ethylene and 1-aminocyclopropane-1-carboxylic acid production by *Bipolaris sorokiniana*. Phytopathology 76:851-855.
9. De Laat, A. M. M., and Van Loon, L. C. 1982. Regulation of ethylene biosynthesis in virus-infected tobacco leaves. II. Time course of levels of intermediates and in vivo conversion rates. Plant Physiol. 69:240-245.
10. De Laat, A. M. M., and Van Loon, L. C. 1983. The relationship between stimulated ethylene production and symptom expression in virus-infected tobacco leaves. Physiol. Plant Pathol. 22:261-273.
11. Gepstein, S., and Thimann, K. V. 1980. The effect of light on the production of ethylene from 1-aminocyclopropane-1-carboxylic acid by leaves. Planta 149:196-199.
12. Hodges, C. F., and Coleman, L. W. 1984. Ethylene-induced chlorosis in the pathogenesis of *Bipolaris sorokiniana* leaf spot of *Poa pratensis*. Plant Physiol. 75:462-465.
13. Jackson, M. B., and Campbell, D. J. 1976. Production of ethylene by excised segments of plant tissue prior to the effect of wounding. Planta 129:273-274.
14. Kende, H., and Boller, T. 1981. Wound ethylene and 1-aminocyclopropane-1-carboxylate synthase in ripening tomato fruit. Planta 151:476-481.
15. Kimmerer, T. W., and Kozlowski, T. T. 1982. Ethylene, ethane, acetaldehyde, and ethanol production by plants under stress. Plant Physiol. 69:840-847.
16. Koch, F., Baur, M., Burba, M., and Elstner, E. F. 1980. Ethylene formation by *Beta vulgaris* leaves during systemic (beet mosaic virus and beet mild yellowing virus, BMV + BMYV) or necrotic (*Cercospora beticola* Sacc.) diseases. Phytopathol. Z. 98:40-46.
17. Konze, J. R., and Kwiatkowski, G. M. K. 1981. Rapidly induced ethylene formation after wounding is controlled by the regulation of 1-aminocyclopropane-1-carboxylic acid synthesis. Planta 151:327-330.
18. McKeon, T. A., Hoffman, N. E., and Yang, S. F. 1982. The effect of plant-hormone pretreatments on ethylene production and synthesis of 1-aminocyclopropane-1-carboxylic acid in water-stressed wheat leaves. Planta 155:437-443.
19. Montalbini, P., and Elstner, E. F. 1977. Ethylene evolution by rust-infected, detached bean (*Phaseolus vulgaris* L.) leaves susceptible and hypersensitive to *Uromyces phaseoli* (Pers.) Wint. Planta 135:301-306.
20. Primrose, S. B. 1979. Ethylene and agriculture: The role of the microbe. J. Appl. Bacteriol. 46:1-25.
21. Reuveni, M., and Cohen, Y. 1978. Growth retardation and changes in phenolic compounds, with special reference to scopoletin, in mildewed and ethylene-treated tobacco plants. Physiol. Plant Pathol. 12:179-189.
22. Rikin, A., Chalutz, E., and Anderson, J. D. 1984. Rhythmicity in ethylene production in cotton seedlings. Plant Physiol. 75:493-495.
23. Rikin, A., Chalutz, E., and Anderson, J. D. 1985. Rhythmicity in cotton seedlings. Planta 163:227-231.
24. Saltveit, M. E., Jr., and Dilley, D. R. 1978. Rapidly induced wound ethylene from excised segments of etiolated *Pisum sativum* L., cv. Alaska. I. Characterization of the response. Plant Physiol. 61:447-450.
25. Sakai, S., Imaseki, H., and Uritani, I. 1970. Biosynthesis of ethylene in sweet potato root tissue. Plant Cell Physiol. 11:737-745.
26. Tzeng, D. D., and DeVay, J. E. 1984. Ethylene production and toxigenicity of methionine and its derivatives with riboflavin in cultures of *Verticillium, Fusarium,* and *Colletotrichum* species exposed to light. Physiol. Plant. 62:545-552.
27. Wang, C. Y., and Adams, D. O. 1982. Chilling-induced ethylene production in cucumbers (*Cucumis sativus* L.). Plant Physiol. 69:424-427.
28. Wright, S. T. C. 1981. The effect of light and dark periods on the production of ethylene from water-stressed wheat leaves. Planta 153:172-180.
29. Yu, Y., Adams, D. O., and Yang, S. F. 1979. 1-Aminocyclopropane-carboxylate synthase, a key enzyme in ethylene biosynthesis. Arch. Biochem. Biophys. 198:280-286.
30. Yu, Y., and Yang, S. F. 1980. Biosynthesis of wound ethylene. Plant Physiol. 66:281-285.

Disease Control and Pest Management

Control of Metalaxyl-Resistant Causal Agents of Late Blight in Potato and Tomato and Downy Mildew in Cucumber by Cymoxanil

Yigal Cohen and Masha Grinberger

Professor and technician, respectively, Department of Life Sciences, Bar-Ilan University, 52100 Ramat-Gan, Israel.
Research supported in part by Milchan Bros. Company, Israel.
The useful technical assistance of A. Cohen and Y. Dotan is acknowledged.
Accepted for publication 20 February 1987.

ABSTRACT

Cohen, Y., and Grinberger, M. 1987. Control of metalaxyl-resistant causal agents of late blight in potato and tomato and downy mildew in cucumber by cymoxanil. Phytopathology 77:1283-1288.

