Field Control of Potato Late Blight by Synergistic Fungicidal Mixtures

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ABSTRACT

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Five fungicides and six fungicidal mixtures were compared on field-grown potatoes (cv. Alpha) for the control of phenylamide-sensitive and phenylamide-resistant field isolates of *Phytophthora infestans*. Fungicidal mixtures were far more effective in controlling both isolates than the fungicides applied singly. The mixture of mancozeb and cymoxanil (Mancur) and mixtures of mancozeb, cymoxanil, and oxadixyl (Pulsan and Sandocur-M) were highly effective and synergistic in controlling the phenylamide-resistant isolate of the late blight fungus. The cymoxanil mixtures may be suitable for late blight control in areas of Israel where phenylamide-resistant populations of *P. infestans* prevail.

Additional keywords: phenylamide resistance, chemical control, fungicide interaction, acylalanines

Late blight, incited by *Phytophthora infestans* (Mont.) d By., is a major disease of potato (*Solanum tuberosum* L.) in Israel. The disease is severe in all areas, causing considerable reduction in yield and quality. Since the first appearance of resistance to metalaxyl in *P. infestans* in 1982 (3), the proportion of field isolates resistant to the fungicide has remained consistently high (1). Resistant isolates are also common in fields not treated with phenylamide fungicides but located in the same general potato areas (1).

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Knowing that phenylamide-resistant isolates abound in the local population of *P. infestans*, most farmers avoid using the standard Ridomil MZ (metalaxyl plus mancozeb) fungicide. When resistance is encountered, the dilemma worsens because mancozeb and a variety of other protectant fungicides provide only partial control of the disease, especially when rows in the field are closed by the haulm.

Recently, we showed that the fungicidal mixtures Mancur, Pulsan, and Sandocur-M provided acceptable control of both phenylamide-sensitive (MS) and phenylamide-resistant (MR) isolates of the fungus in potted plants under growth chamber conditions (11). In this study, we examined the efficacy of some fungicides and fungicidal mixtures in controlling both MS and MR field isolates of *P. infestans* under field conditions.

MATERIALS AND METHODS

Two experiments were conducted, one in spring (planted in February 1987) and one in fall (planted in October 1987). Certified potato tubers (cv. Alpha, about 100 g each) were planted about 20 cm apart in individual rows 3 m long and 0.9 m apart. Fertilizers were applied at commercial rates 2 wk before planting. Herbicide (metribuzin, 70%, 0.35 kg a.i./ha) was applied before plant emergence. Plants were sprinkle-irrigated (equivalent of 10 mm of rain) twice a week in the spring.

Experimental design. In each season 22 individual plots were grown. Each plot comprised 6 rows, 3 m long, with 15 plants per row. Plots were separated by 2 m of fallow area on all four sides. One randomly chosen row in each plot was left untreated with fungicide, while the other five rows were treated with 100, 50, 25, 12.5, or 6.25% of the recommended commercial dose of a fungicide or fungicidal mixture. Treatment and check rows were allocated by randomized design in all five dilutions.

Two plots were randomly allocated for each fungicide. One plot in each pair was randomly picked for inoculation with the MS isolate of the fungus, and the other plot was inoculated with the MR isolate. Plants were treated with fungicides 10 wk after planting, when the haulm was almost fully developed, and were inoculated with *P. infestans* 10 hr after fungicide was applied.

