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Field Performance of a New Fungicide Ethaboxam Against Cucumber Downy Mildew, Potato Late Blight and Pepper Phytophthora Blight in Korea

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Ethaboxam is the first proprietary fungicide developed in Korea, registered in 1998 and commercialized in 1999 by LG Chemical Ltd., Korea. It is a derivative of aminothiazole carboxamide and formulated into 25% wettable powder for practical application in fields. Ethaboxam effectively controlled cucumber downy mildew caused by *Pseudoperonospora cubensis*, potato late blight caused by *Phytophthora infestans*, and pepper Phytophthora blight caused by *P. capsici*, and was superior or comparable to the commercial standards, when foliarly sprayed 3~5 times until dripping off at approximately 7-day intervals during the growing season. Ethaboxam was required at least 125 mg/liter and 250 mg/liter for effective control of cucumber downy mildew, and potato late blight and pepper Phytophthora blight, respectively. There was no phytotoxicity observed on leaves, stems or fruits of cucumber, potato and pepper from any trial.

Keywords : Guardian, LGC-30473, Oomycetes fungicide, proprietary fungicide.

Late blight of potato and downy mildew of grape and vegetables have been major diseases causing substantial economic losses, and growers are spending approximately 1.0 billion US dollars to control the diseases caused by the Oomycetes pathogens in the world (Schwinn and Staub, 1995). These diseases are also important for stable production of vegetables and potatoes in Korea. In addition, cucumber downy mildew caused by *Pseudoperonospora cubensis* and pepper Phytophthora blight caused by *Phytophthora capsici* are important limiting factors in vegetable production and mainly managed by applying fungicides (Hwang, 1995; Kim, 1997; Oh and Kim, 1992).

Modern fungicides have been usually introduced in the market with traits of selective, systemic and curative activity; 1) the fungicides specifically target pathogens, so that they are much safer for crops, consumers, growers and environments, 2) they protect growing parts or areas which are not covered by applied fungicides, and 3) they control diseases even after infection by pathogens. Furthermore, the fungicides have allowed the reduction of application number and application rate required during the growing season. However, most of them have potential problems such as development of fungicide resistance. For example, resistance to Metalaxyl has been reported in potato and red-pepper in Korea (Choi et al., 1992; Ham et al., 1991; Hwang, 1995; Koh, et al., 1994; Lee et al., 1994; Oh and Kim, 1992), and the resistant strains often have better fitness than the wild type in the natural habitat (Kadish and Cohen, 1998; Kim et al., 1993; Oh and Kim, 1992). This problem forces us to continuously discover new fungicides with different modes of action as a solution.

In this aspect, Ethaboxam is a valuable addition to the group of fungicides specific to the diseases caused by Oomycetes. Ra et al. (1995) discovered this chemical first in 1993, and thereafter it was registered in 1998 and commercialized in 1999 in Korea. It was presented to have good protective, curative, systemic and persistent activity in the growth chamber tests (Kim, 1997). Ethaboxam has been tested in over 200 field trials throughout the world, mainly in Europe since 1995, and was reported to effectively control grape downy mildew caused by *Plasmopara viticola*, potato

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and tomato late blight caused by *P. infestans*, lettuce downy mildew caused by *Bremia lactucae* (Kim, 1997). Its field performance against cucumber downy mildew and pepper Phytophthora blight in Korea has not been reported yet.

This study was conducted 1) to confirm field performance of Ethaboxam against potato late blight in Korea compared to that in Europe, and 2) to determine its fungicidal activity against cucumber downy mildew and pepper Phytophthora blight in Korea, and 3) to select a minimum application rate for effective control of each disease.

Materials and Methods

Fungicides and their application. Ethaboxam {Chemical abstract index name: *N*-(cyano-2-thienylmethyl)-4-ethyl-2-(ethylamino)-5-thiazolecarboxamide; IUPAC name: *N*-(α-cyano-2-thenyl)-4-ethyl-2-(ethylamino)-5-thiazolecarboxamide} is a derivative of aminothiazole carboxamide and was formulated into 25% wettable powder (WP) for the fields tests (Fig. 1). The commercial standards, Fluazinam (Frowncide™, 50% WP), Fosetyl-Al (Aliette™, 80% WP), Mancozeb (Dithane M-45™, 75% WP), Metalaxyl (Ridomil™, 25% WP), and Metalaxyl+Copper oxychloride (Ridomildong™, 15+35% WP) were purchased from markets for this study. Each fungicide was diluted in tap water to the concentrations recommended by the manufacturers and used at the concentration of 250 mg/liter for Fluazinam, 1,600 mg/liter for Fosetyl-Al, 1,500 mg/liter for Mancozeb, 250 mg/liter for Metalaxyl, and 500 (=150+350) mg/liter for Metalaxyl+Copper oxychloride. Ethaboxam (Guardian™, 25% WP) was diluted at the concentration of 63, 125, 250 and/or 500 mg/liter to select a minimum application rate for each disease. The fungicides were foliarly sprayed 3~5 times until dripping off at 6~13 days, mostly 7 days, of the application intervals (Table 1).