A relatively high dosage of cymoxanil foliar spray was required to control late blight in potato and downy mildew in cucumber in growth chambers. ED_{90} values for control of metalaxyl-sensitive field isolates of *Phytophthora infestans* ranged between 164 and 459 μg/ml, and for metalaxyl-resistant isolates, between 112 and 525 μg/ml. ED_{90} values for control of metalaxyl-resistant isolates of *Pseudoperonospora cubensis* ranges between 201 and 878 μg/ml. Complete control of both pathogens was achieved at concentrations between 500 and >1,000 μg/ml. Preventive and curative efficacy of the fungicide lasted for 5 and 3 days, respectively. Cymoxanil was readily taken up by leaves, roots, and stems. When applied to roots and stems, it showed acropetal systemic translocation in cucumber and tomato but not in potato. No systemic translocation occurred when applied to leaf laminae. Translaminar translocation occurred in potato and tomato but not in cucumbers. The fungicide was toxic to roots of tomato plants.

Additional key words: Oomycetes, systemic fungicides.

Cymoxanil (Curzate), a systemic fungicide selectively active against fungi of the Peranosporales, has been commercially available since 1979 (8,14). In plants, it has a half-life of only a few days (11); therefore, it is more effective when combined with either a protectant (e.g., mancozeb), another systemic (e.g., oxadixyl or propramocarb), or with both a systemic and a protectant (1,3, 8–11,14,15). In Europe, cymoxanil used in a foliar spray at a relatively low concentration of 80–112 μg/ml demonstrated good preventive and curative activity against grape downy mildew and

late blight in potato and tomato (8,11). In Israel, however, fivefold concentrations were required to control late blight in potato and downy mildew in cucumber (3,4). The present research was conducted to further examine the systemicity and control efficacy of cymoxanil against Israeli isolates of *Phytophthora infestans* (Mont.) de Bary and *Pseudoperonospora cubensis* (Berk. & Curt.) Rost. with the aim to provide an alternative systemic fungicide for control of acylanilide-resistant genotypes of the pathogens that predominate in Israel (7,13). A preliminary report on this study was given before (5).

MATERIALS AND METHODS

Plants. Potato (*Solanum tuberosum* L.) cultivar Alpha, tomato (*Lycopersicon esculentum* L.) cultivar Hosen-Ayalon, cucumber (*Cucumis sativum* L.) cultivar Dalila, and muskmelon (*Cucumis melo* L.) cultivar Ananas-Yoknean were used. Potato tubers (60–100 g each) were planted in 1-L pots, one tuber per pot, and grown in the greenhouse at 22–28 C for 6–7 wk. At this stage, plants had three to five shoots each, with about nine or 10 compound leaves per shoot. Tomato plants were grown in 0.5-L pots, one plant per pot, and used at the five-leaf stage. Cucumbers were used at either the cotyledonary stage, 10 plants per 0.5-L pot; the two-leaf stage, one plant per 0.1- or 0.5-L pot; the six-leaf stage in 1-L pots; or the 12-leaf stage in 10-L pots. Tomato and cucumbers were grown in the greenhouse at 22–34 C. All test plants were grown in sandy loam and fertilized twice a week with 1% NPK (20-20-20).

Fungi. Field isolates of *Phytophthora infestans* were collected from blighted potato fields during 1983–1986 and kept on detached potato leaves in petri dishes at 12 C by repeated inoculations. Details on isolates are given in Table 1. Metalaxyl-sensitive isolates were kept on leaflets floating on water. These isolates were controlled in inoculated leaflets floated on 1 μg/ml metalaxyl. Metalaxyl-resistant isolates were kept on detached leaflets floated on 100 μg/ml metalaxyl. Freshly produced sporangia were collected into cold (4 C) tap water, calibrated with a cytometer to about 2×10^4 sporangia per milliliter, and used for inoculation tests.

Field isolates of *Pseudoperonospora cubensis* were collected in 1984–1986 and kept on muskmelon cotyledons by repeated inoculations at 20 C. Sporangia were collected and calibrated in the manner described for *P. infestans*.

Inoculations were done by spraying the adaxial (upper) leaf surfaces with a fine glass atomizer. Inoculated plants were kept at 17 C in a moisture-saturated atmosphere in the dark for about 20 hr, then transferred to 20 C cabinets illuminated with CW fluorescent lamps (120 $\mu E \cdot m^{-2} \cdot s^{-1}$) for 12 hr/day. Disease records were usually taken 7 days after inoculation.

Zoospore release and zoospore germination. Freshly produced sporangia were mixed with cymoxanil (95% technical grade) and incubated in 5-cm petri dishes at 18 C in the dark. Sucrose (0.1 M) was added to zoospores of *P. cubensis* for cyst germination. Release and germination were examined microscopically at 4 and 20 hr, respectively. Sporangial-fungicide mixtures were also applied to detached potato leaflets, which were incubated in petri dishes at 18 C for 20 hr. Calcofluor (0.01% aqueous solution) was then added, and leaves were examined with an epifluorescent microscope for the presence of germinating cystospores by the method described before (6).

Disease assessments. In potato and tomato, leaflets infected of leaflets inoculated were counted and expressed as percentage of leaflets infected. Lesions showing a hypersensitive reaction (smaller than 2 mm) were considered healthy. With true leaves of cucumber, lesions per leaf were counted or the proportion of leaf area occupied by lesions and color of lesions (greenish, yellow, or brown) were recorded and expressed as a disease index using the method described elsewhere (2).

Fungicide. Two formulations of cymoxanil were used: 50WP formulation, obtained from U. Gisi, Sandoz, Switzerland, and technical grade (95%), obtained from Y. Sheinboin, Milchan Bros., Israel. The 50WP fungicide was dissolved in water. The technical-grade fungicide was first dissolved in methanol (2%) and then in warm (50 C) water. Methanol solutions (2%) were used as controls. Fungicide concentrations given are in units of active ingredient.

