Control of Fungal Diseases of Greenhouse Tomato Under Long-Wave Infrared-Absorbing Plastic Film

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ABSTRACT

Vakalounakis, D. J. 1992. Control of fungal diseases of greenhouse tomato under long-wave infrared-absorbing plastic film. Plant Dis. 76:43-46.

Two tomato cultivars, Earlypak No. 7 and Dombo, were grown during the 1986–1987 and 1988–1989 crop seasons in a greenhouse covered with a long-wave infrared absorbing (IRA)-vinyl film (4-mil thick with a lower limit of transmission at 385 nm and light transmittance in the visible region, approximately 85%) and in a control greenhouse covered with a common agricultural (CA)-polyethylene film (6.3-mil thick with a lower limit of transmission at 340 nm and light transmittance in the visible region, approximately 85%). Transmittances in the region from 7,000 to 14,000 nm (where IR emission by soil and plants during the night takes place) in the IRA- and CA-plastic film-covered greenhouses were approximately 7.3 and 50.9%, respectively. At the end of the crop seasons, total disease index for all three diseases (early blight, caused by *Alternaria solani*; leaf mold, caused by *Cladosporium fulvum*; and gray mold, caused by *Botrytis cinerea*) on both cultivars was much less in the IRA-vinyl greenhouse (40–50%) than in the CA-vinyl greenhouse. In the IRA-vinyl greenhouse, the first harvest of mature fruits from both cultivars was made about 60–70 days earlier and plant growth (height, stem diameter, inflorescence number, infructescence number, and fruit production) was better than in the CA-vinyl greenhouse.

Crops are normally exposed to solar radiation extending from the far-ultraviolet (UV) (higher than 280 nm) through the visible and infrared (IR) spectra (lower than 2,000 nm) (6). UV radiation (280–380 nm) is important in a number of plant disease responses. It can influence both pathogen and host and also cause indirect effects on plant diseases (7). Man's activities, such as erecting greenhouses covered with UV-absorbing (UVA)-vinyl films, can significantly reduce plant diseases by inhibiting fungal sporulation (4,5,8). Recently, Vakalounakis (11) controlled early blight of greenhouse tomato in Crete, caused by *Alternaria solani* Sorauer, by inhibiting sporulation of the pathogen with UVA-vinyl film.

IR radiation (>750 nm) has little known photobiological activity. During the day, shortwave IR radiation (approximately 750–2,000 nm) reaches the Earth's surface, causing significant heating of soil and plants (7). During the night, soil and plants cool in response to long-wave IR (approximately 7,000–14,000 nm) emission into the atmosphere (law of Stefan-Boltzmann) (1). Cooling of plants changes the rate of several metabolic processes, including plant-pathogen relationships. Thus, diseases of roots as well as aerial tissues could be affected by the cooling of plants and soil during the night caused by long-wave IR emission. In addition, cooling of plants could also cause some indirect effects on plant diseases by reducing the vigor of plants. Cooling of the air caused by long-wave IR emission increases relative humidity, which favors most foliage diseases (2,10). Therefore, it could be possible to control vegetable diseases in commercial greenhouses by reducing the heating losses of soil and plants during the night with long-wave IR radiation-absorbing (IRA)-plastic films.

The present study describes successful control on greenhouse tomato of early blight (caused by *A. solani*), leaf mold (caused by *Cladosporium fulvum* Cooke), and gray mold (caused by *Botrytis cinerea* Pers.:Fr.) by growing the plants under IRA-vinyl film.

Accepted for publication 23 April 1991.

MATERIALS AND METHODS

Two greenhouse experiments to determine the effectiveness of a long-wave IRA-vinyl film in comparison with a common agricultural (CA)-polyethylene film on disease development and plant growth were carried out. For this purpose, two tomato (*Lycopersicon esculentum* Mill.) cultivars, Earlypak No. 7 and Dombo, were grown in a 5 × 8 m experimental greenhouse covered with a long-wave IRA-vinyl film (PR vinyl; Mitsui Toatsu Chemicals Inc., Nagoya, Japan) with a thickness of 4 mil, a lower limit of transmission at 385 nm, and light transmittance in the visible region, approximately 85%. Another experimental greenhouse of the same size with a CA-polyethylene film (extra-extra low-density polyethylene; Plastica Kritis S. A.; Heraklio, Crete, Greece) with a thickness of 6.3 mil, a lower limit of transmission at 340 nm and light transmittance in the visible region, approximately 85%, served as a control. Transmittances of the IRA- and CA-plastic films, in the region from 7,000 to 14,000 nm, were approximately 7.3 and 50.9%, respectively. The greenhouses, constructed in 1984, were oriented in a similar direction (from north to south) and located 4 m from each other at the Katsambas area, Heraklio, Crete. Soil type in both greenhouses was silt loam with pH 7.4, total calcium carbonate 35%, and electrical conductivity of 2 mmhos/cm. Plants were grown in sterilized soil according to local commercial procedures. During experiments, no supplemental heating or pesticides were used.

