Unique Vapor Activity by CGA-64251 (Vangard) in the Control of Powdery Mildews Roomwide in the Greenhouse

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ABSTRACT

Szkolnik, M. 1983. Unique vapor activity by CGA-64251 (Vangard) in the control of powdery mildews roomwide in the greenhouse. Plant Disease 67:360-366.

Unique and complete control of powdery mildews in 112-m^3 greenhouse rooms at 21–28 C was achieved for 3 mo and longer by vapor action of CGA-64251 (Vangard) applied to cheesecloth, cotton or olefin fiber cord, or polypropylene shading cloth. The vapor inhibited spore germination and repressed mildew colonies. The powdery mildew fungi controlled in these trials were *Podosphaera leucotricha* (on apple), *Sphaerotheca fuliginea* (on cucurbits), *Erysiphe polygoni* (on beans and peas), *Uncinula necator* (on grape), *S. pannosa* (on rose), *Oidium caricae* (on papaya), and *E. cichoracearum* (on broadleaf plantain). The vapor phase control was highly effective in greenhouses into which outside air was introduced through vents and evaporative coolers. No phytotoxic effect of CGA-64251 vapor on exposed plants was detected. When these plants were moved from a CGA-64251-treated to an untreated room, the foliage was readily colonized by their respective mildews.

Fungicides play a diverse role in the control of plant diseases through many chemical and physical modes of action. The broad category of physical modes of action includes 1) protection and retentiveness of formulated fungicides to the plant surface, 2) after-infection or eradicative activity, 3) presymptom activity, 4) postsymptom activity, and 5) fungicide mobility (8). Fungicide mobility includes 1) penetration of waxes, cuticle, and cell walls and movement of the toxicant within plant tissues (systemic action); and 2) relocation (redistribution) of fungicidal residues on the plant surface by the action of rainfall or other forces. Still another mode of action, that of the vapor phase of a fungicide, which provides disease control without application of the chemical directly to the plant, has received relatively little research attention. This activity is not a new phenomenon, as attested to by Martin's citation of an 1852 report by Bergman that vapors from sulfur painted onto greenhouse heating pipes controlled powdery mildew (4).

In recent years, several researchers have reported positive vapor action within limited environments with fungicides other than sulfur. Bent (1) found that the treatment of the proximal, distal, or lateral half of cucumber leaves with drazoxolon resulted in vapor action control of powdery mildew as far as 17.8 mm into the untreated area of the leaf. Hislop (3) attributed the infection-free zone surrounding fungicide deposits on bean leaves inoculated with *Botrytis fabae* Sard. to the action of vapor from fungicides. Solel (7) found that vapor from maneb, fentin acetate, and several benzimidazole fungicides inhibited germination of *Cercospora beticola* Sacc. spores by use of fungicide hanging-drop mounts on sugar beet leaves. Scheinpflug and Paul (6) reported that vapor from triadimefon-treated barley plants in 6.6-cm pots centrally located in an open-top cabinet provided substantial control of powdery mildew on untreated plants in two rows of pots adjacent to the treated row. Petsikos-Panayotarou (5) obtained protection against powdery mildew of squash at the three-leaf stage with vapors

Approved by the director of the New York State Agricultural Experiment Station for publication as Journal Paper No. 3445.

Accepted for publication 27 August 1982.

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of imazalil, triadimefon, or bipirimate applied to the cotyledons. Gallian and Coyier (2) controlled powdery mildew on detached rose leaves in closed greenhouse chambers with vapor from nuarimol and fenapanil heated to 150 C. I (9,10) reported near-complete control of powdery mildew on untreated apple seedlings in a 0.3-m^3 closed chamber at normal greenhouse temperatures by vapor from seedlings or cheesecloth treated with either CGA-64251 (Vangard) or triadimefon. I also reported that vapor from a canopy of CGA-64251-treated cheesecloth over about 50 15-cm pots of untreated apple seedlings on a greenhouse bench provided substantial control of powdery mildew (10). Triadimefon was not effective when used in this manner (*unpublished*).

This paper presents the results of a managed experiment on mildew control in an entire greenhouse room and of several applied trials for roomwide protection against powdery mildews with modified techniques of vapor-action treatment. Brief reports on these have appeared previously (11,12).

MATERIALS AND METHODS

Greenhouse controlled experiment. Treatment of entire greenhouse was limited to one material and rate. CGA-64251 was chosen because of its unique effectiveness both in closed fumigation chambers and beneath loose cheesecloth canopies. Curity Grade 50 cheesecloth (11 × 9 threads per centimeter) of 7.7 m^2 area was soaked in 800 ml of a suspension containing 3.85 g of CGA-64251 10W. To attain relative uniformity of treatment, the cheesecloth was repeatedly kneaded with the suspension to express and reabsorb it. The entire suspension was taken up by the cloth, which was then spread horizontally to near dryness to avoid eventual dripping from the cloth and loss of dry fungicide powder from the cloth during handling. The cloth was suspended as a curtain from hooks on a rod mounted in the center of the greenhouse 2.8 m above the floor, with the bottom of the curtain extending to 20 cm above the greenhouse bench that held the plant material (Fig. 1). The 3.85 g of 10% active CGA-64251 in the curtain in the 112-m^3 greenhouse room provided about 3.43 mg of active fungicide per cubic meter.