Fungicide applications. Unless otherwise stated, the fungicide (50WP) was applied by spraying the adaxial leaf surfaces. Care was taken to avoid runoff of fungicide droplets to the soil surface. Acropetal systemicity of the fungicide was tested by either drenching the soil (10 ml), immersing the root system of bare-rooted plants (50 ml), or placing the cut ends of plant cuttings (20 ml) in cymoxanil (95% technical grade) solutions. Acropetal systemicity from stems was tested by painting 0.1 g of cymoxanil-lanolin paste on the hypocotyls of cucumbers or the two or three lower internodes of potato shoots. To prepare lanolin-fungicide paste, 4 g of cymoxanil (95%) was mixed thoroughly with 10 g of lanolin (BDH, England) to produce a 27.1% formulation. Systemicity from leaves was examined by spraying the fungicide (50WP) onto one or more leaves and testing the magnitude of disease control in untreated leaves. Translaminar translocation was tested in leaves sprayed with the fungicide (50WP) on one surface (either adaxial or abaxial) and inoculated on the other surface.

TABLE 1. Dosage-control data for cymoxanil (50WP) against field isolates of *Phytophthora infestans* on potato plants (cultivar Alpha) in growth chambers at 20 C

Isolate[a]	ED_{90}[b] (μg/ml)	r^2	MIC[c] (μg/ml)
Bet-Kama, 1983, S	262	0.91	1,000
Nir-Eliyahu, 1984, S	459	0.92	>1,000
Sufa, 1986, S	164	0.93	1,000
Aza, 1983, R	125	0.81	500
Nir-Yizhak, 1984, R	346	0.95	>1,000
Gevuloth, 1984, R	168	0.99	1,000
Kfar Saba, 1985, R	289	0.96	1,000
Raanana, 1985, R	125	0.87	1,000
Magdiel, 1986, R	112	0.86	500
Mishmereth, 1986, R	525	0.89	1,000

[a] Site and year of collection. S = metalaxyl-sensitive isolate, controlled in potato leaf disks floated on 1 μg/ml metalaxyl; R = metalaxyl-resistant isolate, fungus sporulated profusely on leaf disk floated on 100 μg/ml metalaxyl.
[b] Computed by PROBIT procedure (*SAS User's Guide: Statistics.* SAS Institute Inc., Cary, NC, 1982).
[c] Minimal inhibitory concentration: dosage with which complete control of the disease was observed in plants treated with 25, 50, 100, 250, 500, and 1,000 μg/ml.

TABLE 2. Dosage-control data for cymoxanil (50WP) against field isolates of *Pseudoperonospora cubensis* on cotyledonary and two-leaf cucumber and muskmelon plants in growth chambers at 20 C

Isolate[a]	Plant	ED_{90}[b] (μg/ml)	r^2	MIC[c] (μg/ml)
Beerothayim, 1985, S	Cucumber[d]	316	0.93	1,000
Beerothayim, 1985, S	Muskmelon[d]	197	0.98	500
Bar-Ilan 3, 1985, R	Cucumber[d]	363	0.92	500
Bar-Ilan 3, 1985, R	Muskmelon[d]	201	0.97	1,000
Beerothayim, 1985, S	Cucumber[e]	647	0.98	>1,000
Bar-Ilan 2, 1985, R	Cucumber[e]	455	0.97	>1,000
Shuval A, 1986, R	Cucumber[e]	443	0.98	>1,000
Shuval B, 1986, R	Cucumber[e]	878	0.98	>1,000

[a] Place and year of collection. S = metalaxyl-sensitive isolate, fungus failed to sporulate in plants sprayed with 10 μg/ml metalaxyl; R = metalaxyl-resistant isolate, fungus sporulated in plants sprayed with 1,000 μg/ml metalaxyl.
[b] Computed by PROBIT procedure (*SAS User's Guide: Statistics.* SAS Institute Inc., Cary, NC, 1982).
[c] Minimal inhibitory concentration: dosage with which complete control of the disease was observed in plants treated with 25, 50, 100, 250, 500, and 1,000 μg/ml.
[d] Cotyledons, 7–10 days old.
[e] Two-leaf plants, 3 wk old.

Dosage-control data (Tables 1 and 2) were collected from plants sprayed with cymoxanil (50WP) concentrations of 25, 50, 100, 250, 500, and 1,000 μg/ml.

Statistical analyses. ED_{90} and correlation coefficients (r^2) values (Tables 1 and 2) were obtained from probit-log dose response lines computed for each isolate ($n=8$, df = 4) by the PROBIT procedure (Table 1). Experiments were performed twice or more with the following number of plants in each inoculation test: potato, 3–10; tomato, 10; cucumber and muskmelon at cotyledonary stage, 4 × 20; cucumber at two-leaf stage, 8–30; and cucumber at 10-leaf stage, 4. One set of representative data is given for each experiment. Duncan's multiple range test was applied for determining significant differences between treatments at $P=0.05$.

RESULTS

Foliar spray. Isolates of *P. infestans* and *P. cubensis* varied in their sensitivity to cymoxanil. With most isolates, a foliar spray of 1,000 μg/ml was required for complete control of the disease (Tables 1 and 2, Fig. 1). Probit transformations of dosage-control data gave ED_{90} values of 112–525 μg/ml for various isolates of *P. infestans* on potatoes (Table 1) and 197–878 μg/ml for various isolates of *P. cubensis* on cucurbits (Table 2). Fluctuation in ED_{90} values for a specific isolate were not greater than 10% in different experiments. Metalaxyl-sensitive isolates of *P. infestans* did not differ from metalaxyl-resistant isolates in sensitivity to cymoxanil (Table 1). With *P. cubensis*, only one metalaxyl-sensitive isolate was tested (Table 2).

