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Spectral Properties of Selected UV-blocking and UV-transmitting Covering Materials with Application for Production of High-value Crops in High Tunnels†

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ABSTRACT

The spectral properties of selected UV-blocking and UV-transmitting covering materials were characterized by means of a UV–VIS spectroradiometer or a UV–VIS spectrometer to provide researchers and growers with guidelines for selecting suitable materials for use in studying the effects of ambient solar UV radiation on the production of tomatoes and other high-value crops in high tunnels. A survey was made of a wide range of plastic covering materials to identify commercially available products that had the desired characteristics of transmitting high levels of photosynthetically active radiation and of being stable under ambient solar UV radiation. The study was focused on evaluating films that either blocked or transmitted UV wavelengths below 380 nm to determine comparative growth, yield and market quality and to provide a tool for integrated pest management. Based on this survey, two contrasting covering materials of similar thickness (0.152 mm) and durability (4-year polyethylene), one a UV-blocking film and the other a UV-transmitting film, were selected and used to cover two high tunnels at Beltsville, MD. Spectroradiometric measurements were made to determine comparative spectral irradiance in these two high tunnels covered with these materials and under ambient solar UV radiation. Comparative measurements were also made of selected glass and plastic materials that have been used in UV exclusion studies.

INTRODUCTION

Plant productivity of greenhouse crops is greatly influenced by the amount of electromagnetic radiation that they receive. This is determined not only by the type of greenhouse structure but also by the amount of UV radiation, photosynthetically active radiation (PAR) and IR transmitted through the covering material of these structures. Various covering materials have been used in the greenhouse production of horticultural crops (1–8). The number of new materials suitable for greenhouse coverings has grown rapidly in recent years because of advances in plastics design and the incorporation of new additives that alter the physical and spectral properties of these materials and provide increased UV stabilization (9–11).

The comparative transmission of PAR through common greenhouse covering materials is well known (5,6,12) but relatively little has been published on the PAR transmission of newer materials or the spectral properties of covering materials in the UV region. Studies during the past 10 years have focused on development and evaluation of photoselective films that block the transmission of far-red (FR) or IR radiation (7,13–22). Manipulating the spectral transmission of greenhouse coverings to reduce FR radiation has gained interest among both researchers and growers as an attractive nonchemical approach to regulating stem elongation. There has also been growing interest in evaluating anticondensate films (23–25).

During recent years there has been keen interest in the use of high tunnels for production of tomatoes and other high-value crops (26–31). Although high tunnels lack the sophisticated environmental controls available in most greenhouses, they have the advantage of providing the small farmer with a means of growing produce locally for the fresh market using methods less costly than conventional greenhouses. High tunnels also afford the grower a means of providing modest climate control and of starting crops 3–6 weeks earlier in the spring and extending the growing season 3–6 weeks in the fall.

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Abbreviations: CA, cellulose diacetate; DF Super 4, AT Plastics Dura-Film Super 4; FR, far-red; IPM, integrated pest management; PAR, photosynthetically active radiation (400–700 nm); PC, polycarbonate; PE, polyester; T, transmittance; Teflon FEP, copolymer of tetrafluoroethylene and hexafluoropropylene; UV-A, ultraviolet-A radiation (320–400 nm); UV-B, ultraviolet-B radiation (280–320 nm); UV-C, ultraviolet-C radiation (< 280 nm); UV_{BE}, biologically effective UV (weighted with a weighting function); UV-T Plexiglas, UV-transmitting Plexiglas.

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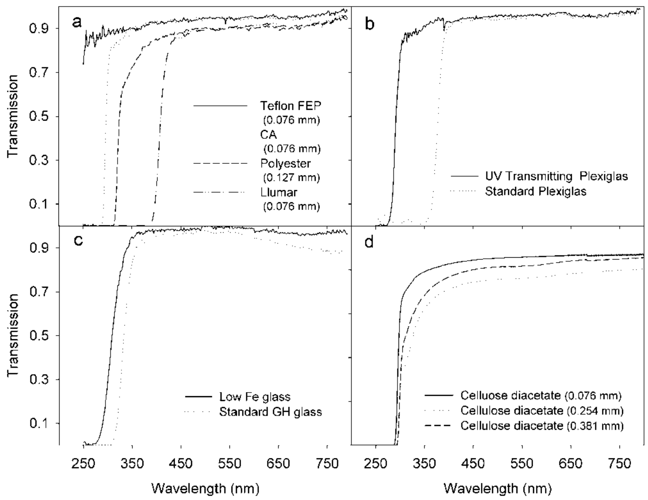

Figure 1. Spectral transmission of selected covering materials: (a) 0.076 mm Teflon FEP, 0.076 mm CA, 0.127 mm polyester and 0.076 mm Llumar; (b) UV-transmitting Plexiglas and standard Plexiglas; (c) low Fe glass and standard greenhouse (GH) glass; and (d) 0.076 mm, 0.254 mm and 0.381 mm CA. Data in Figs. 1a, 1b and 1c obtained with a UV–VIS spectroradiometer and data in Fig. 1d determined with a UV–VIS spectrometer.