Conditions favorable to powdery mildew were maintained in the treatment greenhouse room and an adjacent control room. The average temperature was 23.5 C, ranging in weekly average between 21 and 28 C. The relative humidity (RH) was maintained above 50% RH by bench stones kept wet by a series of parallel bleed-irrigation plastic lines embedded in the stones and by the floor kept wet by a series of drip tubes normally used for automatic irrigation of pots. Twice a week, the houses were brought to RH

Table 1. Level and duration of control of cucumber and bean powdery mildews throughout a greenhouse room by vapor of CGA-64251 (Vangard) from a one-time treated cheesecloth curtain centrally suspended within the room

Weeks into treatment[a]	Treated greenhouse: Leaves infected (%)	Treated greenhouse: Lesions/ infected leaf	Untreated greenhouse: Leaves infected (%)	Untreated greenhouse: Lesions/ infected leaf
		Cucumber		
7	0	0	100	110
9	0	0	100	108
10	0	0	100	109
11	0	0	100	110
12	0	0	100	107
13	0	0	100	99
14	0	0	100	100
15	25	8	100	74
16	35	13	100	88
17	33	27	100	105
		Bean[b]		
14	0	0	100	117
15	0	0	100	198
16	0	0	100	51
17	0	0	82	74
19	0	0	99	14

[a] From date of cheesecloth curtain treatment with CGA-64251. Cheesecloth treated once and centrally suspended in the greenhouse.
[b] Data on bean leaflets.

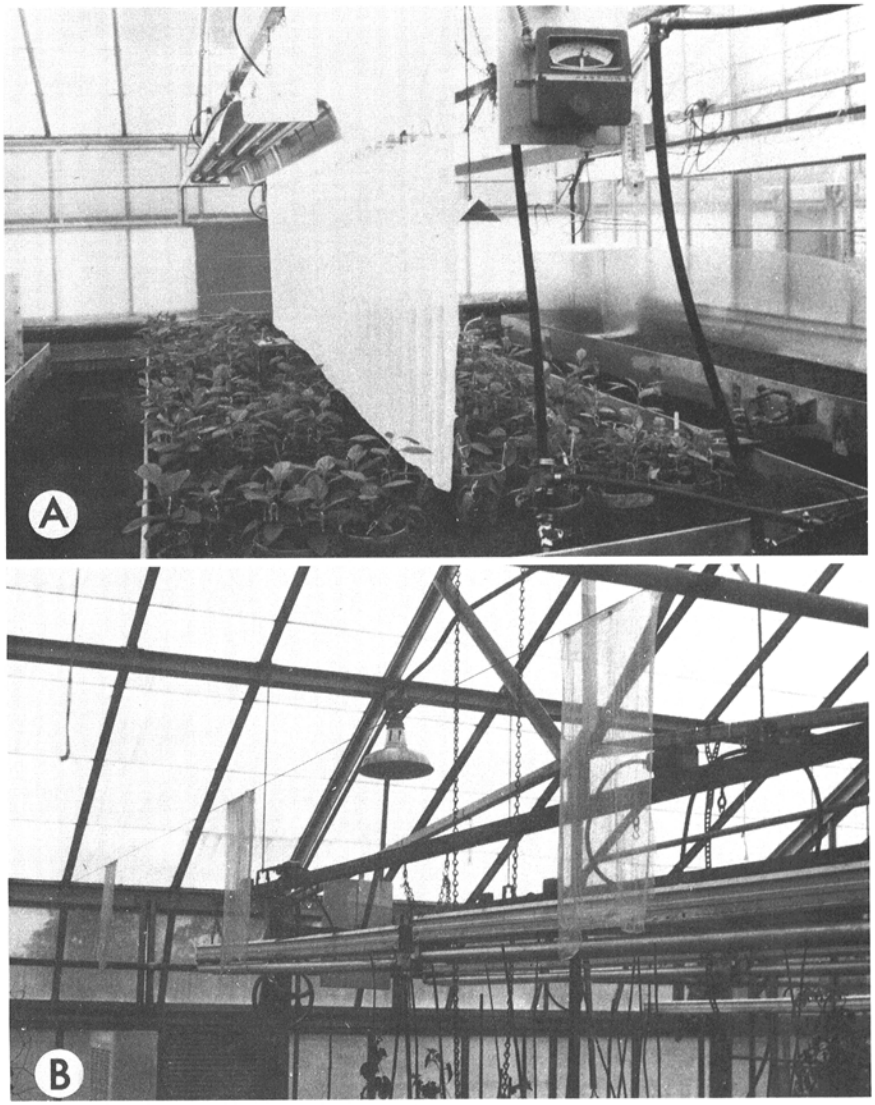

Fig. 1. Cheesecloth curtains treated with CGA-64251 (Vangard) for roomwide protection against powdery mildews by vapor-phase action of the fungicide. **(A)** One centrally located 7.7-m^2 curtain. **(B)** Three of six curtains with a total area of 0.9 m^2 distributed within the greenhouse room.