Preventive vs. curative foliar sprays. Cymoxanil spray was effective in controlling both *P. infestans* in potatoes and *P. cubensis* in cucumbers if applied 0–5 days before inoculation. Its effectiveness gradually diminished when applied 1–3 days after inoculation (Figs. 2 and 3). A foliar spray with 1,000 μg/ml applied 1, 2, and 3 days after inoculation reduced percentage potato leaflets blighted by 79, 60, and 57%, respectively, relative to control unsprayed plants (Fig. 2). Similar treatments applied to 10-leaf cucumber plants reduced number of lesions per leaf by 60, 45, and 19%, respectively (Fig. 3).

Soil drench. Relatively high dosages of cymoxanil were required as soil drenches to control downy mildew in cucumbers. Significant ($P>0.05$) reduction in disease index was obtained with 2.5 mg/0.1-L pot (Fig. 4) or with 10 mg/0.5-L pot (Fig. 5), but complete control was not achieved even by phytotoxic dosages of 10 or 20 mg/0.5-L pot (Figs. 4 and 5). With 20 mg/0.5-L pot, disease index was reduced by 76% in leaf 1 (oldest) and 84% in leaf 2 (youngest) and sporulation by 94% in both leaves relative to untreated control plants (Fig. 5).

Soil drenches of up to 50 mg/1-L pot applied to potato plants failed to significantly reduce the percentage of leaflets infected with *P. infestans*. A drench of 100 mg/1-L pot reduced the percentage of leaflets infected by about 60%.

Toxicity of cymoxanil to root regeneration was evident in cucumber and tomato cuttings. Rootlet growth was adversely affected in tomato cuttings when placed in >50 μg/ml of cymoxanil at 25 C (Table 3). Immersing the cut end of tomato cuttings or the root system of bare-rooted tomato plants in cymoxanil solution of 500 μg/ml for 2–27 hr reduced the percentage of leaflets infected with *P. infestans* by 95–98 and 80–90%, respectively.

Immersing the cut ends of potato cuttings (30 cm long with nine leaves) in cymoxanil solutions for 24 hr before leaf detachment and inoculation with *P. infestans* in petri dishes significantly reduced fungal development. About 50 and 90% inhibition was achieved with 50 and 500 μg/ml cymoxanil, respectively.

Systemicity from stems. Cymoxanil-lanolin paste applied to hypocotyls (about 5 cm long) of two-leaf cucumber plants 2 days

TABLE 3. Effects of cymoxanil (95% technical grade) on root regeneration in tomato cuttings (10 days, 25 C, $n = 10$)

Cymoxanil concentration (μg/ml)	Rootlets per plant (± SD)	Rootlet length (cm ± SD)	Root length per plant (cm)	Root length inhibition (%)
0	58 ± 8	7.4 ± 0.5	429	0
25	48 ± 3	5.8 ± 2.4	278	35
50	40 ± 12	1.9 ± 1.0	76	83
100	20 ± 7	0.5 ± 0.3	10	98
250	10 ± 6	0.4 ± 0.4	4	99
500	5 ± 9	0.08 ± 0.1	0.4	100

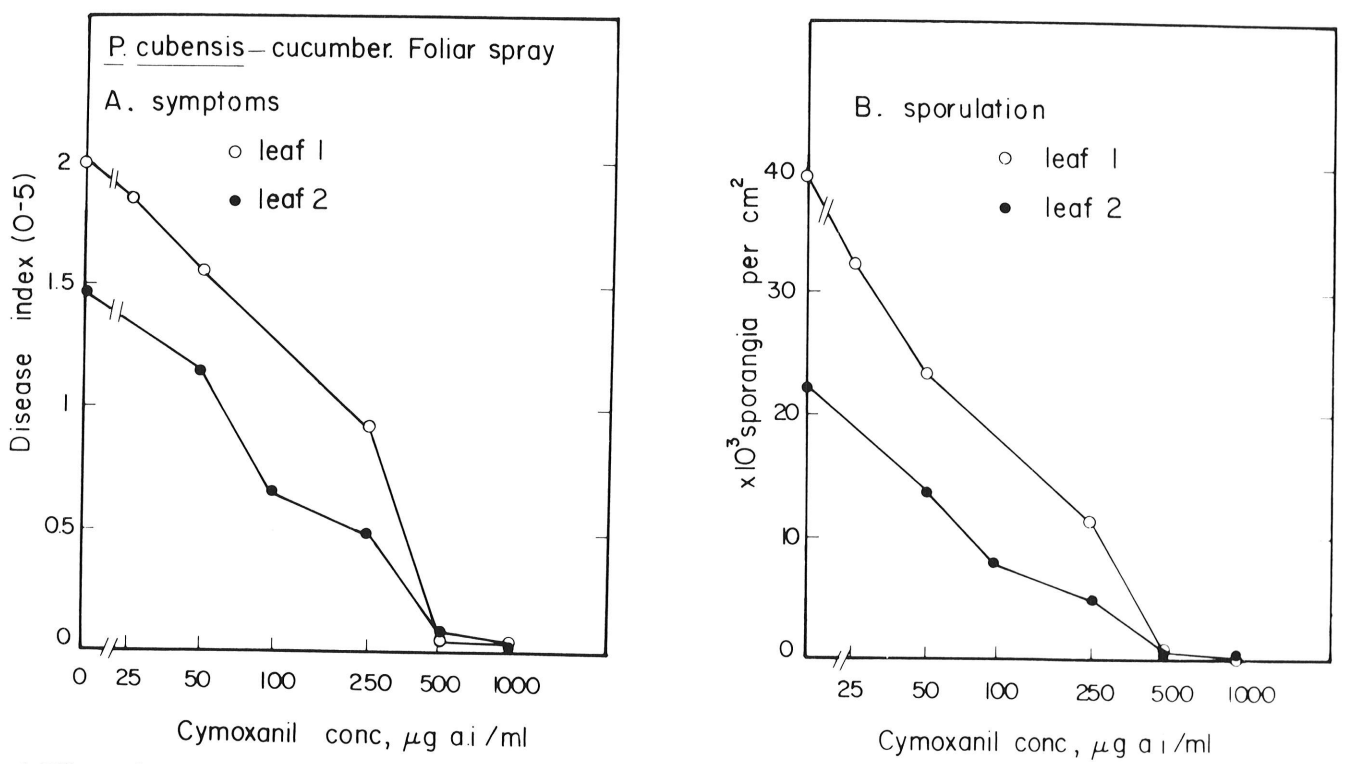

Fig. 1. Efficacy of cymoxanil (50WP) applied to two-leaf cucumber plants before inoculating with *Pseudoperonospora cubensis* (isolate Bar-Ilan 3) on symptom production and fungal sporulation ($n = 8$). Leaf 1, oldest; leaf 2, youngest.