Fungicides and fungicide application. The following five fungicides were used: oxadixyl (2-methoxy-*N*-(2-oxo-1,3-oxazolidin-3-yl)acet-2′,6′-xylidide) (SAN 371F 25 WP, Sandoz); cymoxanil (2-cyano-*N*-[(ethylamino)carbonyl]-2-(methoxyimino) acetamide) (Curzate 50 WP, E.I. du Pont de Nemours & Co.); mancozeb 80 WP; propamocarb (propyl [3-(dimethylamino)propyl] carbamate monohydrochloride) (Previcur N 72, Schering AG); and metalaxyl (methyl *N*-(2-methoxyacetyl)-*N*-(2,6-xylyl)-DL-alaninate) (Ridomil 25 WP, Ciba-Geigy). The following six fungicidal mixtures were used: SAN-518F 64 WP (oxadixyl plus mancozeb, 1:7 [w/w] mixture of active ingredients, Sandoz); Mancur 71.4 WP (cymoxanil plus mancozeb, 1:4 [w/w] a.i., Milchan Bros., Israel); Pulsan 67 WP (oxadixyl, cymoxanil, and mancozeb, 1:0.4:7 [w/w/w] a.i., Sandoz); Sandocur-M 69.1 WP (oxadixyl, cymoxanil, and mancozeb, 1:2:7 [w/w/w] a.i., Sandoz); SAN-518F Pr 65.1 EC (oxadixyl, mancozeb, and propamocarb, 1:7:2 [w/w/v] a.i.); and Ridomil MZ 63.5 WP (metalaxyl plus mancozeb, 1:7.5 [w/w] a.i., Ciba-Geigy).

All fungicides were suspended in water and were sprayed 10 hr before inoculation. Fungicides were applied with a 15-L backpack sprayer (Iris-15, Birchmeier, Switzerland) equipped with Duro-nozzle 1.5 at a rate of 150 ml per row (about 500 L/ha). All fungicidal doses are given in grams of active ingredient per hectare.

Fungal isolates and inoculation. One MS field isolate (collected from a blighted potato field at Nir-Eliyahu, Israel, in May 1984) and one MR field isolate (collected from a blighted potato field at Mishmereth, Israel, in April 1986) of *P. infestans* were used. Isolates were maintained on detached potato leaflets floating on water (isolate MS) or metalaxyl (100 mg/L) (isolate MR) in petri dishes at 10 C and were propagated on potato tuber slices at 20 C in a moist atmosphere in the dark. Inoculum was prepared as described before (7). The MS isolate was fully controlled in inoculated potato tuber disks floated on metalaxyl at 0.1 mg/L, whereas the MR isolate was still sporulating on tuber disks floated on metalaxyl at 1,000 mg/L (1,7).

Plants were spray-inoculated with about 150 ml of sporangium suspension per row (2,000 sporangia per milliliter) with the aid of the backpack sprayer described above.

Disease assessment and control efficacy determination. The number of infected leaflets per row was counted 10 days after inoculation. The percentage control efficacy (PCE) of each fungicide was calculated as follows: $PCE = 100(1 - x/y)$, where x is the number of infected leaflets in a fungicide-treated row in a plot and y is the number of infected leaflets in the untreated control row in the plot.

The fungicide concentration that was required to control 90% of the disease relative to fungicide-free inoculated plants (ED_{90} obs) was determined with the aid of dose-response curves and PROBIT (9). The expected ED_{90} value of a fungicidal mixture (ED_{90} exp) was calculated using the Wadely formula as described previously (5,8). The increased control efficacy of a fungicidal mixture, or synergy factor (SF), was calculated as follows: $SF = ED_{90}\ exp\ /\ ED_{90}\ obs$. SF values greater than 1 suggest synergistic interaction between components of a mixture (5,8).

RESULTS

The fungicide-free rows inoculated with the MS fungus ($n = 11$) averaged 517 ± 38 blighted leaflets per row in the spring and 551 ± 46 in the fall ($t = 1.343$, $P \geq 0.1$). Corresponding numbers in the fungicide-free rows inoculated with the MR fungus ($n = 11$) were 590 ± 64 and 634 ± 49 ($t = 1.294$, $P > 0.1$).

Table 1 indicates the efficacy of the five single fungicides against the MS and MR isolates. Whereas the disease incited by the MS isolate was fully controlled by 125 g/ha of either oxadixyl or metalaxyl, the disease incited by the MR isolate was almost unaffected by 250 g/ha of these fungicides. Both isolates were fully controlled by propamocarb, cymoxanil, and mancozeb at doses of 2,160, 500, and 2,000 g/ha, respectively (Table 1).

Table 2 shows the efficacy of the six fungicidal mixtures in controlling the MS and the MR isolates. The two mixtures of phenylamide and mancozeb (SAN-518F and Ridomil MZ) were less effective against the MR isolate but more effective against the MS isolate than either of the phenylamides oxadixyl or metalaxyl (Table 2). The other four mixtures did not differ significantly ($P = 0.05$) in their ability to control the two isolates (Table 2).