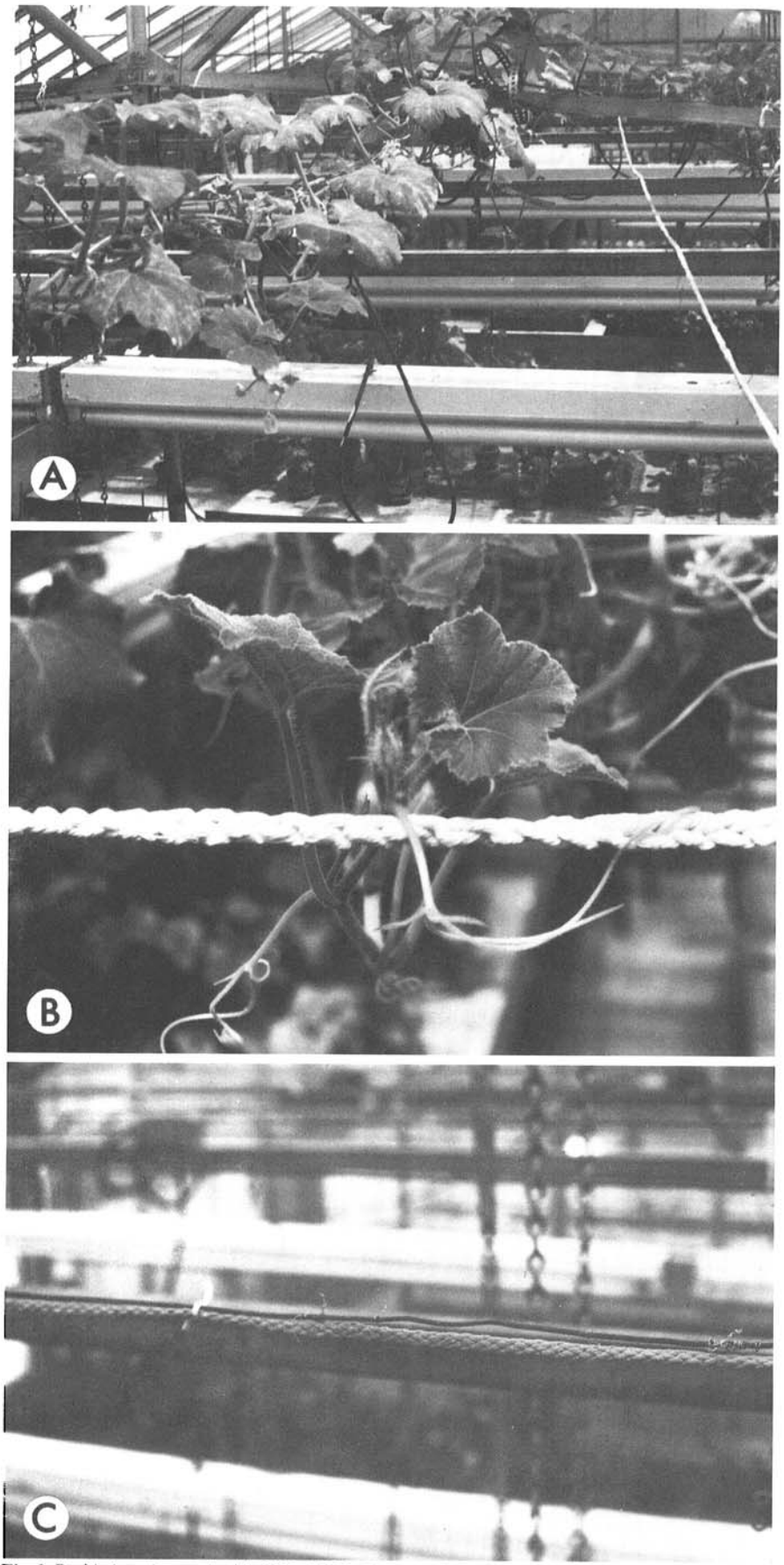

Fig. 2. Braided cord treated with CGA-64251 (Vangard) for roomwide protection against powdery mildews by vapor action of the fungicide. **(A)** One 8.5-m length of braided cotton cord protects an entire greenhouse room. **(B)** Close-up of braided cotton cord. **(C)** Close-up of braided Herculon olefin fiber cord.

above 90% by misting for 16 hr (overnight) with ¼ JN air-water atomizing nozzles (Spraying Systems Co., Wheaton, IL 60187). All vents were kept closed, and the only outside air introduced into the room was admitted through the door during access to the room for plant maintenance and conduct of the experiment.

At weekly intervals, new groups of dry potted apple, *Malus domestica* Borkh. (cultivar McIntosh, five plants per pot), seedlings were mass-inoculated by liberally dusting them with powdery mildew conidia from infected plants. Half of the plants were placed on benches in treated and half in untreated rooms. Determination of possible gradient effects of vapor from the cheesecloth curtain was made by placing six pots of inoculated plants in a row 10–90 cm from the curtain, three on either side of the curtain and three pots in a row on an adjacent bench 1.4–2.2 m from the curtain (Fig. 1). Pots of inoculated cucumber, *Cucumis sativus* L. (cultivar Marketer), and bean, *Phaseolus vulgaris* L. (cultivar Red Kidney), were placed about 1–3 m from the curtain. Studies included the interchange of plants after long exposures in the treated and untreated rooms to determine possible residual effects from the vapor treatment. Duration of the vapor effects was determined by continued weekly introduction of freshly inoculated plants.

Fungicide efficiency was determined by counting mildew lesions on the one or two youngest leaves present when the plants were placed in the respective greenhouse rooms and on the next two leaves that developed.

Applied usage. It was first determined that vapors from the CGA-64251-treated curtain provided complete long-term protection against powdery mildew and that 3.43 mg of active CGA-64251 per cubic meter was well within safety standards when compared with the LC_{50} level (>2000 mg/m^3) determined by inhalation studies (J. R. James, *personal communication*). Treatments were then extended to other greenhouse rooms where powdery mildews on various plants persisted as problems in spite of spraying with fungicides. In these studies, unlike the controlled experiment, the greenhouse rooms were normally maintained to include introduction of outside air via vents and evaporative coolers.