In the first experiment, seeds were sown in plastic pots on 10 September 1986. Seedlings were transplanted to each greenhouse in four rows with 12 plants per row on 14 October 1986. Each row consisted of six plants of each cultivar planted in alternation. Disease ratings were taken on 3 and 29 April and 22 May 1987. In the second experiment, seeds were sown on 21 September 1988 and seedlings were transplanted to each greenhouse on 31 October 1988. Disease ratings were taken on 11 April and 5 and 30 May 1989. During the experimental periods, the air and soil temperatures at 10- and 20-cm depths, as well as the relative humidity (RH) outside and inside the greenhouses, were recorded daily. Because of the regular occurrence of early blight, leaf mold, and gray mold at Katsambas, artificial inoculations were not made. Disease development was evaluated on a 0–4 visual rating scale, corresponding to the percentage of leaf area damaged by all three diseases, where 0 = no disease, 1 = 1–9, 2 = 10–24, 3 = 25–49, and 4 = 50–100% damaged. The number of fruits and stems affected by gray mold, as well as plant height, stem diameter, inflorescence number, infructescence number, and fruit production, were recorded. At the end of the two experiments on 26 May 1987 and 31 May 1989, respectively, the plants were dug up and their roots and stem bases were examined for foot and root rot disease caused by *Fusarium oxysporum* Schlectend.:Fr. f. sp. *radicis-lycopersici* W. R. Jarvis & Shoemaker, which is a common disease of tomato at Katsambas.

RESULTS

Two main differences between the IRA- and CA-plastic covers used in our experiments were their transmittance of long-wave IR radiation and water vapor.

Table 1. Mean air and soil temperatures (C) and relative humidities (RH) (%) in two greenhouses located at Katsambas, Heraklio, Crete, which were covered with an infrared-absorbing (IRA)-vinyl film or with a common agricultural (CA)-polyethylene film

	CA-polyethylene film								IRA-vinyl film									
			Soil temp.								Soil temp.						Outside air temp.	
	Air temp.		10 cm		20 cm		RH		Air temp.		10 cm		20 cm		RH			
Date	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Dec. 1986	9.7	25.3	13.4	16.5	13.6	15.7	67.6	91.4	10.9	27.4	13.9	17.1	14.5	16.1	61.7	87.6	8.7	17.6
Jan. 1987	8.1	29.9	13.0	16.3	13.4	15.5	60.0	93.0	9.0	32.8	13.7	16.9	14.6	16.7	56.7	89.3	9.3	18.2
Feb. 1987	8.9	30.1	12.2	17.8	12.8	15.5	55.7	93.2	9.5	31.6	14.0	19.9	14.9	17.4	54.2	87.5	9.6	18.3
Mar. 1987	5.5	30.8	12.1	19.8	12.9	16.9	57.2	94.5	6.1	33.1	12.9	21.8	13.8	17.9	54.0	90.2	6.4	19.5
Dec. 1988	10.5	22.5	14.0	17.2	14.2	16.4	67.0	93.0	11.2	24.5	14.6	17.8	15.1	16.9	60.0	89.2	9.6	18.5
Jan. 1989	8.5	24.2	13.6	16.3	14.0	15.8	68.5	94.0	9.5	27.3	14.5	17.4	15.4	17.3	61.0	89.9	9.7	17.9
Feb. 1989	7.7	24.0	12.0	16.8	12.7	15.3	60.8	93.8	8.4	25.5	13.9	19.0	14.6	17.1	59.3	86.2	8.8	17.5
Mar. 1989	6.9	24.5	11.8	17.5	12.8	16.6	62.3	94.9	7.5	26.9	12.7	20.9	13.8	17.3	58.8	90.1	8.6	20.4