before inoculation with *P. cubensis* significantly ($P>0.01$) reduced disease development. Eight and a half milligrams of cymoxanil in 0.1 g of lanolin reduced disease development by 83–96% relative to inoculated plants treated with 0.1 g of lanolin. Data in Figure 6 show that the efficacy of cymoxanil paste was gradually lost 4–9 days after stem application. Three-leaf cucumber plants painted on the hypocotyl with 27% cymoxanil formulation 1 day before inoculation were fully protected against downy mildew. Similarly treated plants kept in the greenhouse 4, 7, and 9 days before inoculation developed one, two, and three new leaves, respectively, and were protected from the disease in leaf 3 by 100, 45, 45, and 25% in plants inoculated 1, 4, 7, and 9 days after stem painting, respectively (Fig. 6). Cymoxanil-lanolin paste painted on lower two or three internodes of potato stems 1 or 2 days before inoculation had no significant effect on the development of *P. infestans*.

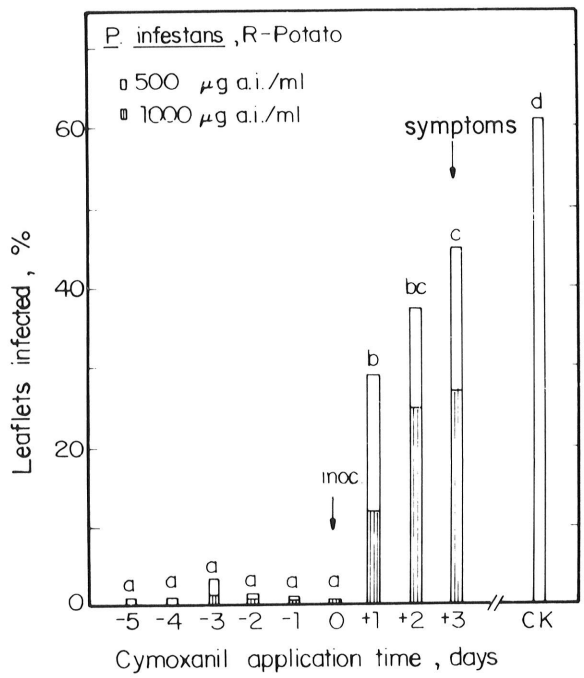

Fig. 2. Preventive and curative efficacy of cymoxanil (50WP) foliar spray in controlling *Phytophthora infestans* (isolate Nir-Yizhak) in potato plants. Open columns = plants sprayed with 500 μg/ml cymoxanil; striped columns = 1,000 μg/ml. Different letters above columns represent significant differences between the 1,000-μg/ml treatments according to Duncan's multiple range test ($P>0.05$, $n = 10$). CK = nonsprayed inoculated plants. Numbers on the x-axis are days before or after inoculation.

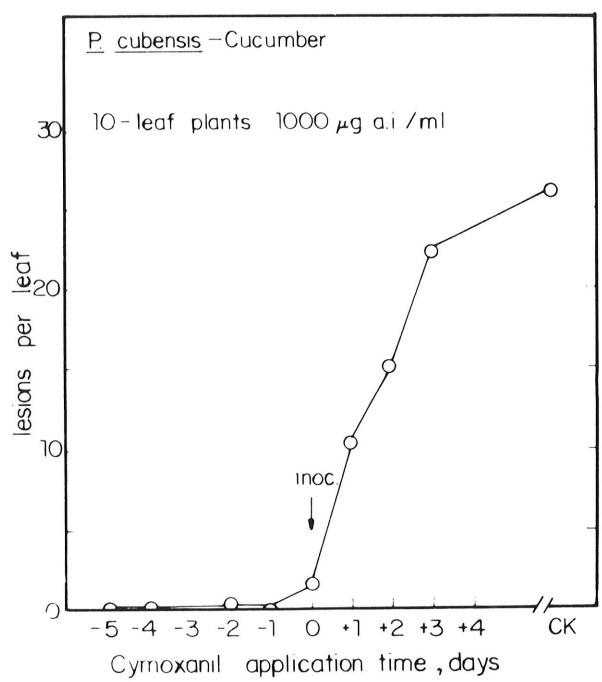

Fig. 3. Preventive and curative efficacy of cymoxanil (50WP, 1,000 μg/ml) foliar spray in controlling *Pseudoperonospora cubensis* (isolate Bar-Ilan 3) in 10-leaf cucumber plants. Different letters above circles represent significant differences according to Duncan's multiple range test ($P>0.05$, $n = 4$).

