Control of Cucurbit Powdery Mildew with JMS Stylet-Oil

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ABSTRACT

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Laboratory and greenhouse studies were conducted to determine the effect of JMS Stylet-Oil on cucurbit powdery mildew. In laboratory studies, JMS Stylet-Oil (1.5%) applied with a low-pressure sprayer (138 kPa) significantly reduced colony size, but did not eradicate pre-existing mildew colonies. Applying oil every 4 days was more effective than a single application. Oil did not significantly reduce spore viability, since spores taken from sprayed colonies readily formed new colonies. Although oil appeared to cause abnormalities of conidiophores and spores immediately after application, this effect was temporary. Tween 20 had an inhibitory effect on mildew growth and increased the effectiveness of oil when the two were applied together. Efficacy of oil was increased by using a high-pressure sprayer (1380 kPa). In the greenhouse experiment, JMS Stylet-Oil (0.75%) applied once to summer squash either 4 h before transfer of conidia to inoculation sites or 5 days after inoculation suppressed the size of the area infected by 48 to 60%. A single application of oil 5 days before inoculation was not effective. A 4-day spray program beginning 5 days after inoculation was effective. Compared with nontreated plants, oil-treated plants had fewer symptomatic leaves (71 vs. 34%, excluding leaf 1 and inoculated leaves) and fewer colonies (244 vs. 26) 20 days after inoculation.

Additional keywords: biocompatible fungicide, mineral oil, *Podosphaera* (*Sphaerotheca*) *xanthii*, *Sphaerotheca fuliginea*, *Sphaerotheca fusca*

Identifying biocompatible materials with low toxicity that can effectively replace conventional chemical fungicides is a valuable contribution to disease management. Severity of several diseases has been effectively reduced by mineral oils (4,7,14,19,30), plant oils (9,25), film-forming antitranspirants (6,27), sodium or potassium bicarbonates (7,11,19,30), and bicarbonates mixed with oils (1,7,8,11,19,26) applied to cucurbit crops (6,8,11,14,25,26,30), asparagus (6), bean (9), rice (6), sugar beet (6), tomato (6), wheat (1,6,27), apple (6), grape (19), and ornamental crops (4,7). Most work has been done with powdery mildew diseases (1,4,7,8,11,14,19,25,26,30). Diseases caused by insect-transmitted viruses (22,23), bitter rot of apple (6), black spot and powdery mildew of rose (7), Cercospora leaf blight of sugar beets (6), early blight and Septoria leaf spot of tomato (6), rust of bean and wheat (9,27), sheath blight and neck rot of rice (6), stem blight of asparagus (6), and Alternaria leaf spot (30), anthracnose (6), downy mildew (6), and gummy stem blight of cucurbits (30) also have been suppressed; however, these diseases have not been controlled as well

as powdery mildew when compared in the same experiment (1,30). In contrast, bicarbonates and oils used alone or combined in other experiments have not been effective for control of powdery mildew of cucurbits (3,5,20,28,29) or for other diseases (2,10,12,24).

Additional research is warranted on managing powdery mildew of cucurbits with biocompatible materials. Previous successes (8,11,14,25,26,30) indicate management is possible while previous failures (3,5,20,28,29) indicate the need for more research. Powdery mildew of cucurbits is caused by *Podosphaera* (sect. *Sphaerotheca*) *xanthii* (Castagne) U. Braun & N. Shishkoff (also known as *Sphaerotheca fusca* (Fr.) S. Blumer and *S. fuliginea* (Schlechtend.:Fr.) Pollacci) (21). It is one of the most important diseases of cucurbit crops (15). Fungicide applications are the principal management practice (15). Therefore, identifying an effective management program with biocompatible materials for cucurbit powdery mildew could have a major impact on quantity of conventional fungicides applied to cucurbit crops.

The biocompatible material JMS Stylet-Oil (JMS Flower Farms, Inc., Vero Beach, FL) suppressed powdery mildew in a previous experiment conducted with field-grown squash (14). The purity of this paraffinic oil is sufficiently high that it exceeds the standards set by the United States Food and Drug Administration for "Food Grade Quality" mineral oil (J. Simons, *personal communication*). JMS

Stylet-Oil was registered for use in the United States to control insects, mites, and aphid-transmitted plant viruses when the current study was started (EPA Registration No. 65564-1).