In 2002, a new project was established in the U.S. Department of Agriculture Sustainable Agricultural Systems Laboratory. One of the objectives of this project was to determine the feasibility of using season-extending high tunnels as a tool for integrated pest management (IPM) by altering the spectral transmission of the plastics in the UV region. The objective of the present study was to determine the spectral transmittance of a range of plastic covering materials that might be suitable for covering two high tunnels that were erected at the Beltsville Agricultural Research Center in Beltsville, MD in 2004.

The goal was to identify commercially available products that either transmitted or blocked UV wavelengths and at the same time had the characteristics of transmitting high levels of PAR and being stable under ambient solar UV radiation for up to 4 years. The study focused on evaluating plastic films that either blocked or transmitted UV wavelengths below 380 nm and that could be used in high tunnel studies on the effects of UV radiation on comparative growth, yield and market quality and as a tool for IPM.

Numerous covering materials have been used in UV exclusion studies on higher plants (32–42). However, data on the comparative spectral transmission of these materials in the UV, visible and near IR regions are minimal (42). Thus, comparative measurements were also made on selected glass and plastic materials that have been used in UV exclusion studies to provide investigators with baseline information for selecting suitable filters in future studies.

MATERIALS AND METHODS

Experimental samples

Experimental samples were obtained from a number of plastics manufacturers and greenhouse suppliers. Different film thicknesses were evaluated whenever possible. In those cases in which samples of the same material were obtained from different vendors, only one of the scans is shown. Current sources of each film are shown.

Several covering materials that have been used in UV-enhancement and UV-exclusion studies were compared. Aclar 22 C (polychlorotrifluoroethylene, or PCTFE), a clear, UV-transmitting (UV-T) film, is available from Honeywell (Morristown, N J). Cellulose diacetate (CA) is available from Grafix Plastics (Cleveland, OH) and is commonly used to exclude UV-C radiation and transmit UV-B and UV-A radiation. Another supplier of CA is GE Polymershapes (Huntersville, NC). Polyester transmits UV-A wavelengths and is commonly used in UV-enhancement studies as a control when used with CA to exclude UV-B radiation; polyester is the generic name for Mylar (a proprietary name given by DuPont Co.). Polyester is available from a number of vendors, including Grafix Plastics and GE Polymershapes (Huntersville, NC).

Teflon FEP, a copolymer of tetrafluorethylene and hexafluoropropylene, transmits radiation at 245 nm and above, and Tedlar TUT, a polyvinyl fluoride product that transmits UV-A, UV-B and UV-C radiation are available from DuPont Co. (Circleville, OH). Dura-Film Super 4 (DF Super 4) (43), a clear polyethylene that blocks UV up to 380 nm, is manufactured by AT Plastics Inc. (Brampton, Ontario, Canada); it was obtained from Griffin Greenhouse Supplies (Leola, PA). Tyco Tufflite IV (Tyco Plastics and Adhesives Division of Tyco, Inc., Monroe, LA) is a clear polyethylene film that transmits solar UV radiation; it was obtained from Maryland Plants and Supply (Baltimore, MD). Several Klerk (Klerk Plastic Products Manufacturing, Inc., Richburg, SC) greenhouse films were evaluated including Klerk K 50 IRAC, (an anti-condensate film with infrared retention) and Klerk Cool Lite 380 (an anticondensate film that diffuses PAR and blocks UV up to 380 nm). Plexiglas (Atoglas) (polymethylmethacrylate) is available from Arkema Inc (Philadelphia, PA). Llumar (NRS90 clear) is available form CP Films Inc (Martinsville, VA). Low Fe glass (Starphire) is available from Pittsburgh Plate and Glass (Pittsburgh, PA).

Measurements of spectral transmission

Measurements of spectral transmission of selected UV filters were determined with a Perkin Elmer UV–VIS scanning spectrometer (model Lambda 10). Samples were placed in a quartz cuvette and held in a specially designed mount to orient the films vertically in the center of the cuvette perpendicular to the light source. Spectral scans of each sample were run from 200 to 800 nm, taking care to orient the films so that the light beam from the spectrometer entered through the outer surface and exited through the inner surface.

Spectroradiometer measurements

The spectral characteristics of the UV filters were determined with a UV–VIS spectroradiometer (model 752, Optronic Laboratories Inc., Orlando, FL). Calibration for wavelength accuracy and absolute flux sensitivity of the spectroradiometer was performed in a temperature-controlled calibration room, using a fluorescent lamp and a 200-W tungsten quartz–halogen standard lamp traceable to the National Institute of Standards and Technology.