Table 2. Effect of an infrared-absorbing (IRA)-vinyl film in comparison with a common agricultural (CA)-polyethylene film on early blight, leaf mold, and gray mold of greenhouse tomato cultivars Earlypak No. 7 (EP) and Dombo

	Total disease index[a,b]			
	IRA		CA	
Observation date	EP	Dombo	EP	Dombo
1986–1987				
3 April	0.2 ± 0.4	0.1 ± 0.2	0.6 ± 1.0	0.9 ± 1.0
29 April	1.0 ± 0.3	0.7 ± 0.4	1.8 ± 0.8	1.9 ± 0.7
22 May	2.2 ± 1.0	1.9 ± 0.7	4	3.8 ± 0.6
1988–1989				
11 April	0.3 ± 0.2	0.2 ± 0.4	0.8 ± 0.8	1.0 ± 0.8
5 May	0.8 ± 0.3	0.7 ± 0.5	1.7 ± 0.5	1.8 ± 0.5
30 May	1.5 ± 1.0	1.4 ± 0.7	3.7 ± 0.8	3.5 ± 0.7

[a]Symptoms of early blight, leaf mold, and gray mold assessed in total on a 0–4 visual rating scale, corresponding to the percentage of leaf area damaged, where 0 = no disease, 1 = 1–9, 2 = 10–24, 3 = 25–49, and 4 = 50–100% damaged.
[b]Mean ± standard deviation on 24 plants.

Transmittances of the IRA- and CA-plastic films in the region from 7,000 to 14,000 nm, where IR emission by plants and soil during the night takes place, were approximately 7.3 and 50.9%, respectively. This reduced percentage of long-wave IR transmittance in the IRA-plastic cover resulted in higher mean minimum temperatures during the night in the IRA-vinyl greenhouse in comparison with the CA-plastic greenhouse (Table 1). On the other hand, during the period from December 1986 to March 1987, the maximum differences in the absolute minimum night temperatures between the IRA-vinyl greenhouse and the CA-plastic greenhouse were 4, 5, and 5 C in the air and in the soil at 10- and 20-cm depths, respectively. During the period from December 1988 to March 1989, the differences were 5, 6, and 6 C, respectively (*data not presented*). The higher water vapor transmittance in the IRA-vinyl greenhouse, combined with the increase in temperature, resulted in a decrease in mean maximum RH in comparison with the CA-plastic greenhouse (Table 1). On the other hand, during the period from December 1986 to March 1987, the maximum difference in the absolute maximum night RH between the IRA-vinyl greenhouse and the CA-plastic greenhouse was 10%, whereas during the period from December 1988 to March 1989, the difference was 12% (*data not presented*).

In the first experiment, the first spots of early blight appeared on 9 January 1987 on Earlypak No. 7 and on 27 January on Dombo in the CA-plastic greenhouse, whereas they appeared on 27 January on Earlypak No. 7 and on 10 February on Dombo in the IRA-vinyl greenhouse. For leaf mold, the first leaf spots were observed in the CA-plastic greenhouse on 26 March on Earlypak No. 7 and on 3 April on Dombo, whereas in the IRA-vinyl greenhouse, they appeared on 10 April on Earlypak No. 7 and on 17 April on Dombo. For gray mold, the first leaf symptoms were observed in the CA-plastic greenhouse on 5 March on Earlypak No. 7 and on 12 March on Dombo, whereas in the IRA-vinyl greenhouse, they appeared on 13 March on Earlypak No. 7 and on 19 March on Dombo.

At the end of the crop season, disease indices for Earlypak No. 7 and Dombo in the IRA-vinyl greenhouse were 55 and 50%, respectively, of those in the CA-plastic greenhouse (Table 2). In the CA-plastic greenhouse, four fruits with gray mold were found in Earlypak No. 7 and 13 in Dombo, in comparison with none on either cultivar in the IRA-vinyl greenhouse. On the other hand, in the IRA-vinyl greenhouse, one plant of each cultivar had severe gray mold on the stem, compared with three plants of Earlypak No. 7 and nine plants of Dombo in the CA-plastic greenhouse.