The purpose of this study was first to evaluate JMS Stylet-Oil in vitro, where environmental conditions could be controlled and mildew growth could be quantified and then to evaluate JMS Stylet-Oil in the greenhouse where it could be applied with equipment selected to maximize coverage. Specific objectives were to examine the impact on powdery mildew development of application time relative to inoculation time and to evaluate a 4-day spray interval. Additional experiments were conducted to elucidate the mode of action. This particular oil was selected because of its safety and the effort made during its development to create an effective product.

MATERIALS AND METHODS

Laboratory experiments using detached-leaf culture. Detached-leaf culture was accomplished using leaf chambers fashioned from two plastic Petri dishes as described previously (13). Yellow straight-neck squash (*Cucurbita pepo* L.) 'Seneca Prolific' plants were raised from seed in controlled environment chambers set at 23 to 25°C with a 14-h photoperiod. Leaves were removed from 4- to 7-week-old plants with a sterile razor blade. After the leaf lamina was trimmed to fit inside the upper portion of the leaf chamber, the petiole was inserted through a hole into soil mix contained in the bottom portion. Leaves were incubated for 3 to 4 days to ensure that they were not contaminated with powdery mildew prior to inoculation. An isolate of *P. xanthii* (LI3-S17-3) collected in 1994 from a pumpkin experimental field plot in Riverhead, NY, was used for all experiments. The isolate was maintained on detached leaf culture between experiments.

Five experiments were conducted to measure the growth of powdery mildew colonies on detached leaves sprayed with oil suspensions at various times before or after inoculation (Table 1). In all experiments, leaves treated with oil emulsions or water immediately before inoculation were allowed to dry before conidia were applied. Inoculation was at six sites per leaf, and colony diameter was measured 14 to 19 days after inoculation and averaged over the six sites. Leaves were inoculated by using a fine paint brush to transfer a clump of about 10 to 20 conidia to each site.

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In the first set of experiments, leaves were sprayed with a 0.75% emulsion of JMS Stylet-Oil 2 days before, immediately before, immediately after, or 2 days after inoculation. Controls were sprayed with water immediately before inoculation. In the second set of experiments, leaves were sprayed with a 1.5% oil emulsion 2 days before inoculation, just prior to inoculation, or 4 days following inoculation. Controls were sprayed with water prior to inoculation. In the third set, leaves were sprayed once with a 1.5% oil emulsion 4 days after inoculation or every 4 days (four times total). Controls were sprayed with water immediately prior to inoculation. In the fourth set of experiments, leaves were sprayed immediately prior to inoculation with water, a 0.75% oil emulsion, a 0.75% solution of Tween 20 (polyoxyethylene sorbitan monolaurate), or a mixture of oil and Tween 20, both at 0.75%. In all experiments, treatments were applied at 138 kPa with a DeVilbiss Model 152 atomizer (DeVilbiss Health Care, Inc., Somerset, PA) attached to a compressed air source. Finally, to determine if control of powdery mildew was influenced by the pressure used to deliver the spray, an experiment was done measuring the growth of powdery mildew colonies on detached leaves sprayed with 1% JMS Stylet-Oil suspensions that had been applied either at 138 kPa with a DeVilbiss atomizer bottle or at

1380 kPa with a gasoline-powered backpack sprayer (Echo Inc. Model SHR-2100) and ALBUZ lilac ceramic nozzles. Each type of experiment was run twice with 3 to 5 replicate leaves per treatment.

Changes in morphology or viability of conidia in treated colonies. To determine whether oil caused morphological changes in *P. xanthii*, microscopic examination of cleared and stained material was done on treated colonies at various times after treatment. Colonies were excised from leaves using a #9 cork borer, added to 98% ethyl alcohol, and heated to a gentle boil on a laboratory hot plate for 1 h. The cleared tissue was then added to a saturated solution of chlorazol black e (Sigma C-1144 lot 53H0554) in alcohol (modified from [18]). When tissue had stained sufficiently (2 h to overnight), it was examined microscopically at $\times 400$.