RESULTS

Comparative measurements of spectral transmittance of Teflon FEP (0.076 mm), CA (0.076 mm), polyester (0.127 mm) and Llumar (0.076 mm) are shown in Fig. 1a. CA has been the film of choice in UV-B (enhancement) studies because it excludes UV-C wavelengths but transmits UV-B and UV-A. Polyester in turn, blocks the transmission of UV-B but transmits UV-A wavelengths. Llumar excludes virtually all wavelengths below 400 nm. Figure 1d shows that the shape of the spectra is greatly influenced by the thickness of the CA. Figure 1b shows the comparative transmittance of UV-T and standard Plexiglas. This figure indicates that standard Plexiglas excludes UV-B wavelengths and a portion of the UV-A region whereas UV-T Plexiglas transmits all wavelengths in the UV-B and UV-A region. Figure 1c shows that low Fe glass (Starphire) transmits considerably more UV-B radiation than does standard greenhouse glass.

A comparison of Aclar 22 C (0.254 mm), CA (0.076 mm) and polyester (0.127) is shown in Fig. 2a. This shows that Aclar 22C is an excellent film for transmitting solar UV radiation but would not be suitable for use in UV-B enhancement studies because it would

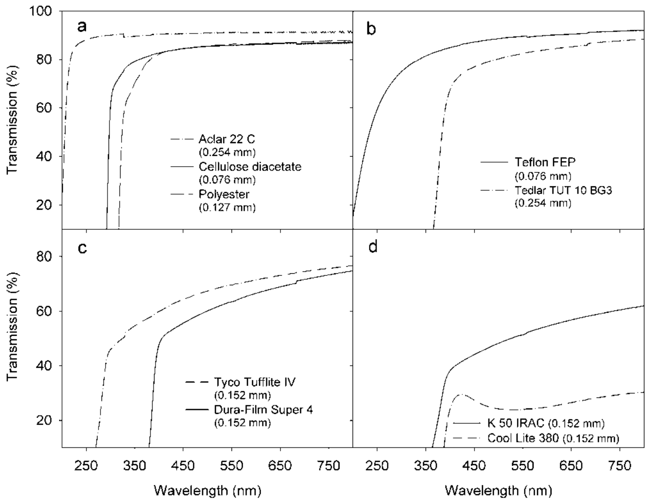

Figure 2. Spectral transmission of selected covering materials: (a) 0.254 mm Aclar 22C, 0.076 mm CA and 0.127 mm polyester; (b) 0.076 mm Teflon FEP and 0.254 mm Tedlar TUT 10 BG3; (c) 0.152 mm Tyco Tufflite IV and 0.152 mm DF Super 4; and (d) 0.152 mm Klerk K 50 IRAC and 0.152 mm Klerk Cool Lite 380. Data obtained with a UV–VIS spectrometer.

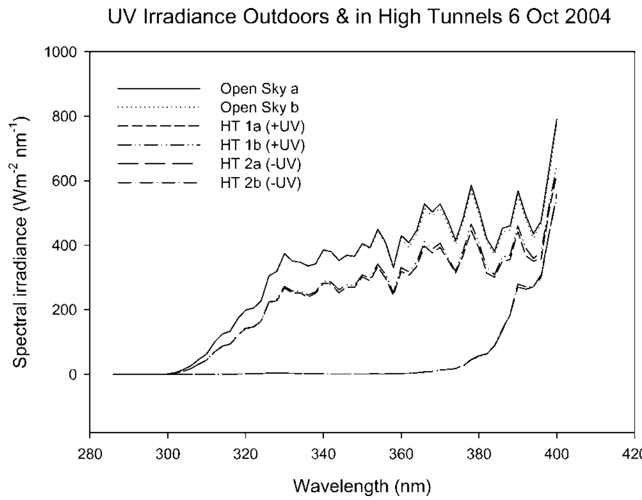

Figure 3. Comparative UV spectral irradiance taken outdoors 6 October 2004 under a sunny, clear open sky and in the center of two high tunnels, one (HT 1a and HT 1b) covered with a UV-transmitting film (+UV) (0.152 mm Tyco Tufflite IV) and the other (HT 2a and HT 2b) covered with a UV-blocking film (–UV) (0.152 mm DF Super 4). Duplicate measurements were taken with a UV–VIS spectroradiometer from 250 to 400 nm, the first run designated by the letter a and the second run by the letter b.

allow the passage of UV-C wavelengths. A comparison of Teflon FEP and Tedlar TUT 10 BG3 is shown in Fig. 2b. These curves indicate that Teflon is similar to Aclar in transmitting ambient solar UV radiation but that Tedlar blocks wavelengths in the UV-B region.