Systemicity from leaves and translaminar translocation. Cymoxanil did not translocate from treated to untreated leaves of cucumber, tomato, or potato. When the fungicide was applied as a foliar spray to leaf 1 of two-leaf cucumber plants, no protection

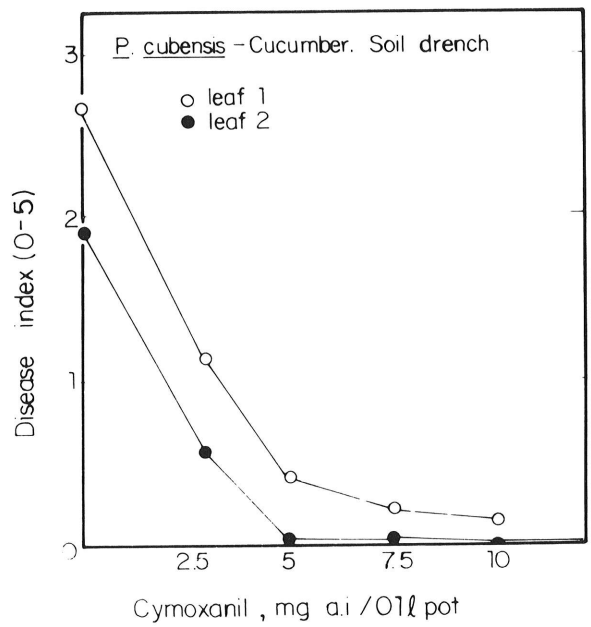

Fig. 4. Effect of a soil drench with cymoxanil (50WP, 5-ml suspension per pot) applied one day before inoculation on the development of *Pseudoperonospora cubensis* (isolate Bar-Ilan 3) on two-leaf cucumber plants ($n = 30$). Leaf 1, oldest; leaf 2, youngest.

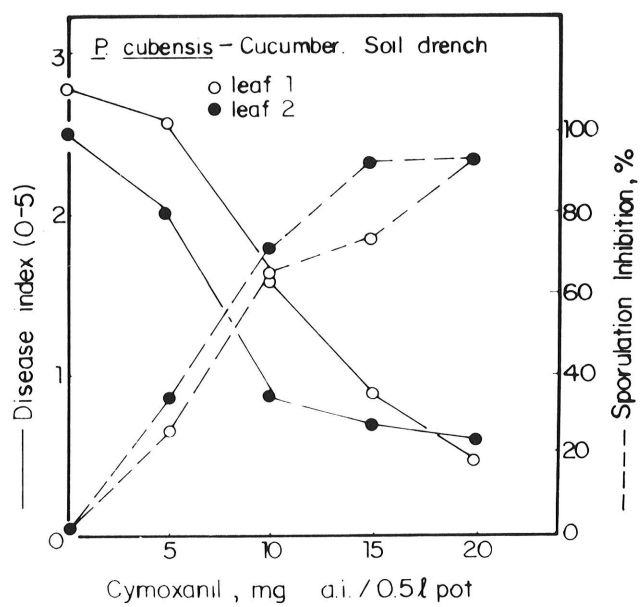

Fig. 5. Effect of a soil drench with cymoxanil (50WP, 10-ml suspension per pot) applied 1 day before inoculation on downy mildew development and on sporulation of *Pseudoperonospora cubensis* (isolate Bar-Ilan 3) in two-leaf cucumber plants ($n = 10$). Leaf 1, oldest; leaf 2, youngest.

against *P. cubensis* was observed in leaf 2. Also, when cymoxanil was applied to leaf 2, no protection against downy mildew was noticed in leaf 1 or cotyledons. Similar results were obtained with potato and tomato plants inoculated with *P. infestans*.

Cymoxanil was rapidly absorbed by leaves of muskmelon, potato, and tomato. Rate of absorption was dependent on fungicide concentration and on the interval between fungicide spraying and washing. In muskmelon cotyledons, washing 1 hr after spraying left about 75–90% of the leaves protected from challenge with downy mildew (Table 4).

Potato and tomato leaves treated with cymoxanil on one surface were protected against *P. infestans* inoculated on the opposite surface, indicating an efficient translaminar translocation of the fungicide in these plant species. Translaminar movement in cucumbers, however, was much poorer (Fig. 7). Plants treated on upper leaf surfaces with 250 μg/ml cymoxanil and inoculated with *P. cubensis* on lower surfaces were 29–34% protected compared with 100% protection recorded in leaves treated on lower surfaces (Fig. 7). Increasing fungicide concentration resulted in a significant ($P > 0.05$) increased translaminar translocation of cymoxanil in cucumbers. Similar results were obtained in cucumber leaves treated with fungicide on lower surfaces and inoculated on upper surfaces.

Effects on zoospore release and zoospore germination. Cymoxanil (95% technical grade) at concentrations of 25, 50, 100, 250, 500, and 1,000 μg/ml inhibited zoospore release in vitro (4 hr at 18 C) in *P. cubensis* (isolate Bar-Ilan 3) to an extent of about 0, 0, 50, 75, 90, and 100%, respectively. When added to normally released zoospores in the water/sucrose solution, germination (20 hr at 18 C) was inhibited by about 50, 75, 90, and 100% at concentrations of 25, 50, 100, and 250 μg/ml, respectively. Sporangial suspensions of this isolate of *P. cubensis* were mixed with cymoxanil (95%) and inoculated onto cucumber cotyledons. Percentages of disease control 7 days later were 12, 19, 16, 75, 86, and 100% by concentrations of 25, 100, 250, 500, and 1,000 μg/ml, respectively.

Minimal inhibitory concentrations of cymoxanil (95% technical grade) for *P. infestans* on detached potato leaves (calcofluor assay [6]) were 250 and 500 μg/ml for isolates Magdiel and Sufa, respectively. At 100 μg/ml, cystospore germination was reduced by about 85 and 35% for these isolates, respectively.