To determine if oil treatments had any toxic effects on mildew conidia, the viability of conidia from treated colonies was tested using two methods. In the first, conidia from a single conidiophore (one to three conidia) were transferred (using an eyelash attached by paraffin wax to a handle made from a capillary-tube) to leaves in detached culture that had just been sprayed with JMS Stylet-Oil at 1.5% (138 kPa) or sprayed with water alone. Four leaves per treatment were inoculated at 12 sites each (sites indicated with a dot of ink

from a Sharpie pen). In the second method, clumps of conidia from oil-sprayed colonies were inoculated onto cotyledon disks. Leaf disks were cut from the cotyledons of 2-week old cv. Seneca Prolific squash plants using a #9 cork borer and placed 4 per plate in 15-cm diameter Petri dishes containing solidified 5% water agar. Conidia were removed from the treated parent colony by an eyelash. Approximately 5 to 10 conidia adhering to the eyelash were transferred. After a week, leaves and cotyledon disks were examined for mildew colonies.

Control of powdery mildew under greenhouse conditions. Plants of yellow squash cv. Seneca Prolific were grown in 10-cm-diameter pots. Fertilizer (20-20-20 Peters all-purpose, J. R. Peters Inc., Allentown, PA) was applied weekly at a rate of 40 mg N in 100 ml per pot. Flowers were removed weekly to encourage vegetative growth. The growing tip plus leaves that had not opened were removed before the last oil application to eliminate leaves that had not been treated. Water was applied to the top of pots to avoid wetting leaves. A Belfort hygrothermograph (Belfort Instrument Company, Baltimore, MD) was used to record temperature and relative humidity.

Oil treatments included a single application of 0.75% JMS Stylet-Oil before or after inoculation and multiple applications made at 4-day intervals. This experiment was conducted twice (Tables 2 and 3). Treatments were arranged in a randomized complete block design with six replications, each on a separate bench, and three plants per treatment in each replication. Plants were removed from the benches and arranged in a line on the floor of the greenhouse for treatment. JMS Stylet-Oil was applied with a gasoline-powered backpack sprayer and hand-held boom equipped with four ALBUZ lilac ceramic nozzles spaced 20-cm apart that delivered 374 liter/ha at 1380 kPa. The boom was held about 30 cm above the top of the plants. The first application was made 4 days before inoculation when plants were three weeks old and had three true leaves.

All plants for each repetition were inoculated on the same day with the *P. xanthii* isolate used in the laboratory experiments. A fine paint brush was used to transfer conidia from detached cotyledons on water agar to two sites on the adaxial leaf surface. The second and third true leaves were inoculated in the first repetition and the third leaf was inoculated in the second.

The effect of oil on viability of conidia produced after inoculation was assessed by transferring conidia from treated and nontreated inoculation sites to nontreated cotyledon disks on water agar. This test was performed several hours after the application made 9 days (repetition 1) or 13 days (repetition 2) after inoculation. A total

Table 1. Growth of powdery mildew colonies on detached leaves sprayed with JMS Stylet-Oil or Tween 20 at different concentrations or spray pressures

Experiment/treatment	Diameter of colony (mm) ^a
Experiment 1—Leaves sprayed with 0.75% oil emulsion:	
2 days before inoculation	16.24 a
Immediately before inoculation	18.82 a
Immediately after inoculation	14.18 a
2 days after inoculation	16.33 a
Control (water immediately before inoculation)	15.78 a
Control (no treatment)	18.01 a
Experiment 2—Leaves sprayed with 1.5% oil emulsion:	
2 days before inoculation	11.76 bc
Just prior to inoculation	12.72 b
4 days following inoculation	10.30 c
Control (water)	15.25 a
Experiment 3—Leaves sprayed with	
Water immediately prior to inoculation	18.25 a
1.5% oil emulsion 4 days after inoculation	13.52 b
1.5% oil emulsion every 4 days	9.24 c
Experiment 4—Leaves sprayed with	
Water immediately prior to inoculation	14.14 a
0.75% oil emulsion	12.22 ab
0.75% solution of Tween 20	10.18 b
Oil and Tween 20, both at 0.75%	7.42 c
Experiment 5—Leaves sprayed with 1% oil emulsion	
At 138 kPa with DeVilbiss atomizer bottle	60.00 a
At 1,380 kPa with backpack sprayer	10.00 b
Control (water immediately prior to inoculation)	13.20 c

^a Numbers are the means of two repetitions each containing 3 to 5 replicate leaves per treatment. Values within an experiment followed by different letters differed significantly at $P \leq 0.05$ by analysis of variance.

of 14 inoculation sites on treated leaves were included. Presence or absence of growth resulting from these conidia was recorded.