Figure 2c illustrates the sharp contrast in spectral transmission between UV-transmitting Tufflite IV film and UV-blocking DF Super 4 film. Figure 2d indicates that anticondensate films transmit much lower levels of PAR than do either Tufflite IV film or DF Super 4 film.

Figure 3 shows spectral transmission in the UV region under the two high tunnels in comparison to open sunlight. As expected, Tufflite IV showed a distinct difference in UV irradiance from that of the UV-blocking film, DF Super 4. The fluctuations in UV irradiance for Tufflite IV and open sunlight were similar but the absolute level of UV irradiance was slightly less with Tufflite IV. Duplicate scans in the UV region produced similar curves. Figure 4 shows spectral irradiance measurements taken outdoors on a clear sunny day for the full range of 250 to 792 nm.

DISCUSSION

The use of UV- and blue-absorbing polyethylene films for disease and insect control has gained increased attention (44–51). The prospect of using UV-blocking covering materials as an IPM approach to control fungal diseases and insect-borne diseases should become increasingly popular as consumers clamor for fruits and vegetables that are grown organically.

To date, most studies of the use of UV-blocking barriers to impede insects and reduce the prevalence of fungal diseases have been conducted in plastic greenhouses and other completely enclosed structures (46–51). Whether similar protection can be obtained to the same extent in season-extending high tunnel houses in which the side curtains are opened and closed nearly every day remains to be determined. The suitability of UV-blocking materials such as DF Super 4 (43) to control such pests in the production of tomatoes and other high-value crops in high tunnel houses will require further evaluation. Such an evaluation will necessitate that insect population surveys be conducted. To date, there are no peer-reviewed studies on the efficacy of using DF Super 4 as a UV-blocking covering. In selecting contrasting covering materials (Tufflite IV to transmit UV and DF Super 4 film to block UV), we chose two films that transmit similar amounts of PAR. Unless this is done, it is difficult to separate the effects caused by differences in UV transmission from those caused by differences in PAR transmission.

Three main filter materials have been used in UV exclusion studies to transmit solar UV-A and UV-B (32–34,36,38–40,52,53). These are Aclar, Teflon FEP and CA; UV-transmitting Plexiglas

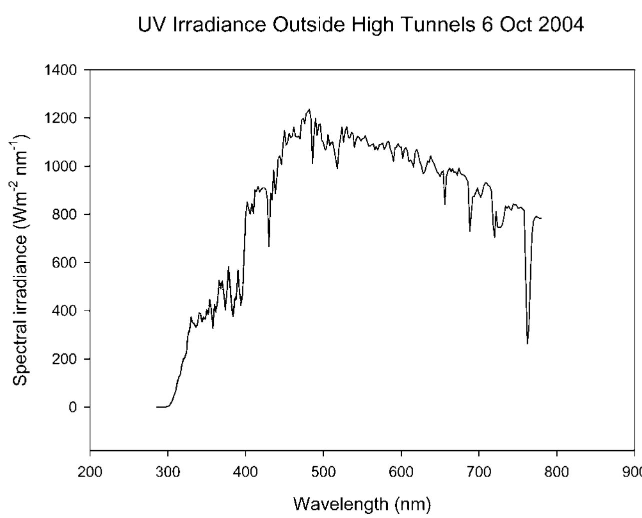

Figure 4. UV spectral irradiance taken outdoors 6 October 2004 under a sunny, clear open sky between two high tunnels located at Beltsville, MD. Measurements were taken with a UV–VIS spectroradiometer from 250 to 792 nm.

and other UV-B transparent acrylic filters have also been used (33,35,37,42).

UV exclusion filters afford investigators an attractive means of assessing the biological effects of ambient solar UV radiation. To conduct meaningful UV exclusion experiments, careful consideration should be given to selecting appropriate filters. Such filters should have the proper spectral cutoff, be relatively stable under ambient UV and be free of artifacts. CA filters have been widely used in UV-B enhancement experiments because of their ability to exclude germicidal wavelengths emitted by fluorescent sun lamps that are commonly used in these studies. CA has a UV cutoff at *ca* 292 nm, close to the spectral cutoff of sunlight; it has been widely used in UV-B enhancement studies under field and controlled-environment conditions to remove wavelengths below 290 nm (41,42). A recent paper by Krizek and Mirecki (42) indicates that CA should be used with caution in UV exclusion studies because it may have a phytotoxic effect on sensitive plants such as cucumber (*Cucumis sativus* L.) as a result of outgassing of a plasticizer known to be used in the manufacture of CA or as a result of some breakdown product. To avoid possible confounding effects from use of CA and to obtain maximum transmission of UV and visible radiation, Krizek and Mirecki (42) recommend that Teflon or Aclar be used in lieu of CA in UV exclusion studies.

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