Evaluation of Seed and Foliar Fungicides for Control of Karnal Bunt of Wheat

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ABSTRACT

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Eight seed-applied and 16 foliar-applied fungicides were evaluated for control of Karnal bunt of wheat. Control (>80%) was obtained with two applications of either propiconazole or etaconazole or four applications of mancozeb or copper hydroxide when these fungicides were applied to wheat plants at Feeke's growth stage 10.0–10.5. Best control by propiconazole and etaconazole was obtained when they were applied 72 hr after inoculation rather than before inoculation. None of the systemic fungicides applied to seed reduced Karnal bunt infection.

Karnal bunt of wheat (*Triticum aestivum* L.) caused by *Tilletia indica* Mitra (= *Neovossia indica* (Mitra) Mundkur) occurs in India, Pakistan, Iraq, Afghanistan, and more recently, in Mexico (15). The potential increase in the geographic range of this disease and the economic impact that might result is uncertain. Resistance in bread wheat cultivars has thus far not been found, and chemical control measures have not been developed. For these reasons, wheat from Karnal bunt areas is subject to stringent international quarantines (2).

Teliospores of *T. indica* are resistant to extremes of heat, cold, and harsh chemical treatment (27,28) and can survive up to 4 yr in field soil (16). Germination begins after 5–6 days of incubation under optimal conditions of high soil moisture and temperatures of 15–22 C (10,28). The disease occurs irregularly; high incidence is associated with temperatures of 15–20 C and high humidity or rainfall during spike emergence (3,16). The glumes of emerging spikes are presumed to be infected by airborne sporidia produced by teliospores after germination at the soil surface (15,18). Sporogenous hyphae develop inside the pericarp of the developing seed (23) and partially or completely replace the seed by a mass of dark teliospores. The disease cycle is completed when teliospores are deposited on the soil when the wheat is harvested and threshed. Teliospores beneath the soil surface or residing on buried infested or infected seed apparently do not contribute to infection (5,15,28).

Reports on chemical control of Karnal bunt are few and contradictory. Foliar-applied fungicides are reported both to control (17,21,26) or to have no effect (4) on Karnal bunt incidence. Although reduced infection was obtained on two occasions with carbendazim (17,26), no other compounds were consistently reported effective. Seed treatments with mercury compounds (1,18,19), hot water (5,21), formaldehyde (18,19), and copper carbonate (18,19) were reported to reduce Karnal bunt; others (4,14,20,22) reported seed treatments to be ineffective. These and other seed treatments do inhibit teliospore germination (28,29) and may prove useful in limiting soil infestation from planting of infested or infected seed. The purpose of this study was to evaluate seed- and foliar-applied fungicides for their potential to control Karnal bunt after natural infection or artificial inoculation.

MATERIALS AND METHODS

The spring wheat cultivar Seri 79 was used in all tests. Seed was 18 mo old at planting and contained about 6% Karnal bunt-infected kernels. Seed was planted 4 cm deep at a rate of 4 g/m in furrow-irrigated clay soil where a high incidence of Karnal bunt had occurred 2 yr previously. All experiments were conducted at the Centro de Investigaciones Agrícolas de Noroeste, Sonora, Mexico. Eight formulations were tested as seed treatments, and 16 formulations were tested as foliar treatments. The formulations and percent active ingredients applied to both seeds and foliage were benomyl, 50% (Benlate); bitertanol, 30% (Baycor); furmecyclox, 40% (Campogran); nuarimol, 9.5% (Trimidol); propiconazole, 25% (Tilt); thiabendazole, 30% (Mertect LSP); and triadimefon, 25% (Bayleton). The formulations applied only to foliage were copper hydroxide, 50% (Kocide 101); etaconazole, 10% (Vangard); fentin hydroxide, 19.7% (Duter); mancozeb, 80% (Manzate 200); maneb, 80% (Maneb); PCNB, 24% (Terrazan); thiram, 75% (Thiram); and triadimenol, 15% (Baytan).

The foliar fungicides were applied with a CO_2 sprayer operated at 20 lb/in.^{2} in a water volume of 350 L/ha. They were applied initially when 25% of the spikes had emerged (Feeke's growth stage 10.1). The systemic fungicides were applied again after 7 days, whereas the contact fungicides were applied three more times

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Table 1. Effects of two applications of foliar fungicides on natural incidence of Karnal bunt of wheat planted on three dates[a]

Treatment	Rate (a.i./ha)	Infected kernels (no./kg) 7 Nov.[b]	28 Nov.	18 Dec.
Untreated	...	42.8	42.0	48.0
Nuarimol	95 ml	42.6	56.0	26.2
Fentin hydroxide	340 g	12.8	24.8	20.8
Mancozeb	2.4 kg	4.8	9.6	12.0
Propiconazole	250 g	4.4	9.2	0.0
$LSD_{0.05}$		3.2	3.4	3.5

[a] Each valve represents the mean of 12 replicates.
[b] Planting date.

after the first application at intervals of 3–4 days.

In one experiment, four fungicides were applied to plants seeded on 7 and 28 November and 18 December 1984. Nuarimol, fentin hydroxide, mancozeb, and propiconazole were applied on each planting date to 20 replicate plots in a randomized block design containing four double rows 4 m long at rates listed in Table 1. In a second experiment, 16 fungicides were applied to plants seeded on 7 and 28 November 1984. The fungicides were applied to four replicate plots containing four double rows 3 m long at rates listed in Table 2. Multiple planting dates were used to increase the chance of obtaining a high incidence of natural infection because of the simultaneous occurrence of spike emergence and weather conditions conducive to Karnal bunt development.