The effect of oil on powdery mildew development was assessed at inoculation sites and on other leaves. Area covered with powdery mildew at inoculation sites was estimated by measuring length and width, then multiplying these numbers together. The first measurement was made 3 days after inoculation, before growth had occurred. Secondary colonies were counted on inoculated leaves and on younger leaves above this leaf. Number of symptomatic leaves per plant was determined. Total number and percentage of leaves with symptoms per plant were determined. General condition of inoculated leaves was assessed as an additional measure of the impact of oil and powdery mildew.

Data analysis. SuperANOVA version 1.1 or Minitab 8.21 for the Macintosh computer was used. Multiple comparison testing was done using Tukey's method. Data were tested for random and normal distributions and log-transformed if necessary.

RESULTS

Laboratory experiments. When leaves were sprayed with 0.75% JMS Stylet-Oil 2 days before inoculation, immediately before or immediately after inoculation, or 2 days after inoculation, no significant difference in colony diameter was observed compared with controls (Table 1, experiment 1). When leaves were sprayed with 1.5% oil, water-sprayed control colonies had a significantly larger diameter than any of the oil-treated leaves. In addition, colonies sprayed 4 days after inoculation were significantly smaller than colonies sprayed immediately before inoculation and somewhat smaller than colonies where oil had been sprayed 2 days before inoculation (Table 1, experiment 2). When leaves were sprayed once at 1.5% oil 4 days after inoculation or every 4 days, oil-treated colonies were significantly smaller than controls, and repeatedly sprayed colonies were significantly smaller than colonies sprayed once (Table 1, experiment 3). When leaves were sprayed immediately prior to inoculation with water, a 0.75% oil emulsion, a 0.75% Tween 20 (polyoxyethylene sorbitan monooleate) solution, or a mixture in water of oil and Tween 20, both at 0.75%, oil-

treated colonies did not differ from controls, but Tween-treated colonies were significantly smaller. Colonies treated with Tween plus oil were significantly smaller than all other treatments (Table 1, experiment 4). In the experiment testing different spray pressures, control (water-treated) leaves had mildew colonies with an average diameter of 1.32 cm, those sprayed with oil at 138 kPa averaged 0.6 cm, and those sprayed with oil at 1380 kPa averaged 0.1 cm. Both oil treatments significantly reduced colony diameter compared to the control, but oil treatment at 1380 kPa yielded significantly smaller colonies than treatment at 138 kPa (Table 1, experiment 5).

Changes in morphology or conidium viability in treated colonies. When a 0.75% emulsion was sprayed on leaves with 2-day-old *P. xanthii* colonies, slight differences from control colonies were apparent 1 day after spraying. The chains of conidia from oil-treated colonies were curled, and some conidia had clumped together. Four days after treatment, most oil-treated colonies had distinct fringes of dense, nonsporulating mycelium. The center of most colonies was dead, and in living portions abnormalities in conidiophores

Table 2. Efficacy of JMS Stylet-Oil for control of powdery mildew of yellow straightneck squash in repetition 1 of greenhouse experiment

Treatment	Increase in area of colony at inoculation site (%) ^v		No. colonies on inoculated leaf		No. symptomatic leaves		No. powdery mildew colonies			
	9 days ^{w,x}	15 days ^{w,x}	9 days ^{w,y}	15 days ^{w,y}	15 days ^w	20 days ^w	15 days ^w		20 days ^w	
							Leaf 3	Leaves 4 to 10 ^y	All leaves ^y	Leaves 4 to 10
Control (No Oil)	358.1 b ^z	1621.8 c	17.3 c	58.7 b	4.0 c			68.7 b	63.5 b	97.6 bc
Oil 5 days before inoculation	215.3 ab	1066.6 b	19.2 c	69.0 b	4.8 bc			77.3 b	67.9 b	118.7 c
Oil 4 hours before inoculation	142.6 a	1094.0 bc	14.3 bc	61.5 b	4.2 bc			63.2 b	53.1 b	80.1 b
Oil 5 days after inoculation	146.9 a	801.7 b	9.8 b	53.5 b	4.3 b	11.1 b	55.4 b	63.3 b	72.1 b	593.3 b
Oil 5, 9, 13 days after inoculation	127.1 a	365.6 a	3.4 a	19.1 a	1.7 a	10.0 a	16.9 a	5.1 a	16.4 a	194.0 a
Probability > F	0.0011	0.0001	0.0001	0.0001	0.0001	0.0146	0.0001	0.0001	0.0001	0.0001

^v The second leaf of each plant was inoculated at two spots by transferring spores with a fine paint brush. The initial size of the inoculation sites was determined by measuring the area with spores visible to the unaided eye 2 days after inoculation.