Studies were conducted to determine 1) whether there was a critical relationship between the area of treated cheesecloth and volume of the room, 2) the influence on performance in greenhouses under normal maintenance with introduction of outside air, and 3) the efficacy of treatment methods other than impregnated cheesecloth.

In the area-volume relationship studies, cheesecloth, 3.8, 1.9, and 0.9 m^2, was impregnated with 3.85 g of CGA-

64251 10W in separate 112-m^3 greenhouse rooms. In one room, a single centrally located 3.8-m^2 curtain suspended 2.8 m above the floor was used against bean mildew; in another room, four small curtains of 0.47 m^2 each (total 1.9 m^2) were suspended from two horizontal wires 1.8 m apart and 2.3 m off the floor in approximately four corners of the room, 1.5 m from the walls; and in a third room, six smaller curtains of 0.15 m^2 each (total 0.9 m^2) were suspended from two parallel wires 1.8 m apart, 2.3 m above the floor (Fig. 1).

In additional trials: 1) an 8.5-m-long braided cotton rope was impregnanted with 3.85 g of CGA-64251 10W. The rope was extended as a single strand 2.3 m above the floor horizontally across a 10.5-m-wide (224-m^3) greenhouse room, which provided 1.72 mg of active CGA-64251 per cubic centimeter (Fig. 2); and 2) a suspension of 7.7-g 10% CGA-64251 in 350 ml of water was applied with a paint sprayer in 10-cm-wide bands 1.3 m apart onto a polypropylene shading cloth suspended horizontally 2.1 m above the floor in a 224-m^3 greenhouse room.

In further trials: 1) two 3-m-long pieces of Herculon braided olefin fiber cord (Puritan Mills, Inc., Madison, GA 30650) (Fig. 2) were impregnated with 3.85 g of CGA-64251 10W in water. The cords were tied to two horizontal wires 1.8 m apart and 2.3 m above the floor in a 112-m^3 greenhouse room; 2) two 3-m-long pieces of Herculon cord were impregnated with 0.39 g of CGA-64251, 99.5% technical grade, dissolved in 120 ml of methanol. The cords were mounted 1.8 m apart horizontally 2.3 m above the floor in a 112-m^3 greenhouse room; and 3) four 0.47-m^2 pieces of cheesecloth were impregnated with 0.39 g of CGA-64251, 99.5% technical grade, dissolved in 180 ml of methanol. The cloth was hung from wires or light fixtures 2.3 m above the floor in a 112-m^3 greenhouse room.

As in the rigidly controlled experiment, all of the applied trials were a one-time treatment using the materials described.

RESULTS AND DISCUSSION

Controlled experiment. Vapor from the CGA-64251-impregnated 7.7-m^2 cheesecloth curtain provided complete protection against apple powdery mildew (Figs. 3 and 4). This unique protection occurred throughout the 112-m^3 greenhouse room for extended periods at temperatures and RH highly favorable to the mildew pathogens. Complete protection of apple lasted for 11 wk, at which time diminishing levels of CGA-64251 vapor were manifested in a gradient control effect both in time and in distance from the treatment source. Beginning the 12th week from the start of treatment, control of mildew on apple seedlings about 1.9 m from the cheesecloth gradually diminished week by week until the 16th week, when no further control occurred. In contrast, seedlings about 40 cm from the cheesecloth had small weekly incremental increases in infection but still showed a substantial level of protection at the 16th week.

Complete protection against cucumber powdery mildew covered a span of 14 wk before the onset of diminishing control was observed (Table 1). Substantial protection of newly inoculated cucumber plants exposed to CGA-64251 vapor treatment 17 wk from the time of curtain treatment was still in effect even at distances of 2 m from the curtain where

Table 2. Plant species that were fully protected against their specific powdery mildew diseases in the greenhouse by the vapor action of the fungicide CGA-64251 (Vangard)[a]

Pathogen	Plant species
Erysiphe cichoracearum DC.	Lettuce (*Lactuca sativa* L.)
	Broadleaf plaintain (*Plantago major* L.)
E. graminis DC.	Wheat (*Triticum aestivum* L.)
	Rye (*Secale cereale* L.)
E. polygoni DC.	Bean (*Phaseolus vulgaris* L.)
	Clover (*Trifolium pratense* L.)
	Cabbage (*Brassica oleracea* L. var. *capitata* L.)
	Broccoli (*B. oleracea* L. var. *botrytis* L.)
	Chinese cabbage (*B. campestris* L. subsp. *pekinensis* (Lour.) Olsson)
	Pea (*Pisum sativum* L.)
	Cowpea (*Vigna unguiculata* (L.) Walp.)
Podosphaera leucotricha (Ellis & Everh.) Salm.	Apple (*Malus domestica* Borkh.)
Sphaerotheca caricae (*Oidium caricae*)	Papaya (*Carica papaya* L.)
S. fuliginea (Schlecht.) Poll.	Cucumber (*Cucumis sativus* L.)
	Jelly melon (*C. metuliferus* (Naud.) Mey.
	Muskmelon (*C. melo* L.)
	Squash (*Cucurbita pepo* L.)
	Wild squash (*C. ecuadorensis* Cutler & Whitaker)
S. pannosa (Wallr.) Lev.	Rose (*Rosa odorata* Sweet)
Uncinula necator (Schw.) Burr.	Grape (*Vitis labrusca* L.)

[a] CGA-64251 10W in water or the 99.5% technical grade in methanol was applied to cheesecloth, braided cotton or olefin fiber cord, or polypropylene shading cloth spaced in the greenhouses for roomwide protection.