DISCUSSION

A large variation in sensitivity to cymoxanil was observed among 10 field isolates of *Phytophthora infestans* on potato. This sort of variation was not expected on the basis of the experimental conditions. Because differences were consistent, they might be considered as heritable traits of the isolates. ED_{90} values for five isolates ranged 100–200 μg/ml; for three isolates, 250–350 μg/ml; and for two isolates, 450–525 μg/ml. Gisi et al (10) reported an ED_{90} of 103 ± 22 μg/ml for *P. infestans* on tomato, and Samoucha and Gisi (*personal communication*) observed ED_{90} of 16–20 mg/L of soil for *P. infestans* on potato cultivar Bintje. Variation was also observed among *P. cubensis* isolates; the most sensitive had an ED_{90} of 197 μg/ml and the least sensitive had an ED_{90} of 878 μg/ml. Although our findings with *P. cubensis* agree with those of Pappas (12), those with *P. infestans* deviated greatly from those of Gisi et al (10) and Klopping and Delp (11), who observed excellent control of *P. infestans* on potato and tomato with 80 μg/ml cymoxanil. We have no reasonable explanation for the differences in sensitivity among our own isolates or between the Israeli and the European isolates of *P. infestans*. Probably, more isolates should be tested in Europe to get a better picture of sensitivity of *P. infestans* to cymoxanil there.

This reduced sensitivity to cymoxanil was a major reason for formulating a different cymoxanil-containing three-way mixture in Israel from that used in Europe. Pulsan (1), marketed in Europe to control potato late blight, is composed of mancozeb:oxadixyl: cymoxanil at a ratio of 7:1:0.4, whereas Sandocur-M, marketed in

TABLE 4. Control of *Pseudoperonospora cubensis* in muskmelon cotyledons after spray with cymoxanil (50WP) and washing[a]

Concentration (μg a.i./ml)	Cotyledons infected (% ± SD)		
	No washing	Washing (1 hr)	Washing (4 hr)
0	88.1 ± 13.3	...	...
250	15.5 ± 4.0	35.3 ± 13.1	33.9 ± 0.9
500	0	24.8 ± 5.7	0
1,000	0	9.9 ± 11.3	0

[a] Cotyledons (4 × 20 per treatment) were rinsed with tap water for 60 sec 1 and 4 hr after fungicide droplets had dried.

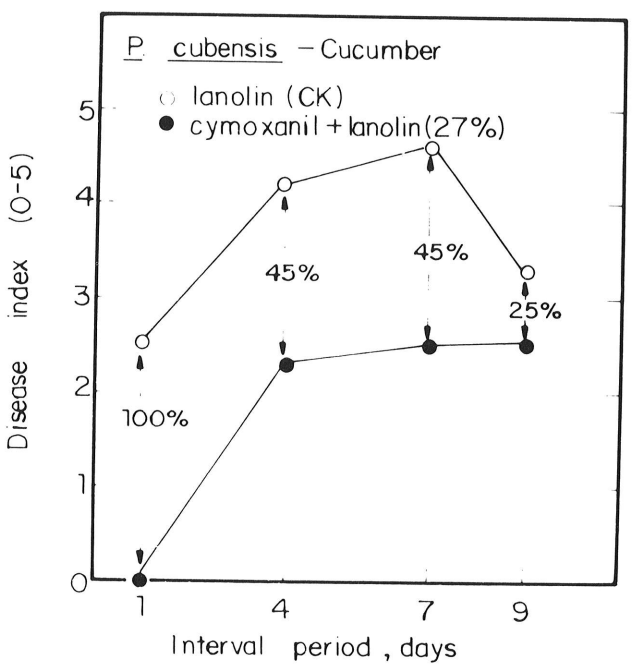

Fig. 6. Effects of delayed inoculation on control efficacy of *Pseudoperonospora cubensis* by cymoxanil applied to stems of cucumber plants.

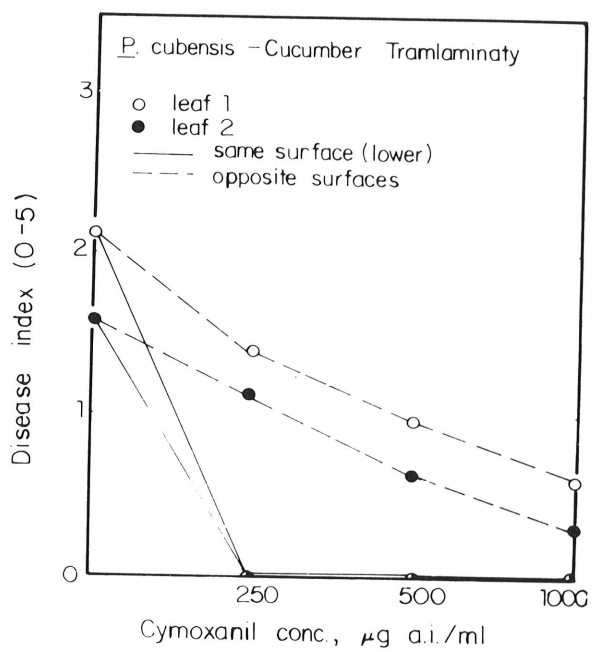

Fig. 7. Control of *Pseudoperonospora cubensis* (isolate Bar-Ilan 3) in two-leaf cucumber plants sprayed on either lower or upper leaf surfaces with cymoxanil (50WP) and inoculated on lower leaf surfaces ($n = 10$). Note poor disease control in leaves treated on upper surface and inoculated on lower surface.

Israel for the same purpose, contains the same ingredients but at a ratio of 7:1:2 (3).

Cymoxanil was equally effective against metalaxyl-sensitive and metalaxyl-resistant isolates of *P. infestans*. A similar conclusion drawn for *P. cubensis* is based on one sensitive isolate only. Metalaxyl-sensitive isolates of *P. cubensis* have been rare in Israel since 1984 (13).

Cymoxanil was readily taken up by leaves of cucumber and potato. It translocated effectively through laminae of potato but showed poor translaminar translocation in cucumber. Klopping and Delp (11) reported good translaminar translocation in tomato but not in grapes. No translocation from one leaf to another was observed in cucumber, potato, or tomato. Cymoxanil translocated from roots to foliage, but relatively high dosages were required to achieve good disease control by soil drenches. The toxicity of the fungicide to root growth of tomato and cucumber may be partially responsible for the lack of efficacy of the fungicide in soil drenches.