^w Number of days after inoculation.

^x Logarithmic transformation was used to stabilize variance. Table contains de-transformed values.

^y Square root transformation was used to stabilize variance. Table contains de-transformed values.

^z Numbers are the means of three plants from each of six replications. Numbers in a column with a letter in common are not significantly different according to Fisher's protected LSD ($P = 0.05$).

Table 3. Efficacy of JMS Stylet-Oil for control of powdery mildew of yellow straightneck squash in repetition 2 of greenhouse experiment

Treatment	Increase in area of colony at inoculation site (%) ^v		No. colonies on inoculated leaf		No. (%) of symptomatic leaves		No. colonies on leaves above inoculated leaf
	9 days ^w	15 days ^{w,x}	9 days ^{w,y}	15 days ^{w,y}	15 days ^w	20 days ^w	20 days ^{w,y}
Control (No Oil)	440.4 c ^z	1971.4 d	9.7 cd	19.4 a	3.1 (34.1) b	8.9 (71.4) c	244.4 cd
Oil 5 days before inoculation	355.3 bc	1246.4 cd	10.3 d	19.7 a	2.9 (29.1) b	9.4 (71.9) c	266.8 d
Oil 4 hours before inoculation	228.7 ab	1263.7 cd	5.7 bc	24.1 a	2.6 (28.9) b	8.9 (70.7) c	169.0 bc
Oil 5 days after inoculation	186.3 a	811.8 bc	2.9 ab	24.0 a	2.3 (27.2) b	8.8 (70.6) c	157.7 b
Oil 5, 9, 13 days after inoculation	182.5 a	344.1 a	1.3 a	17.1 a	0.3 (3.5) a	6.8 (55.6) b	46.8 a
Oil 5,9,13,17,21 days after inoc.	231.8 ab	476.5 ab	1.8 a	19.5 a	0.4 (4.8) a	4.1 (33.6) a	25.7 a
Probability > F	0.0059	0.0003	0.0001	0.9100	0.0001	0.0001	0.0001

^v The third leaf of each plant was inoculated at two spots by transferring spores with a fine paint brush. The initial size of the inoculation sites was determined by measuring the area with spores visible to the unaided eye 2 days after inoculation.

^w Number of days after inoculation.

^x Logarithmic transformation was used to stabilize variance. Table contains de-transformed values.

^y Square root transformation was used to stabilize variance. Table contains de-transformed values.

^z Numbers are the means of three plants from each of six replications. Numbers in a column with a letter in common are not significantly different according to Fisher's protected LSD ($P = 0.05$).

and conidia were apparent; conidiophores were bent and malformed and some abnormally large or small spores were produced. By 6 days following treatment, only two of six oil-treated colonies had distinct fringes and no deformities were evident in still-living mycelium. Eight days after treatment, dead centers of oil-treated colonies continued to expand, but new growth appeared normal. When oil was applied before inoculation or at the same time, no abnormalities were observed.

Another experiment measured mildew growth on leaves sprayed with a 1.5% oil emulsion 1 day before, immediately after, or 2 days or 6 days after inoculation. Leaves treated 1 day before or immediately after inoculation showed no differences from control (water-treated) leaves 3 to 4 days or 6 to 7 days after treatment, but margins of the colonies were different at 8 to 9 days after treatment, when a nonsporulating fringe was apparent in most colonies. Leaves sprayed 2 days after inoculation showed fringed or irregular colony margins 4 days after treatment and had some conidiophore abnormalities; by 6 or 8 days after treatment, margins were still fringed or irregular compared to controls, but abnormalities were not visible. Leaves sprayed with oil 6 days after inoculation showed strong abnormalities 2 days following treatment, but less by 4 days after treatment. Conidia transferred from treated colonies produced normal powdery mildew colonies on leaf disks.

Treatments made immediately before inoculation did not prevent colony initiation when a clump of conidia were used. However, when one to three conidia from healthy colonies were transferred onto leaves in detached culture that had just been sprayed with 1.5% oil or with water, 88% of the inoculation sites on water-treated leaves developed colonies, while 40% of the sites on oil-treated leaves did.

