemistry & Photobiology*, 86, 324–330.
- Legarra, S., Weintraub, P. G., Plaza, M., Viñuela, E., & Fereres, A. (2012). Dispersal of aphids, whiteflies and their natural enemies under photosensitive nets. *BioControl*, 57, 523–532. <http://dx.doi.org/10.1007/s10526-011-9430-2>.
- Leigh, M. (2004). *Ultraviolet blocking greenhouse polyethylene covers for insect pest crops: May 2003–September 2004*. www.organic.aber.ac.uk/library/UVBlockingpolytunnels.pdf.
- Loebenstein, G., Alper, M., Levy, S., & Menagem, E. (1975). Protecting peppers from aphid-borne viruses with aluminium foil or plastic mulch. *Phytoparasitica*, 3, 43–53.
- Marcel, A. K., Jansen, M. A. K., Gaba, V., & Greenberg, B. M. (1998). Higher plants and UV-B radiation: Balancing damage, repair and acclimation. *Trends in Plant Science*, 3, 131–135.
- Marco, S. (1986). Incidence of aphid transmitted virus infections reduced by whitewashes sprays on plants. *Phytopathology*, 76, 1344–1348.
- Matteson, N., Terry, I., Ascoli, C. A., & Gilbert, C. (1992). Spectral efficiency of the western flower thrips, *Frankliniella occidentalis*. *Journal of Insect Physiology*, 38, 453–459.
- Mazokhin-Porshnykov, G. A. (1969). Structure of faceted eyes and visual centers. In T. H. Goldsmith (Ed.), *Insect vision* (pp. 1–19). New York: Plenum Press.
- Mazor, M., & Erez, A. (2004). Processed kaolin protects fruits from Mediterranean fruit fly infestations. *Crop Protection*, 23, 47–51.
- Mazza, C. A., Izaguirre, M. M., Zavala, J., Scopel, A. L., & Ballaré, C. L. (2002). Insect perception of ambient ultraviolet-B radiation. *Ecological Letters*, 5, 722–726.
- McEnrone, W. D., & Dronka, K. (1966). Color vision in the adult female two-spotted spider mite. *Science*, 154, 782–784.
- Mellor, H. E., Bellingham, J., & Anderson, M. (1997). Spectral efficiency of the glasshouse whitefly *Trialeurodes vaporariorum* and *Encarsia formosa* its Hymenopteran parasitoid. *Entomologia Experimentalis et Applicata*, 83, 11–20.
- Messika, Y., Antignus, Y., Lapidot, M., Ben Yakir, D., Chen, M., & Zimmerman, C. (1999). Effect of UV filtration on the spread of insect pests and spraying regime in green herbs grown in 'walk-in' tunnels. *Gan Sadeh Vameshek*, 53–55 (in Hebrew).
- Messika, Y., Lapidot, M., & Antignus, Y. (1997). The effect of UV-absorbing sheets on the infestation of green spice crops with insect pests. *Hassadeh*, 77, 27–31 (in Hebrew).

- Messika, Y., Nishri, Y., Gokkes, M., Lapidot, M., & Antignus, Y. (1998). UV-absorbing films and Aluminet screens—An efficient control means to block the spread of insect and viral pests in *Lisianthus*. *Dapey Meyda, the Flower Grower Magazine*, 13, 55–57 (in Hebrew).
- Mizrahi, S., Sacs, Y., Mor, N., Elad, Y., Reuveni, R., & Antignus, Y. (1998). Comparative study on the protection effects of commercial polyethylene films with different absorption spectra against insect, fungal and viral pests. *Gan Sadeh Vameshek*, 33–37 (in Hebrew).
- Moericke, V. (1955). Neue untersuchungen uber das farbensehen der homopteran. In *Proceedings of conference on potato diseases 2nd meeting, Lisse-Wageningen, Netherlands, 1954* (pp. 55–69).
- Moller, R. (2002). Insects could exploit UV-green contrast for landmark navigation. *Journal of Theoretical Biology*, 214, 619–631.
- Morandin, L. A., Laverty, T. M., Kevan, P. G., Khosla, S., & Shipp, L. (2001). Bumble bee (Hymenoptera: Apidae) activity and loss in commercial tomato greenhouses. *Canadian Journal of Entomology*, 133, 883–893.
- Morandin, L. A., Laverty, T. M., Kevan, P. G., Khosla, S., & Shipp, L. (2002). Effect of greenhouse polyethylene covering on activity level and photo-response of bumble bees. *Canadian Journal of Entomology*, 134, 539–549.