Although application of the fungicide to the lower part of the stem was efficient in controlling *P. cubensis* in cucumber and *P. infestans* in tomato, it had no effect on the development of *P. infestans* in potato. This, and the fact that soil drench treatments with cymoxanil were also inefficient in controlling late blight in potato, may indicate poor stem and root uptake and/or poor acropetal translocation of cymoxanil in potato.

Cymoxanil showed considerable curative activity when applied to potato foliage inoculated with *P. infestans* and, to a lesser extent, to cucumber inoculated with *P. cubensis*. In potatoes, about 60% control was still achieved as late as 3 days postinoculation, when symptoms were already incipient.

Cymoxanil foliar sprays did not lose efficacy for 5 days (longest period tested) at 20 C but did so within 4 days when applied as a lanolin paste to cucumber stems. Because no reduction in effectiveness was observed with cymoxanil-lanolin paste stored at room temperature for several weeks, we assume that the fungicide is rendered ineffective after penetrating the stem (8). Biodegradation of cymoxanil in plant tissue needs further study.

We conclude that cymoxanil shows several characteristics that make it a promising compound for the control of Oomycetes: 1) It is similarly effective against metalaxyl-sensitive and metalaxyl-resistant isolates of *P. cubensis* and *P. infestans*; 2) it is readily taken up by leaves, hence it is resistant to washing; 3) it shows acropetal systemic translocation in cucumber and tomato; and 4) it has a considerable curative activity against both *P. infestans* and *P. cubensis*.

Other workers reported on synergistic interaction between cymoxanil and protectant fungicides (8,10,11), acylanilides (1,9), and propamocarb (9). Because higher synergism values were observed toward acylanilide-resistant Oomycetes genotypes, reduced dosages of mixtures may be used that in turn will impose a reduced selection pressure by the acylanilide ingredient and thus may delay the buildup of resistant genotypes.

LITERATURE CITED

1. Barnavon, M., and Gisi, U. 1985. L'association oxadixyl, mancozebe, cymoxanil et les phenomenes de resistance chez le mildieu de la vigne. Pages 395-398 in: Fungicides for Crop Protection, 100 Years of Progress. Monogr. 31. I. M. Smith, ed. Br. Crop Brot. Counc. Publ., Croydon, England. 503 pp.
2. Cohen, Y. 1977. The combined effects of temperature, leaf wetness, and inoculum concentration on infection of cucumbers with *Pseudoperonospora cubensis*. Can. J. Bot. 55:1478-1487.
3. Cohen, Y. 1986. Fungicide mixtures controlling late blight in potatoes. Med. Fac. Landbouwwet. Rijksuniv. Gent 51/2b:715-718.
4. Cohen, Y., Eyal, H., and Sheinboim, Y. 1985. Efficacy of cymoxanil in controlling metalaxyl-resistant isolates of *Phytophthora infestans* and *Pseudoperonospora cubensis*. Pages 307-310 in: Fungicides for Crop Protection, 100 Years of Progress. Monogr. 31. I. M. Smith, ed. Br. Crop Prot. Counc. Publ., Croydon, England. 503 pp.
5. Cohen, Y., and Grinberger, M. 1986. Systemic antifungal activity of cymoxanil against *Pseudoperonospora cubensis* and *Phytophthora infestans*. (Abstr.) Phytopathology 76:1116.
6. Cohen, Y., Pe'er, S., Balass, O., and Coffey, M. D. 1987. A fluorescent technique for studying growth of *Peronospora tabacina* on leaf surfaces. Phytopathology 77:201-204.
7. Cohen, Y., and Reuveni, M. 1983. Occurrence of metalaxyl-resistant isolates of *Phytophthora infestans* in potato fields in Israel. Phytopathology 73:925-927.
8. Douchet, J. P., Absi, M., Hay, S. J. B., Muntan, L., and Viliani, A. 1977. European results with DPX-3217, a new fungicide for the control of grape downy mildew and potato late blight. Pages 535-540 in: Proc. Br. Crop Prot. Conf. Pests Dis. 2nd. Br. Crop Prot. Counc. Publ., Croydon, England.
9. Garibaldi, A., Romano, M. L., and Gullins, M. L. 1985. Synergism between fungicides with different mechanisms of action against acylalanine-resistant strains of *Phytophthora* spp. EPPO Bull. 15:545-551.
10. Gisi, U., Binder, H., and Rimbach, E. 1985. Synergistic interactions of fungicides with different modes of action. Trans. Br. Mycol. Soc. 85:299-306.
11. Klopping, H. L., and Delp, C. J. 1980. 2-Cyano-*N*-[(ethylamino) carbonyl]-2-(methoxyimino) acetamide, a new fungicide. J. Agric. Food Chem. 28:467-468.
12. Pappas, A. C. 1985. Resistance to acylalanines in *Pseudoperonospora cubensis*. EPPO Bull. 15:411-418.
13. Samoucha, Y., and Cohen, Y. 1985. Occurrence of metalaxyl-resistant isolates of *Pseudoperonospora cubensis* in Israel: A 5-year survey. EPPO Bull. 15:419-422.
14. Schwinn, F. J. 1983. New developments in chemical control of *Phytophthora*. Pages 327-334 in: *Phytophthora*: Its Biology, Taxonomy, Ecology, and Pathology. D. C. Erwin, S. Bartnicki-Garcia, and P. H. Tsao, eds. American Phytopathological Society, St. Paul, MN. 392 pp.
15. Staub, T. H., and Hubele, A. 1980. Recent advances in the chemical control of Oomycetes. Pages 389-422 in: Chemie der Pflanzenschutz- und Schadlingsbekampfungsmittel. R. Wegler, ed. Springer-Verlag, Berlin.