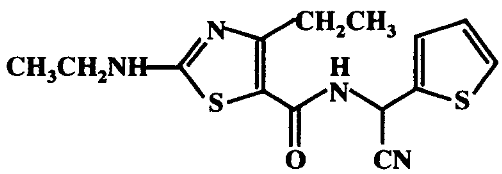

Fig. 1. Chemical structure of Ethaboxam.

Experimental design and data analysis. Field trials were conducted at the sites where the target diseases occurred endemically with frequent epidemic development in Korea (Fig. 2). All trials were designed in randomized complete blocks with three or four replications, and details are specified for trial site, cultivar, plot size, date of application and assessment of disease and phytotoxicity, and trial year in Table 1. Cucumber (*Cucumis sativus*) was grown inside plastic tunnel except the Chonan trial conducted in an open field. Each experimental unit consisted of at least 20 plants spaced at 40 cm apart in two rows spaced at 80~100 cm apart. The fungicides were applied at least from the 10 leaf stage of cucumber with a slight natural infection at lower leaves. Potato

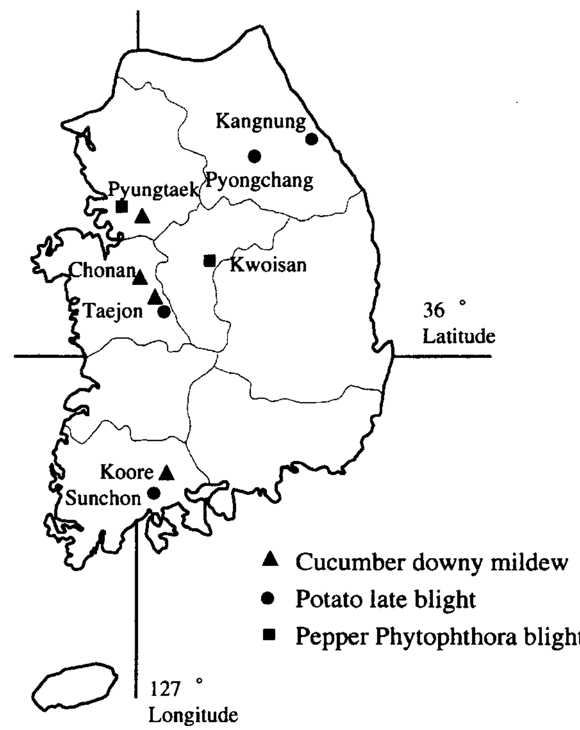

Fig. 2. Field trial sites in Korea.

Table 1. Specification of field trials in Korea

Corp disease[a]	Site	Cultivar	No. Replications	Plant No. per unit	Sampling unit	Application dates	Estimation date	Year
Cucumber downy mildew	Taejon	Baegdadaki	3	30	100 leaves	Jan 30, Feb 7, Feb 13, Feb 21	Mar 2	1996
	Koore	Kyeulsali-chungjang	3	30	100 leaves	Apr 23, Apr 30, May 7	May 14	1996
	Pyungtaek	Baegdadaki	4	40	100 leaves	Apr 28, May 6, May 13, May 20	May 25	1998
	Chonan	Baegdadaki	4	20	100 leaves	Jun 22, Jun 29, Jul 6	Jul 13	1998
Potato late blight	Taejon	Dejima	4	40	24 plants	Jun 17, Jun 23, Jun 29	Jul 3	1998
	Sunchon	Dejima	3	60	20 plants	May 27, Jun 3, Jun 10, Jun 17	Jun 20	1995
	Pyongchang	Superior	3	80	40 plants	Jun 30, Jul 9, Jul 18, Jul 29	Aug 7	1996
	Kangnung	Superior	3	60	20 plants	Jul 21, Jul 29, Aug 5, Jun 12,	Aug 17	1998
Pepper	Kwoisan	Dongband	3	40	30 plants	Jun 8, Jun 15, Jun 22, Jun 29, Jul 6	Jul 13	1996
Phytophthora blight	Pyungtaek	Bukang	3	40	40 plants	Jul 3, Jul 16, Jul 28, Aug 10	Aug 18	1998

[a]Cucumber downy mildew is caused by *Pseudoperonospora cubensis,* potato late blight by *Phytophthora infestans* and pepper Phytophthora blight by *P. capsici.*

(*Solanum tuberosum*) was grown in open fields. Each experimental unit consisted of at least 40 plants spaced at 20~30 cm apart in four rows spaced at 80 cm apart. The fungicides were applied from the time near the rainy monsoon season when the soil surface was completely covered with growing potato plants in each row. Pepper (*Capsicum annuum*) was grown in open fields. Each experimental unit consisted of 40 plants spaced at 50 cm apart in one row. The fungicides were applied from the time near the rainy monsoon season when pepper plants were 70~100 cm high with small green peppers.