- Mound, L. A. (1962). Studies on the olfaction and color sensitivity of *Bemisia tabaci* (GENN.) (Homoptera, Aleurodidae). *Entomologia Experimentalis et Applicata*, 5, 99–104.
- Mutwiwa, U. N., Brogemeister, C., Von Elsner, B., & Tantu, H. (2005). Effects of UV absorbing plastic films on greenhouse whitefly (Homoptera: Aleyrodidae). *Journal of Ecological Entomology*, 98, 1221–1228.
- Nguyen, T. H. N., Borgemeister, C., Max, J., & Poehling, H.-M. (2009). Manipulation of ultraviolet light affects immigration behavior of *Ceratothripoides claratris* (Thysanoptera: Thripidae). *Journal of Economic Entomology*, 102, 1559–1566.
- Onuma, K., & Nakagaki, S. (1982). The growth of vegetable crops and establishment of insect and mite pests in a plastic greenhouse treated to exclude near UV radiation. (1) The growth of pepper and cucumber. *Bulletin of Ibaraki-Ken Horticultural Experimental Station*, 10, 31–38 (in Japanese).
- Onzo, A., Sabelis, M. W., & Hanna, R. (2010). Effects of ultraviolet radiation on predatory mites and the role of refuges in plant structures. *Environmental Entomology*, 39, 695–701.
- Orozco-Santos, M., Perez-Zamora, O., & Lopez-Arriaga, O. (1995). Effect of transparent mulch on insect populations, virus diseases, soil temperature, and yield of cantaloupe in a tropical region. *New Zealand Journal of Crop and Horticultural Science*, 23, 199–204.
- Paul, N. D., Jacobson, R. J., Taylor, A., Wargent, J. J., & Moore, J. P. (2005). The use of wavelength-selective plastic cladding materials in horticulture: Understanding of crop and fungal responses through the assessment of biological spectral weighting functions. *Photochemistry and Photobiology*, 81, 1052–1060.
- Pressman, E., Moshkovitz, A., Rsenfeld, K., & Shaked, R. (1996). *The effects of UV-blocking films on quality parameters of tomato and pepper fruits*. Final report submitted to Ginegar plastic industries LTD, Israel.
- Puterka, G. J., Glenn, D. M., & Pluta, R. C. (2005). Action of particle films on the biology and behavior of pear psylla (Homoptera: Psyllidae). *Journal of Economic Entomology*, 98, 2079–2088.
- Racah, B. (1986). Non-persistent viruses: Epidemiology and control. In K. Maramorosch, F. A. Murphy, & A. J. Shatkin (Eds.), *Advances in virus research* (pp. 387–429). New York: Academic Press.
- Racah, B., & Fereres, A. (March 2009). Plant Virus Transmission by Insects. In *Encyclopedia of Life Sciences (ELS)* Chichester: John Wiley & Sons, Ltd. <http://dx.doi.org/10.1002/9780470015902.A0021525.a0000760.pub2>.

- Rapisarda, C., & Tropea-Garzia, G. (2002). Tomato yellow leaf curl Sardinia virus and its vector *Bemisia tabaci* in Sicilia (Italy): Present status and control. *OEPP/EPPO Bulletin*, 32, 25–29.
- Raviv, M., & Antignus, Y. (2004). UV radiation effects on pathogens and insect pests of greenhouse-grown crops. *Photochemistry & Photobiology*, 79, 219–226.
- Reuveni, R., & Raviv, M. (1992). The effect of spectrally-modified polyethylene films on development of *Botrytis cinerea* in greenhouse grown tomato plants. *Biology and Agricultural Horticulture*, 9, 77–89.
- Robson, T. M., Pancotto, V. A., Flint, S. D., Ballare, C. L., Sala, O. E., Scopel, A. L., et al. (2003). Six years of solar UV-B manipulations affect growth of sphagnum and vascular plants in a Tierra del Fuego peat land. *New Phytology*, 160, 379–389.
- Rozema, J., Björn, L. O., Bornman, J. F., Gaberscik, A., Häder, D. P., Trost, T., et al. (2002). The role of UV-B radiation in aquatic and terrestrial ecosystems an experimental and functional analysis of the evolution of UV-absorbing compounds. *Journal of Photochemistry & Photobiology*, 66, 2–12.