Control of powdery mildew under greenhouse conditions. Powdery mildew developed quickly under the favorable environmental conditions. The greenhouse was maintained at 20 to 22°C, except during sunny afternoons when the temperature rose to a maximum of 32 to 38°C. Relative humidity ranged from 25 to 100%. New conidia were produced at inoculation sites within 5 days, based on the more powdery appearance at that time. New colonies were observed 7 days after inoculation on a few plants probably due to off-target movement of conidia during inoculation. New colonies resulting from spread of conidia from inoculation sites were observed primarily on inoculated leaves 9 days after inoculation (Tables 2 and 3). Many colonies were observed on noninoculated leaves 15 days after inoculation (Table 2).

Three of the treatments involved applying JMS Stylet-Oil either once before inoculation or once after inoculation in order to assess the efficacy of a preventive or

curative application. Based on assessments made at the inoculation sites 9 days after inoculation, powdery mildew development was suppressed significantly by the preventive treatment made 4 h before inoculation and by the curative treatment made 5 days after inoculation, but not by the preventive treatment made 5 days before inoculation (Tables 2 and 3). The size of the area affected by powdery mildew at inoculation sites also was smaller for treated leaves than for nontreated leaves 15 days after inoculation; however, the difference was not significant for all treatments. Of these three treatments, only the oil treatment made 5 days after inoculation significantly suppressed powdery mildew development on noninoculated leaf tissue based on the number of colonies on inoculated leaves 9 days after inoculation.

A 4-day spray program with at least three successive applications of oil beginning 5 days after inoculation provided good suppression of powdery mildew on inoculated leaves and on the other leaves (Tables 2 and 3). Powdery mildew colonies on oil-treated leaves were smaller and did not have the powdery appearance of a typical healthy colony; the conidia looked clumped together. Conidia looked normal, however, when examined through a dissecting microscope. Oil-treated conidia were viable since powdery mildew developed on all leaf disks inoculated with conidia taken from leaves one day after treatment. After the spray program was terminated, powdery mildew had begun to develop by 7 days after the last spray in the first experiment. Between 15 and 20 days after inoculation (which was 2 and 7 days after the last spray, respectively), the number of leaves affected and the number of powdery mildew colonies increased substantially (Table 2). Powdery mildew was suppressed 2 days after the last spray for plants treated three times based on the number of leaves affected 15 days after inoculation (Table 3). Five days later, there were significantly more leaves with powdery mildew on plants sprayed three times than on plants sprayed five times. Powdery mildew had developed extensively on plants treated five times by 7 days after the last spray, which was 28 days after inoculation: colonies were observed on all leaves, and the number counted per plant ranged from 540 to 2220. Leaves on plants treated with oil appeared greener than expected from powdery mildew control alone. Eleven of 18 inoculated leaves on plants treated five times with oil were still mostly green 28 days after inoculation, whereas only one of 54 inoculated leaves was mostly green on plants that were not treated with oil after inoculation in the second experiment.

DISCUSSION

Powdery mildew of cucurbits was suppressed with JMS Stylet-Oil both in labo-

ratory and in greenhouse studies. Treatments made immediately before inoculation did not prevent colony initiation in either environment when a clump of about 25 conidia were used. Inoculations were just as successful on treated leaves as on nontreated leaves. However, colony initiation by naturally dispersed conidia was prevented in the greenhouse. This discrepancy in treatment effect may have been due to the larger quantity of conidia at a site following artificial inoculation compared with natural dispersal; placing one to three conidia on leaves after treatment with JMS Stylet-Oil led to only half the number of colonies formed on water-sprayed leaves. Colony initiation of powdery mildew on cucumber was reduced by formulated vegetable oils applied 1 day before inoculation (25). Northover and Schneider also saw protective action with preinoculation sprays for grape powdery mildew (17).

JMS Stylet-Oil slowed expansion of colonies resulting from natural infection and artificial inoculation in both laboratory and greenhouse studies. Colony size was reduced significantly. A rate of 1.5% was required when a low-pressure sprayer (138 kPa) was used in laboratory studies. However, when a high-pressure sprayer (1380 kPa) was used to apply the oil emulsions in a finer mist, a lower oil concentration (0.75%) was effective. Powdery mildew colony size also was reduced by formulated vegetable oils applied to cucumber (25).