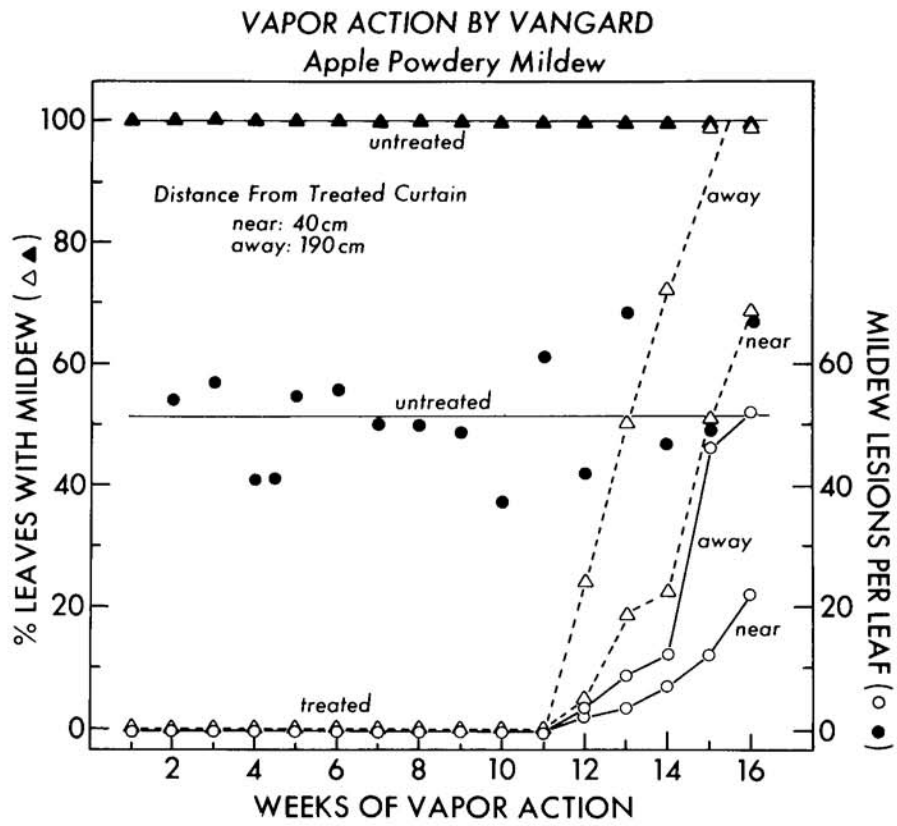

Fig. 3. Complete protection of apple against powdery mildew by vapor action of CGA-64251 (Vangard) impregnated once into a 7.7-m^2 cheesecloth curtain. After 11 wk, the diminishing level of protection was varied with distance of trees from the curtain.