- Seker, I. (1999). The use of UV-blocking films to reduce insect pests damage in tomato greenhouses and the effect of UV-filtration on the pollination activity of bumble bees. *Gan Sadeh Va'Meshek*, 12, 55–59 (in Hebrew).
- Seliger, H. H., Lall, A. B., & Biggley, W. H. (1994). Blue through UV polarization sensitivities in insects. Optimizations for the range of atmospheric polarization conditions. *Journal of Comparative Physiology*, 175, 475–486.
- Shahak, Y., Gal, E., Offir, Y., & Ben-Yakir, D. (2008). Photosensitive shade netting integrated with greenhouse technologies for improved performance of vegetable and ornamental crops. *Acta Horticulturae*, 797, 75–80.
- Shahak, Y., Ratner, K., Zur, N., Offir, Y., Matan, E., Yehezkel, H., et al. (2009). Photosensitive netting: An emerging approach in protected agriculture. *Acta Horticulturae*, 807, 79–84.
- Stavisky, J., Funderburk, J., Brodbeck, B. V., Olson, S. M., & Andersen, P. C. (2002). Population dynamics of *Frankliniella* spp. and tomato spotted wilt incidence as influenced by cultural management tactics in tomato. *Journal of Economic Entomology*, 95, 1216–1221.
- Steinberg, S., Prag, H., Gouldman, D., Antignus, Y., Pressman, E., Asenheim, D., et al. (1997). The effect of ultraviolet-absorbing plastic sheets on pollination of greenhouse tomatoes by bumblebees. In *Proceedings of the international congress for plastics in agriculture (CIPA)*. Tel-Aviv: Israel.
- Summers, C. G., Mitchell, J. P., & Stapleton, J. J. (2005). Mulches reduce aphid-borne viruses and whiteflies in cantaloupe. *California Agriculture*, 59, 90–94.
- Suwwan, M. A., Akkawi, M. A., Al-Musa, M., & Mansour, A. (1988). Tomato performance and incidence of tomato yellow leaf curl (TYLC) virus as affected by type of mulch. *Scientia Horticulturae*, 37, 39–45.
- Unruh, T. R., Knight, A. L., Upton, J., Glenn, D. M., & Puterka, G. J. (2000). Particle films for suppression of codling moth (Lepidoptera: Tortricidae) in apple and pear orchards. *Journal of Economic Entomology*, 93, 737–743.
- Vaishampayan, S. M., Kogan, M., Waldbauer, G. P., & Wooley, J. T. (1975). Spectral specific responses in the visual behavior of the greenhouse whitefly, *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). *Entomologia Experimentalis et Applicata*, 18, 344–356.
- Vaishampayan, S. M., Waldbauer, G. P., & Kogan, M. (1975). Visual and olfactory responses in orientation to plants by the greenhouse whitefly, *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae). *Entomologia Experimentalis et Applicata*, 18, 412–422.
- Van de Veire, M., & Vacante, V. (1984). Greenhouse whitefly control through the combined use of color attraction system with the parasite wasp *Encarsia formosa* (Hym. Aphelinidae). *Entomophaga*, 29, 303–310.

- van der Blom, Jan. (2010). Applied entomology in Spanish greenhouse horticulture. *Proceedings of The Netherland Entomological Society Meeting*, 21, 9–17.
- Vernon, R. S., & Gillespie, D. R. (1990). Spectral responsiveness of *Frankliniella occidentalis* (Thysanoptera: Thripidae) determined by trap catches in greenhouses. *Environmental Entomology*, 19, 1229–1241.
- Wehner, R., & Labhart, T. (2006). Polarisation vision. In E. Warrent, & D. E. Nilsson (Eds.), *Invertebrate vision* (pp. 291–293). Cambridge University Press: Cambridge.
- Weintraub, P. G., Pivonia, S., & Gera, A. (2008). Physical control of leafhoppers. *Journal of Economic Entomology*, 101, 1337–1340.
- Yokomi, R. H., Bar-Joseph, M., Oldfield, G. N., & Gumpf, J. J. (1981). A preliminary report of reduced infection by *Spiroplasma citri* and virescence in whitewash-treated periwinkle. *Phytopathology*, 81, 914 (abstract).
- Zimmerman-Gries, S. (1979). Reducing the spread of potato leaf roll virus, alfalfa mosaic virus and potato virus Y in seed potatoes by trapping aphids on sticky yellow polyethylene sheets. *Potato Research*, 22, 123–131.