At the end of the experiment, three plants of Dombo and none of Earlypak No. 7 had symptoms of Fusarium foot and root rot in the IRA-vinyl greenhouse, in comparison with 10 plants of Dombo and eight plants of Earlypak No. 7 in the CA-plastic greenhouse. In the IRA-vinyl greenhouse, plant growth was much better than in the CA-plastic greenhouse (Tables 3–5). In the IRA-vinyl greenhouse, the first immature fruits from both cultivars appeared 1 mo earlier and the first harvest of mature fruits was 2 mo earlier than in the CA-plastic greenhouse. At the end of the experimental period, plant height, stem diameter (measured 10 cm above the soil line), and fruit production in the IRA-vinyl greenhouse exceeded that in the CA-plastic greenhouse by 3.6, 12.3, and 160% for Earlypak No. 7 and 13.3, 22.4, and 252% for Dombo, respectively (Tables 4 and 5). The small difference in plant height for Earlypak No. 7 between the IRA-vinyl and the CA-plastic greenhouses at the end of the crop season was attributable to the determinate habit of this cultivar, which had already achieved maximum height before 22 March.

In the second experiment, the first spots of early blight, leaf mold, and gray mold appeared in the CA-plastic greenhouse on 30 January, 3 April, and 13 March 1989 on Earlypak No. 7 and on 16 February, 10 April, and 20 March on Dombo, respectively. In the IRA-vinyl greenhouse, they appeared on 16 February, 15 April, and 20 March on Earlypak No. 7 and 2 March, 24 April, and 27 March on Dombo, respectively.

At the end of the crop season, disease indices on both cultivars in the IRA-vinyl greenhouse were about 40% of those in the CA-plastic greenhouse (Table 2). At the end of the experiment, two plants of Dombo and three plants of Earlypak No. 7 had symptoms of Fusarium foot and root rot in the IRA-vinyl greenhouse in comparison with eight plants from both cultivars in the CA-plastic greenhouse.

Table 3. Effect of an infrared-absorbing (IRA)-vinyl film in comparison with a common agricultural (CA)-polyethylene film on the number of inflorescences and infructescences per plant of greenhouse tomato cultivars Earlypak No. 7 (EP) and Dombo

Observation date	Inflorescences/plant (no.)[a]				Infructescences/plant (no.)[a]			
	IRA		CA		IRA		CA	
	EP	Dombo	EP	Dombo	EP	Dombo	EP	Dombo
1986–1987								
13 Feb.	4.7 ± 0.9	4.1 ± 0.6	3.3 ± 0.6	3.4 ± 0.7	2.7 ± 0.9	2.6 ± 0.6	0.5 ± 0.7	0.5 ± 0.5
22 May	9.4 ± 1.5	10.1 ± 1.3	8.9 ± 1.4	7.8 ± 1.8				
1988–1989								
28 Feb.	4.5 ± 0.4	4.0 ± 0.8	3.0 ± 0.5	3.3 ± 0.6	2.3 ± 0.6	2.1 ± 0.6	0.3 ± 0.4	0.3 ± 0.3
30 May	9.1 ± 1.3	9.9 ± 1.4	8.6 ± 1.2	7.5 ± 1.7				

[a] Mean ± standard deviation on 24 plants.

Table 4. Fruit production of tomato plants of cultivars Earlypak No. 7 (EP) and Dombo in two greenhouses covered with an infrared-absorbing (IRA)-vinyl film or a common agricultural (CA)-polyethylene film[a]

Observation date	Total no. fruits				Total yield (kg/greenhouse)			
	IRA		CA		IRA		CA	
	EP	Dombo	EP	Dombo	EP	Dombo	EP	Dombo
1986–1987								
13 February	9	13	0	0	0.850	1.850	0	0
3 April	61	56	0	3	3.950	8.900	0	0.150
22 May	401	289	226	104	27.450	34.100	10.550	9.700
1988–1989								
28 February	7	15	0	0	0.700	1.700	0	0
20 April	55	49	0	5	3.850	8.600	0	0.230
30 May	380	268	215	96	26.010	31.620	10.040	8.950

[a] Fruits were harvested from 24 plants per cultivar and greenhouse.