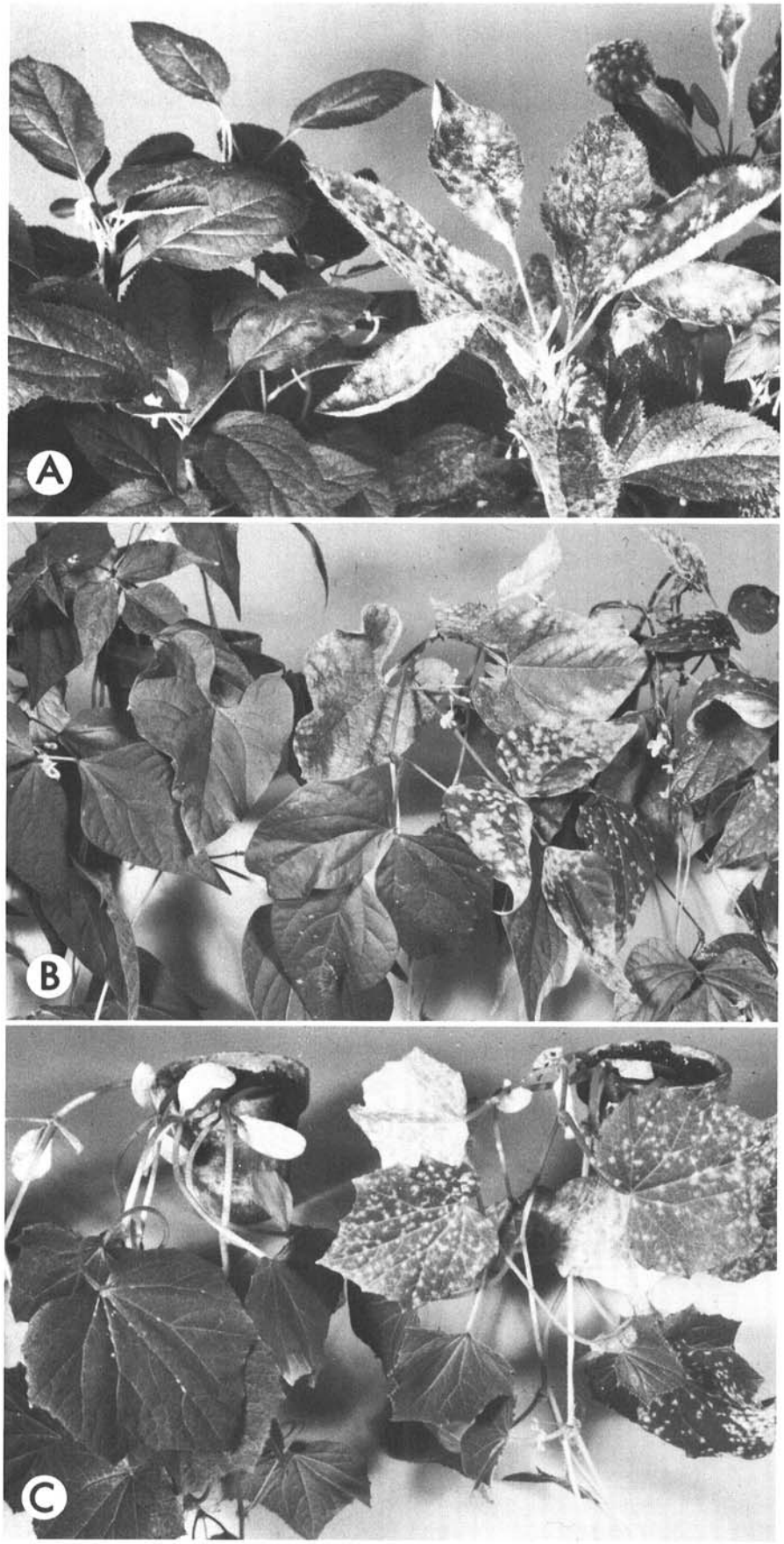

Fig. 4. Protection of **(A)** apple seedlings, **(B)** beans, and **(C)** cucumbers against their respective powdery mildews by the vapor action of CGA-64251 (Vangard). The inoculated apple plants were placed into the room about 12 wk after the one-time treatment of the cheesecloth curtain with CGA-64251.

apple mildew control had ceased.

Bean plants were fully protected against mildew for about 19 wk (Table 1). The experiment was concluded at this time because the high temperatures (reaching 38 C) in the greenhouse, which had been purposely kept unvented, became unfavorable to the powdery mildew pathogens and mildew infections became diminished and erratic.

During this experiment, other plants fully protected against their respective powdery mildews by the CGA-64251 vapor action included peas, grape, rose, and papaya. Limited quantities of these plants precluded their being fully tested on a week-by-week schedule as were the apple, cucumber, and bean. Mildew growth frequently occurred first on the main leaf veins of apple, bean, and cucumber plants as the threshold level of CGA-64251 vapor was reached (Fig. 5).

Residual effect. During this study, symptom-free apple, cucumber, and bean plants from the CGA-64251-treated room were transferred to the untreated room, and severely infected plants of these species were transferred from the untreated to the treated room. The youngest leaves of the formerly protected plants showed visible mildew lesions within 5 days in the untreated room, indicating the lack of any significant CGA-64251 residue on the plants. The youngest leaves still without symptoms on severely infected plants transferred to the vapor treatment room developed very few restricted lesions, but the subsequent new leaves were fully protected against new mildew colonies throughout their exposure in the treated room.

Abnormal lesions. Within a day or two after CGA-64251 exposure, the mildew lesions became abnormally restricted (Fig. 6). To the unaided eye, this was evident as a somewhat smaller lesion and a "clumping" effect. Magnification revealed that the spore chains were curled and intertwined instead of being free and straight or lightly curled as they were in lesions not exposed to the vapor. Preliminary trials to determine spore viability by inoculation of apple seedlings revealed that the spores from restricted lesions did not dehisce freely and independently. Delayed and sparse lesions developed on inoculated leaves, but it could not be determined that these were not the result of contaminant normal mildew spores.

Six months after the beginning of the controlled experiment, the cheesecloth curtain was removed and the greenhouse room was reverted to normal venting and continued mildew research. Abundant powdery mildew development on apple, cucurbits, beans, peas, grape, papaya, and rose was evidence that no significant residue from the CGA-64251 vapor remained in the room.

Applied greenhouse usage. The applied usage of the CGA-64251 vapor in the

successful control of powdery mildews on all hosts in more than 25 greenhouse rooms proved that its action is not restricted to fully closed greenhouse rooms (Table 2). All of the houses were under normal management with the introduction of outside air, as needed, through doorways, automatic ventilation, and evaporative coolers. Complete protection of many hosts against mildew for 3 mo and longer became effective from about the date of room treatment. In some of these rooms, powdery mildew could not previously be controlled even with dilute sprays with dinocap two or three times weekly. Station colleagues whose greenhouse rooms and growth chambers were CGA-64251-treated for vapor action reported no adverse effects either on hosts or diseases from the vapor in their studies with viruses and with fungal and bacterial pathogens. After I determined that CGA-64251 vapor at the levels used in mildew control does not provide protective or eradicative action against the apple scab pathogen, *Venturia inaequalis* (Cke.) Wint., I regularly employed CGA-64251 vapor treatment in greenhouse rooms where powdery mildew would be very undesirable in biological and fungicide evaluation studies on apple scab. One researcher employed the CGA-64251-treated cheesecloth curtain to fully control severe powdery mildew infection of beans used in biological studies on the two-spotted mite, *Tetranychus urticae* Koch. Vapor from the cheesecloth curtain (CGA-64251, 3.4 mg a.i./ m^3) had no deleterious effect on mites at any stage during more than one year's use of the vapor treatment.

Area-volume relationship. Studies on the relationship of area of treated cheesecloth and greenhouse room volume revealed that the 3.85 g of CGA-64251 10W applied to cheesecloth of 7.7, 3.8, 1.9, and 0.9 m^2 area in greenhouse rooms of 112 m^3 provided complete protection of many hosts, particularly cucurbits and beans, against powdery mildews for 3 mo and longer in greenhouse rooms under normal management, allowing for introduction of outside air. Further studies to determine a threshold relationship between treated area and room volume are in progress.