Table 3 shows the doses of the six fungicidal mixtures required to achieve 90% control of the disease incited by the

Table 1. Control of late blight of potatoes incited by a phenylamide-sensitive (MS) and a phenylamide-resistant (MR) field isolate of *Phytophthora infestans* by five fungicides under field conditions

Fungicide Dose (g/ha)	Disease control (% ± SD)[a] MS	MR
Oxadixyl		
15.6	10 ± 10	0
31.25	63 ± 3	0
62.5	85 ± 7	0
125	100	0
250	100	5 ± 5
Metalaxyl		
15.6	30 ± 14	0
31.25	75 ± 7	0
62.5	88 ± 4	0
125	100	0
250	100	7 ± 4
Propamocarb		
135	10 ± 10	0
270	30 ± 11	15 ± 5
540	45 ± 7	30 ± 10
1,080	75 ± 5	65 ± 7
2,160	100	96 ± 2
Cymoxanil		
31.25	20 ± 0	10 ± 10
62.5	35 ± 7	30 ± 0
125	45 ± 5	42 ± 3
250	70 ± 10	75 ± 5
500	100	100
Mancozeb		
125	10 ± 10	0
250	33 ± 10	15 ± 5
500	65 ± 7	42 ± 4
1,000	97 ± 4	77 ± 3
2,000	100	100

[a]Numbers are averages from two field experiments, each with 15 plants per dose per isolate. SD = standard deviation.

Table 2. Control of late blight of potatoes incited by a phenylamide-sensitive (MS) and a phenylamide-resistant (MR) field isolate of *Phytophthora infestans* by six fungicidal mixtures under field conditions

Mixture[a] Dose (g/ha)	Disease control (% ± SD)[b] MS	MR
San-518F (A+E,1+7)		
120	92 ± 3	10 ± 10
240	100	35 ± 5
480	100	80 ± 0
960	100	100
1,920	100	100
Ridomil MZ (B+E,1+7.5)		
119	94 ± 2	15 ± 5
238	100	45 ± 7
476	100	88 ± 3
952	100	100
1,904	100	100
Mancur (D+E,1+4)		
155	87 ± 4	85 ± 0
310	93 ± 3	91 ± 1
621	99 ± 1	99 ± 1
1,242	100	100
2,484	100	100
SAN-518F + Pr (A+C+E,1+2+7)		
142	90 ± 7	65 ± 5
284	93 ± 3	75 ± 7
568	98 ± 0	90 ± 5
1,136	100	100
2,272	100	100
Pulsan (A+D+E,1+0.4+7)		
146	87 ± 3	83 ± 4
292	95 ± 0	93 ± 3
584	100	98 ± 0
1,168	100	100
2,336	100	100
Sandocur-M (A+D+E,1+2+7)		
151	93 ± 3	90 ± 0
302	97 ± 2	95 ± 0
604	100	99 ± 1
1,208	100	100
2,416	100	100

[a]A = oxadixyl, B = metalaxyl, C = propamocarb, D = cymoxanil, E = mancozeb.
[b]Numbers are averages from two field experiments, each with 15 plants per dose per isolate. SD = standard deviation.

Table 3. Doses (g a.i./ha) of fungicides and fungicidal mixtures required for 90% control of potato late blight incited by a phenylamide-sensitive (MS) and a phenylamide-resistant (MR) field isolate of *Phytophthora infestans* under field conditions

	MS isolate				MR isolate			
Fungicide	Observed	P^a	Expected	SF[b]	Observed	P^a	Expected	SF[b]
Oxadixyl (A)	63	0.98	—	—	250	—	1,000[c]	—
Metalaxyl (B)	60	0.87	—	—	250	—	1,000[c]	—
Propamocarb (C)	1,347	0.95	—	—	1,647	0.96	—	—
Cymoxanil (D)	345	0.97	—	—	314	0.96	—	—
Mancozeb (E)	759	0.98	—	—	1,132	0.97	—	—
SAN-518F (A+E,1+7)	100	0.93	320	3.20	549	0.99	1,274	2.32
Ridomil MZ (B+E,1+7.5)	97	0.97	325	3.35	489	0.99	1,257	2.57
Mancur (D+E,1+4)	221	0.99	612	2.76	261	0.99	745	2.85
SAN-518F + Pr (A+C+E,1+2+7)	167	0.99	376	2.25	538	0.99	1,334	2.47
Pulsan (A+D+E,1+0.4+7)	185	0.99	321	1.73	263	0.99	1,112	4.22
Sandocur-M (A+D+E,1+2+7)	115	0.99	329	2.82	150	1.00	791	5.27