In the CA-plastic greenhouse, six fruits with gray mold were found on Earlypak No. 7 and 16 on Dombo in comparison with one on Earlypak No. 7 and three on Dombo in the IRA-vinyl greenhouse. On the other hand, in the IRA-vinyl greenhouse, two plants of Earlypak No. 7 and one plant of Dombo had severe gray mold on the stem compared with five plants of Earlypak No. 7 and 10 plants of Dombo in the CA-plastic greenhouse. In the IRA-vinyl greenhouse, plant growth was much better, immature fruits from both cultivars appeared 35 days earlier, and the first harvest of mature fruits was 70 days earlier than in the CA greenhouse (Tables 3-5). At the end of the experimental period in the IRA-vinyl greenhouse, plant height and fruit production exceeded those in the CA-plastic greenhouse by 2 and 159% for the Earlypak No. 7 and 13.7 and 253% for Dombo, respectively (Tables 4 and 5).

DISCUSSION

The standard polyethylene traditionally used in greenhouses transmits most of the long-wave IR radiation emitted by the ground and plants during the night. As a consequence, the heat accumulated during the day is rapidly lost and the plants remain unprotected against the low temperatures caused by the night cooling of the greenhouses. The low temperatures during the night can give rise to "thermal inversions" (lower temperatures inside than outside the greenhouse), which can cause frost, even when the external temperatures are higher than 0 C (3). The long-wave IRA-vinyl film is fairly impervious to this radiation and, therefore, it reduces the cooling of the greenhouse and the possibility of thermal inversion occurring during the night. Reduction in the cooling of the greenhouse also may reduce RH. In addition, the higher water vapor transmittance of the IRA-vinyl film can result in a decrease in RH. High RH, as it is well known, favors most of foliage diseases (2,10). As a result, lower disease intensities and improved plant development, as well as a larger and earlier crop yield, were observed in our experiments in the IRA-vinyl greenhouse compared with the CA-plastic greenhouse.

The decrease in development of early blight, leaf mold, and gray mold in the greenhouse with the IRA-plastic cover may be an indirect effect of increased temperature in these diseases by increasing the vigor of the plants. The effect also may be a direct effect in reduction of pathogen development from the decreased RH.

We are not aware of practical or experimental control of any plant disease in greenhouse crops by using IRA-plastic covers. Attempts to control several diseases of greenhouse vegetables with UVA-vinyl films were successful, but they were based on the elimination of UV radiation with wavelengths lower than 330 nm, which adversely affected pathogen sporulation (4,5,8,11). In our experiments to examine only the effect of IR characteristics of plastic cover on plant disease development, we eliminated the UV radiation of the solar spectrum by using plastic materials with transmittance in the UV region higher than 330 nm.

The practice of controlling pests in

Table 5. Growth of tomato plants of cultivars Earlypak No. 7 (EP) and Dombo in two greenhouses covered with an infrared-absorbing (IRA)-vinyl film or a common agricultural (CA)-polyethylene film

Observation date	Plant height (mm)[a]				Stem diameter (mm)[a]			
	IRA		CA		IRA		CA	
	EP	Dombo	EP	Dombo	EP	Dombo	EP	Dombo
1986–1987								
13 Feb.	131 ± 17	112 ± 10	107 ± 10	100 ± 11	ND	ND	ND	ND
22 May	199 ± 28	230 ± 11	192 ± 22	203 ± 18	11.9 ± 9.4	14.2 ± 9.0	10.6 ± 1.8	11.6 ± 1.6
1988–1989								
28 Feb.	127 ± 15	108 ± 10	101 ± 8	95 ± 8	ND	ND	ND	ND
30 May	205 ± 25	240 ± 12	201 ± 23	211 ± 17	10.9 ± 8.4	13.8 ± 6.0	10.0 ± 1.4	10.6 ± 1.3

[a] Mean ± standard deviation on 24 plants. ND = not determined.

greenhouse tomato by reducing heat loss from plants and soil and decreasing RH with long-wave IRA-vinyl films may be integrated with other control measures. Sporulation of *A. solani*, *C. fulvum*, and *B. cinerea* could be inhibited by UVA-plastic films. Additional control measures, such as the removal of diseased plant parts, regular fertilizations, adequate spacing between plants, ventilation, regular irrigation, and application of effective fungicides (9,10), should increase disease control.

ACKNOWLEDGMENTS

I thank Professor Yuchi Honda (Faculty of Agriculture, Shimane University, Matsue, Shimane 690, Japan) for providing the IRA-vinyl film. I also thank A. Tsingas (Ciba-Geigy Hellas Ltd., Athens, Greece) and A. Mintsios (Bayer Hellas Ltd., Athens, Greece) for financial support for the publication of this article.

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