Data analysis was conducted with a statistics program, STATISTICA (Statsoft, Oklahoma, USA). Analysis of variance was conducted for comparison between treatment means. When the overall F-test was significant at P=0.05, the means were analyzed for multiple comparison by Fishers protected least significant difference test.

Estimation of disease severity and phytotoxicity. Disease severity was estimated following the Test Guideline for Pesticide Registration in Korea established by the National Institute of Agricultural Science and Technology in Suwon, Korea. For cucumber downy mildew, 100 leaves from 20 plants were sampled and visually assessed 5~9 days after the last application for each experimental unit, and disease severity was determined using the formula as follows.

$$\text{Disease severity } (\%)=\{(4a+3b+2c+1d)/4(a+b+c+d+e)\}\times 100$$

where a = number of leaf with greater than 50% of leaf area infected,
b = number of leaf with 20.1~50% of leaf area infected,
c = number of leaf with 5.1~20% of leaf area infected,
d = number of leaf with 0.1~5% of leaf area infected,
e = number of leaf with no disease.

For potato late blight, 40 plants from each experimental unit were visually assessed 3~8 days after the last application for disease severity using the formula as follows.

$$\text{Disease severity } (\%) = \{(4a+3b+2c+1d)/4(a+b+c+d+e)\}\times 100$$

where a = number of leaf with greater than 75% of leaf area infected and stems partially decayed,
b = number of leaf with 50.1~75% of leaf area infected,
c = number of leaf with 25.1~50% of leaf area infected,
d = number of leaf with 0.1~25% of leaf area infected,
e = number of leaf with no disease.

For pepper Phytophthora blight, all 40 plants in the experimental unit were estimated, and disease incidence was visually assessed 7~8 days after the last application by determining percentage of plants with the typical symptoms.

Phytotoxicity was determined visually by malformation, discoloration or retarded growth of plants during the growing season and examined every time before fungicide application.

Results

Cucumber downy mildew. Ethaboxam effectively controlled cucumber downy mildew and was superior to the commercial standards in the field tests each with different disease pressure (Table 2). In the Taejon and Koore, Ethaboxam was required at least 125 mg/liter to have significantly better control efficacy than the commercial standards, Fosetyl-Al and Mancozeb. In the Pyungtaek trial, fungicidal activity of Ethaboxam was significantly better at 125 and 250 mg/liter than 63 mg/liter. In the Chonan trial, Ethaboxam was relatively less effective compared to the other trials, but still had a good contol of the disease. There was no statistical different between the application rates in this test. Phytotoxicity was not observed on leaves, stems or fruits from any trial.

Potato late blight. Ethaboxam also performed effectively

Table 2. Effect of Ethaboxam against cucumber downy mildew in Korea

Active ingredient	Formulation (a.i.%)	Application rate (mg/liter)	Disease severity (%)[a]			
			Taejon	Koore	Pyungtaek	Chonan
Ethaboxam	WP(25)[b]	500	5.5a[c]	9.6a	–[d]	–
		250	6.3a	11.4a	6.6a	25.2a
		125	–	15.7a	7.5a	33.7a
		63	–	–	11.9b	35.3a
Fosetyl-Al	WP(80)	1,600	43.5c	18.1b	–	–
Mancozeb	WP(75)	1,500	23.8b	25.6c	–	–
Untreated	–	–	58.3c	74.6d	31.6c	65.4b
LSD	–	–	17.7	7.4	3.2	17.2

[a]Disease severity (%) = {(4a+3b+2c+1d)/4(a+b+c+d)}×100, where a=number of leaves with more than 50% of leaf area infected, b= number of leaves with 20.1~50% of leaf area infected, c=number of leaves with 5.1~20% of leaf area infeced, d=number of leaves with 0.1~5% of leaf area infected, e=number of leaves with no disease.
[b]Wettable powder.
[c]Means with the same letter are not significantly different at P=0.05 by Fisher's Protected LSD.
[d]Not tested.