[a] P is the adjusted R^2 statistic (chi-squared test) for the probability of agreement between the experimental dose-response curve and the computed probit model.
[b] SF is the synergy factor calculated from dose-response data according to the Wadely formula (8).
[c] Oxadixyl and metalaxyl at 250 g/ha controlled the disease incited by the MR isolate by only 5–7%. Therefore, 1,000 was chosen as an expected value for these fungicides.

MS and the MR isolates. The relative efficacies against MS and MR were reflected in the synergy factor for each mixture. Ridomil MZ and SAN-518F had the highest SF values for the control of the MS isolate (3.35 and 3.20, respectively), whereas the highest values for the control of the MR isolate (5.27 and 4.22) were obtained with Sandocur-M and Pulsan, respectively (Table 3).

DISCUSSION

Cymoxanil is a systemic acetamide fungicide active against oomycetous fungal pathogens (2,15). Its mode of action differs from that of metalaxyl. Metalaxyl specifically inhibits ribosomal RNA synthesis, whereas cymoxanil affects DNA and, to a lesser extent, RNA synthesis (15).

In a previous study (11), we demonstrated that fungicidal formulations containing cymoxanil were highly active in controlling late blight in potatoes under laboratory conditions, regardless of the fungal sensitivity to phenylamide fungicides. In the present study, cymoxanil mixtures also showed very high activities under field conditions. The cymoxanil-containing mixtures Mancur, Pulsan, and Sandocur-M provided acceptable control of both MS and MR isolates of *P. infestans* in field-grown potatoes. The fungicidal mixtures SAN-518F and Ridomil MZ were very effective in controlling the MS isolate but less effective against the MR isolate of the fungus.

The efficacy of Mancur, Pulsan, and Sandocur-M was reflected in the relatively low doses required to achieve 90% control of the disease incited by the MR isolate. Dosages required in mixtures for 90% control of the MR isolate were far smaller than those expected based on the efficacy of the ingredients when used separately, indicating synergistic interactions between the ingredients of Mancur (mancozeb and cymoxanil) and between those of Pulsan and Sandocur-M (mancozeb, cymoxanil, and oxadixyl).

Gisi et al (5), Grabski and Gisi (6), and Samoucha and co-workers (13,14) reported synergistic interactions in the mixtures mancozeb plus cymoxanil, mancozeb plus oxadixyl, cymoxanil plus oxadixyl, and mancozeb plus cymoxanil plus oxadixyl in the tomato-*P. infestans* and the grape-*Plasmopara viticola* pathosystems in greenhouse experiments. Grabski and Gisi (6) reported higher synergy factors for MR than for MS isolates of *P. infestans* on tomato.

Our previous study (10) showed synergistic interactions between either metalaxyl or fosetyl-Al and five protectant fungicides in controlling late blight in potatoes. We also showed that phenylamide-mancozeb mixtures (SAN-518F and Ridomil MZ) were inefficient in controlling MR isolates of *P. infestans* under growth chamber conditions but that addition of cymoxanil to SAN-518F greatly improved its efficacy (11).

In a recent study (4), we also found that Mancur, Sandocur-M, and Pulsan were very effective in controlling MR isolates of *P. infestans* and simultaneously suppressed the buildup of MR isolates in mixed MS plus MR populations. Other experiments (12) revealed that these three fungicidal mixtures have longer residual activity in controlling MR isolates of *P. infestans* in the field than any of the other seven fungicides tested.

This study and our previous studies (1,4,10–12) indicate that Mancur, Pulsan, and Sandocur-M are preferred to the other fungicides tested for the control of Israeli MR isolates of *P. infestans.*

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