Other treated materials. Excellent control of powdery mildews by CGA-64251 vapor activity was observed with the fungicide applied to materials other than cheesecloth. Full protection of many hosts against powdery mildews for periods in excess of 3 mo occured with 1) CGA-64251 10W (3.85 g/ 112 m^3) applied to braided cotton cord or olefin fiber braided cord or painted in bands onto polypropylene shading cloth; and 2) CGA-64251, 99.5% technical grade (0.39 g/ m^3), dissolved in methanol and applied to olefin fiber braided cord or cheesecloth (Table 2). This indicates that the same benefits of vapor action can possibly be derived from CGA-64251 applied to other surfaces like glass, metal supports, etc., at appropriate rates and area-volume ratios.

Pathogen resistance. Several greenhouse rooms have been on CGA-64251 vapor treatment schedules for about 9 mo under

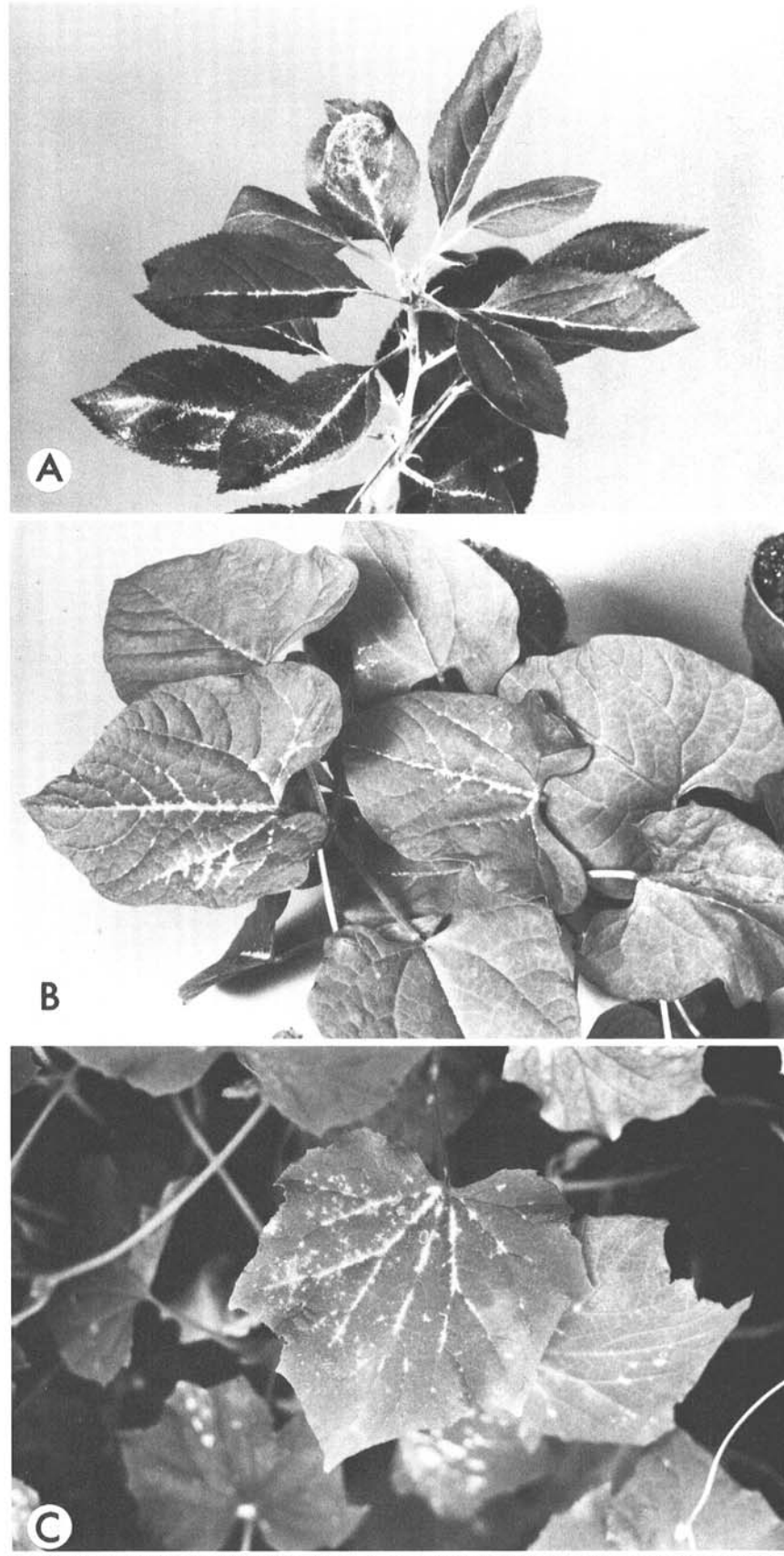

Fig. 5. Powdery mildew of **(A)** apple, **(B)** bean, and **(C)** cucumber often begins to appear at the main leaf veins as the CGA-64251 (Vangard) vapor in the room reaches a threshold level needed for protection.