Table 3. Effect of Ethaboxam against potato leat blight in Korea

Active ingredient	Formulation (a.i.%)	Application rate (mg/liter)	Disease severity (%)[a]			
			Taejon	Sunchon	Pyongchang	Kangnung
Ethaboxam	WP(25)[b]	500	–[c]	23.3b	–	–
		250	15.5ab[d]	10.0a	12.5a	18.3a
		125	27.3b	30.0b	–	55.4b
		63	26.7b	–	–	72.2b
Metalaxyl	WP(25)	250	–	30.0b	23.3b	–
Fluazinam	WP(50)	250	11.1a	–	15.8ab	16.4a
Untreated	–	–	67.4c	85.0c	91.6c	99.9c
LSD	–	–	10.0	10.1	7.9	33.1

[a]Disease severity (%) = {(4a+3b+2c+1d)/4(a+b+c+d)}×100, where a=number of leaves with greater than 75% of leaf area infected, b= number of leaves with 50.1~75% of leaf area infected, c=number of leaves with 5.1~20% of leaf area infeced, d=number of leaves with 0.1~25% of leaf area infected, e=number of leaves with no disease.
[b]Wettable powder.
[c]Not tested.
[d]Means with the same letter are not significantly different at P=0.05 by Fisher's Protected LSD.

Table 4. Effect of Ethaboxam against pepper Phytophthora blight in Korea

Active ingredient	Formulation (a.i.%)	Application rate (mg/liter)	Disease incidence (%)[a]	
			Kwoisan	Pyungtaek
Ethaboxam	WP(25)[b]	500	1.1a[c]	–[d]
		250	3.3a	17.5a
Metalaxyl+Copper oxychloride	WP(15+35)	150+350	3.3a	29.6b
Untreated	–	–	28.8b	97.8c
LSD			10.6	11.9

[a] Disease incidence was estimated by determining percentage of plants with the typical symptoms in the experimental unit.
[b] Wettable powder.
[c] Means with the same letter are not significantly different at P=0.05 by Fisher's Protected LSD.
[d] Not tested.

in all trials against potato late blight and was superior or comparable to the commercial standards in the fields with high disease pressure (Table 3). In all four trials, Ethaboxam resulted in the highest fungicidal activity at 250 mg/liter and was better than Metalaxyl and as effective as Fluazinam. In the Sunchon trial, the higher dose did not improve its fungicidal activity. The application rate at 125 mg/liter or below appeared to be insufficient for controlling potato late blight. Phytotoxicity was not observed on leaves or stems from any trial.

Pepper Phytophthora blight. Ethaboxam also performed effectively in two trials against pepper Phytophthora blight and was comparable to the commercial standard used in the study (Table 4). In the Kwoisan trial with low disease pressure, Ethaboxam resulted in 1.1 and 3.3% of disease incidence at 500 and 250 mg/liter, respectively, and was as effective as Metalaxyl. In the Pyungtaek trial with high disease pressure, Ethaboxam resulted in 17.5% at 250 mg/liter and was significantly better than Metalaxyl. Phytotoxicity was not observed on leaves, stems or fruits from any trial.

Discussion

This is the first report on fungicidal activity of Ethaboxam under the field conditions in Korea. Considering the fact that all the active ingredients of proprietary fungicides currently used in Korea are imported, this discovery is a significant contribution to crop protection from the diseases in Korea. Furthermore, new fungicides with different mode of actions have been required in Korea to control Metalaxyl-resistant isolates of *P. infestans* and *P. capsici* that have higher fitness in the natural habitat (Kadish and Cohen, 1998; Kim et al., 1993; Oh and Kim, 1992). Ethaboxam was reported to have good fungicidal activity *in vitro* against Metalaxyl-resistant strains of *P. infestans* and *P. capsici* (Kim, 1997).

The results in this study showed that 1) the fungicidal activity of Ethaboxam was confirmed in Korea as well as in Europe, 2) Ethaboxam was also very effective against cucumber downy mildew and pepper Phytophthora blight, compared to the commercial standards, and 3) the minimum application rate for the effective control was 125 mg/liter for cucumber downy mildew and 250 mg/liter for potato late blight and pepper Phytophthora blight. Therefore, Ethaboxam may be used to effectively control cucumber downy mildew at 125 mg/liter and potato late blight and pepper Phytophthora blight at 250 mg/liter, when applied foliarly 3~5 times at 7-day intervals during the growing season.

However, there were variations observed in the fungicidal activity between the trial sites. For example, its activity was relatively low at the Chonan trial which was conducted in an open field. It is also noteworthy that Ethaboxam was generally effective against cucumber downy mildew at the lower application rate than potato late blight and pepper Phytophthora blight. This means that the application rate needs to be determined for each crop and disease.

In addition, observations from the field trials in Korea and Europe suggest that the application spectrum of Ethaboxam is mainly determined by the pathogen rather than the crop. Ethaboxam may be still applicable to other diseases caused by Oomycetes, which have not been tested thus far. Studies are currently in progress to expand its application spectrum, to develop mixture products, to reduce its application rate, to locate biochemical action sites, and to evaluate its potential of fungicide resistance.

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