Applying JMS Stylet-Oil to existing colonies did not significantly reduce spore viability. Both JMS Stylet-Oil and Tween 20 appeared to cause abnormalities of conidiophores and spores immediately after application; however, this effect was temporary and its significance is not clear. Although conidia lost dispersal ability due to the adhesive effect of the oil, there was no indication that oil significantly reduced conidial viability, even at 1.5%, since conidia taken from sprayed colonies readily formed new colonies in both laboratory and greenhouse tests. In contrast, colonies of grape powdery mildew were smothered by post-lesion applications of JMS Stylet-Oil at 1.0% made 10 days after inoculation; this was considered an "antisporelative" effect based on number of conidia able to be rinsed off leaves (17).

Powdery mildew of cucurbits can be controlled effectively with the biocompatible material JMS Stylet-Oil applied every 4 to 7 days based on results from this study and a field experiment (16). Less effective control of this disease obtained in other studies with mineral oils most likely is due to the long spray interval used, poor spray coverage, and/or the material used. Poor disease control occurs when a 14-day schedule is used with JMS Stylet-Oil or Sunspray ultrafine oil (3,11,28). This is not surprising based on results from the present study. JMS Stylet-Oil applied at 0.75%

is less expensive than the chlorothalonil product Bravo Ultrex applied at 3 kg/ha (\$21.50/ha versus \$49.72/ha); therefore, it would be economical to use JMS Stylet-Oil when an application interval of less than 7 days was required due to conditions being favorable for powdery mildew development. Thorough spray coverage of targeted tissue is especially important for control with contact fungicides. Coverage of foliage with oil can be improved by using high spray pressure (>1380 kPa), high spray volume (>690 liter/ha), close nozzle spacing (25 cm), and nozzles that produce small uniform droplets (J. Simons, unpublished). JMS Stylet-Oil was more effective in the present study when applied at 1380 kPa with ALBUZ lilac ceramic hollow cone nozzles than at 138 kPa with a DeVilbiss atomizer bottle. Low spray pressure (<345 kPa) and low spray volume (<468 liter/h) are often used in fungicide evaluation experiments. In addition, formulation has a substantial effect on efficacy of oils (J. Simons, unpublished); therefore, previous results obtained with other oils cannot be used as an indication of potential efficacy of JMS Stylet-Oil. Phytotoxicity due to JMS Stylet-Oil was not observed during the field experiment; according to the label, problems can occur if this product is used when temperature is below 10°C, above 32°C, or when plants are under heat or moisture stress.

JMS Stylet-Oil could be used effectively within an IPM spray program initiated after disease detection. Powdery mildew severity was significantly lower than nontreated plants for cucurbits receiving applications initiated 5 days after inoculation in this greenhouse study and with applications initiated after disease detection in the field (16). An IPM spray program could be effective with other oils. Formulated vegetable oils suppressed powdery mildew on cucumber when sprayed six days after inoculation (25).

An integrated chemical control program may be needed to achieve good control of powdery mildew on abaxial leaf surfaces and control of other foliar diseases. Systemic fungicides are an important component of existing conventional fungicide programs because it is difficult to deliver spray material to abaxial leaf surfaces, where powdery mildew develops more severely, in dense vining cucurbit crops (15). Applying systemic fungicides in addition to bicarbonates or oils has been recommended (30). JMS Stylet-Oil suppressed powdery mildew on abaxial leaf surfaces compared with nontreated leaves in a field study, but not as effectively as the systemic fungicide myclobutanil (14). Sunspray ultrafine oil applied with sodium bicarbonate on an alternating 8 to 9 day spray schedule with triadimefon plus

chlorothalonil was as effective as applying triadimefon plus chlorothalonil every 8 to 9 days (5). Sunspray ultrafine oil was more effective when combined with sodium bicarbonate for rose powdery mildew (7). Conventional protectant fungicides such as chlorothalonil have a broader range of activity than biocompatible materials. Neither JMS Stylet-Oil nor the other biocompatible materials evaluated for powdery mildew effectively suppressed downy mildew (14). Sunspray ultrafine oil applied with sodium bicarbonate did not suppress *Alternaria* leaf blight or anthracnose of cucurbits (2,10). In another study, gummy stem blight and *Alternaria* leaf blight were controlled with oil, but not as effectively as was powdery mildew (30).

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