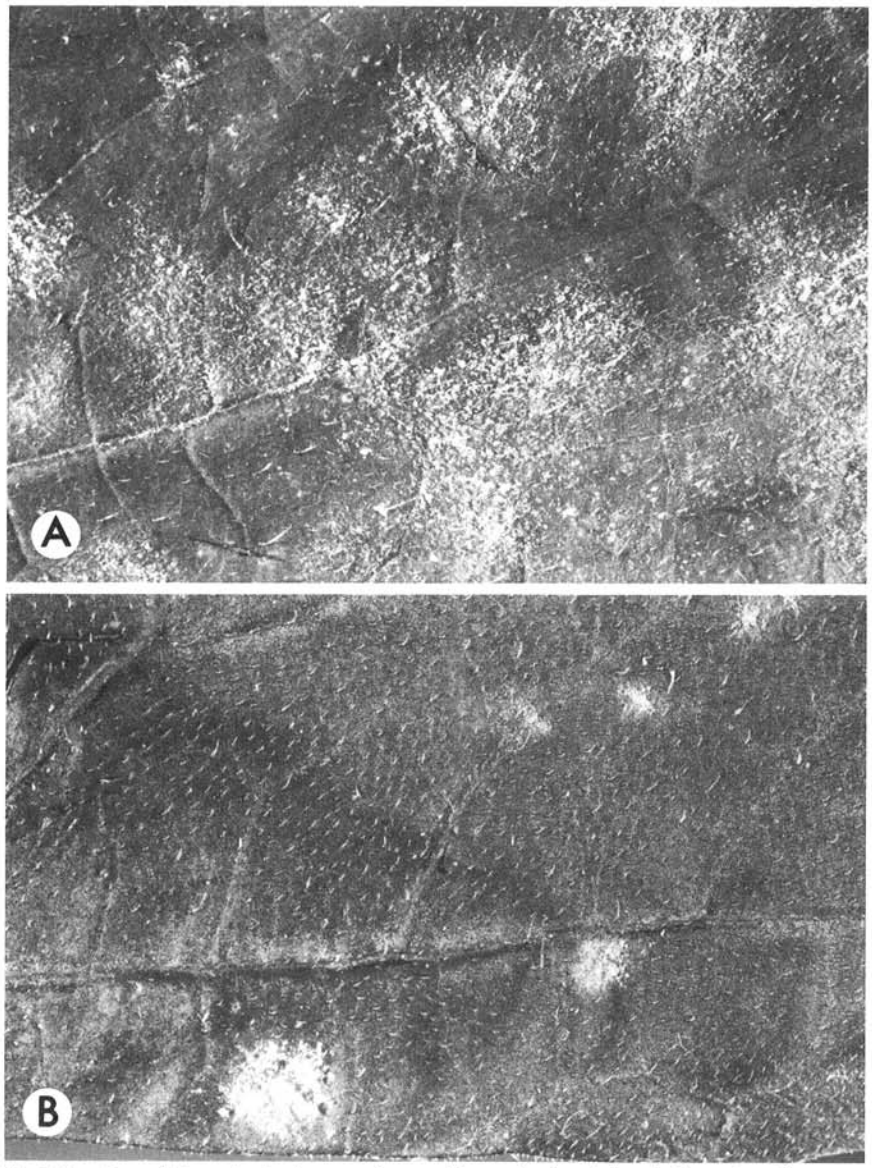

Fig. 6. Powdery mildew colonies become abnormally restricted on infected plants placed in a room treated for CGA-64251 (Vangard) vapor action. Cucumber leaf with **(A)** normal and **(B)** restricted mildew colonies.

a schedule of re-treatment of the cheesecloth every 3–4 mo for sustained full protection against mildew. In one house with treated olefin braided cord, a few mildew lesions were detected on squash leaves at the end of 2 mo. Because the room was under continuous treatment for 9 mo, resistance in *Sphaerotheca fuliginea* to CGA-64251 was suspected. Comparative studies in closed vapor chambers (10) with the suspect inoculum and that of a sensitive source showed that no resistance had developed at this time. Failure of full protection for more than 2 mo in the one greenhouse indicates the need to either increase the level of CGA-64251 or to increase the length, beyond the 6 m, of the type of olefin cord used in this study.

All of the studies on CGA-64251 vapor action so far indicate that the excellent protective action occurs from 1) a constant presence of very low levels of vapor, even in ventillated rooms; 2) a favorable specific gravity of CGA-64251 vapor with respect to air; and 3) favorable convection movement of the vapor without adverse stratification. All of the CGA-64251-treated materials were mounted well above the plants in the room and out of the way of personnel.

Powdery mildews differ in their response to the vapor treatment as evidenced by the duration of effective control. Bean mildew was effectively controlled for the longest period of time, followed in order by mildews of cucurbits, apple, and rose.

Some observations point to a possible reduction of CGA-64251 vapor activity at low temperatures. Mildew colonies were observed on apple and squash in treated greenhouse rooms where temperatures dropped to about 14 C. Although this approaches a low temperature level for powdery mildew infections, there is a need to determine whether the release of CGA-64251 vapor indeed diminishes at this temperature and if the air concentration of the vapor falls to near-threshold levels.

Benefits from the CGA-64251 vapor action can be considerable to researchers plagued with powdery mildew problems and to commercial growers of susceptible plants in greenhouses and screenhouses. Some evidence points to possible fringe benefits of vapor action in fields sprayed conventionally with CGA-64251. Such action, not recognized as vapor action at one time, is now attributed to powdery mildew suppression on apple with triarimol applied by airplane in an orchard program for scab control. In this aerial program, sulfur and dinocap failed to provide control of mildew.

ACKNOWLEDGMENTS

I thank R. Provvidenti for his continuing supply of vegetable plant materials and for use of his greenhouse in applied studies on vapor action.

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