To determine the most effective time of systemic fungicide application and to ensure that some infection would occur, tillers were boot-inoculated before and after fungicide application in the second experiment. The plants seeded on 7 November were inoculated 24 hr before and after fungicide application, whereas those seeded on 28 November were inoculated 72 hr before and 48 hr after the first fungicide application. The boot inoculation was performed by injecting 1 mm of a water suspension containing 10,000 secondary sporidia of *T. indica* into the top of the wheat boot (24). The inoculation was made when the spike was still enclosed (Feeke's growth stage 10.0), with the awns emerged about 1 cm (25). The sporidia were cultured by a sporidial shower technique described previously (24).

Seed treatments were applied to seed in units of 100 g. All formulations were mixed with water to a volume of 5 mm and applied as slurries at the rates listed in Table 3. The calculated amounts of fungicide formulations were increased by 10% to compensate for loss of fungicide during treatment. Seed was planted on 7 November 1984 in a randomized block design with four replicates of each treatment in four double rows 4 m long. To ensure infection, 50 tillers within each plot were boot-inoculated as described.

Incidence data resulting from natural infection and artificial inoculation were obtained and analyzed independently. The inoculated spikes were removed before harvest, and the incidence of infected tillers was determined by hand-threshing each of the inoculated heads. The percentages of infected tillers were arc sine-transformed (9) and analyzed in a one-way analysis of variance procedure. Because the incidence of Karnal bunt from inoculation was many times higher than that from natural infection, the analysis of data from artificially inoculated tillers ignored natural incidence. The number of naturally infected kernels was determined by visual inspection of 600-cm^3 of seed after harvest from the center two double rows of each plot and threshing by machine. The log of the number of infected kernels was used in a one- or two-way analysis of variance.

RESULTS

Natural incidence of Karnal bunt was low but uniform in adjacent plots. None of the wheat-heading dates coincided with weather reported conducive to disease development. Presumably, the furrow irrigations, applied routinely as heading approaches, provided sufficient soil moisture and humidity for low levels of infection to occur.

In the first experiment, involving four fungicides and three planting dates, propiconazole, mancozeb, and fentin hydroxide reduced natural infection by *T. indica* to about 10, 20, and 50% of the controls, respectively (Table 1). Propiconazole was significantly better than mancozeb only with the last planting date. The effectiveness of nuarimol was variable. Karnal bunt incidence was significantly reduced by nuarimol only in the wheat of the third planting date; the chemical had no effect on wheat of the second date and actually significantly increased incidence in the second date (Table 1).

Karnal bunt incidence resulting from natural infection was more variable and the foliar fungicides less effective in the second experiment (Table 2). Results from the two planting dates were combined into a two-way analysis of variance that showed no significant difference in disease incidence between the two planting dates. Natural infection was reduced more than 50% by copper hydroxide, propiconazole, etaconazole, mancozeb, PCNB, and maneb (Table 2). Within the systemic fungicide-treated plots in which spikes were artificially inoculated before and after fungicide application, only propiconazole and etaconazole showed significant control of Karnal bunt after all four inoculation times (Table 4). Best control was obtained when the inoculation preceded fungicide application by 72 hr; poorest control was obtained when the inoculation followed fungicide application by 48 hr (Table 4).

Fungicides applied as seed treatments controlled neither natural nor artificial infection by *T. indica* (Table 3). Nuarimol and thiabendazole reduced the number of tillers and delayed heading by about 1 wk; therefore, although the incidence of Karnal bunt was significantly less in inoculated plants, these plants were not comparable to those of the controls or other treatments. The mean incidence of natural infection was 93.8 kernels per kilogram (SD = 15.5) and was not significantly different among any of the treatments.

DISCUSSION

This study evaluated the control of Karnal bunt obtained with high rates of seed- or foliar-applied fungicides after natural infection or artificial inoculation. Although the study was limited to results from only one season, it nevertheless shows in replicated experiments that several commercially available and registered fungicides applied to foliage significantly reduced Karnal bunt. Many of these fungicides are already used on cereals to control other pathogens (6).

Because the modes of infection are so different, chemicals effective for control of other bunt diseases of wheat provide only a fair guide for chemical control of Karnal bunt. Etaconazole reduced the incidence of both Karnal (Tables 1, 2, and 4) and dwarf bunt (7) after application to foliage, although only

Table 2. Average effect of two applications of foliar fungicides on natural incidence of Karnal bunt of wheat planted on two dates[a]

Treatment	Rate (a.i/ha)	Infected kernels (no./kg) (natural infection)
Untreated	···	78.8
Nuarimol	95 ml	113.8
Furmecyclox	570 g	93.6
Imazalil	1 L	87.6
Triadimenol	570 g	87.6
Thiabendazole	600 g	81.8
Benomyl	500 g	81.6
Triadimefon	570 g	77.8
Bitertanol	570 g	68.8
Thiram	2 kg	42.0
Fentin hydroxide	330 g	39.6
Maneb	2.7 kg	36.8
Mancozeb	2.4 kg	33.2
PCNB	10 kg	31.6
Mancozeb	1.2 kg	25.4
Etaconazole	250 g	19.6
Propiconazole	250 g	19.6
Copperhydroxide	3.0 kg	18.6
$LSD_{0.05}$		9.7

[a] Each value represents the mean of eight replicates.

Table 3. Effects of systemic fungicide seed treatment on the incidence of Karnal bunt in inoculated wheat plants

Treatment	Rate (g a.i./kg)	Percent infected spikes[a] (inoculated plants)
Untreated	···	66.1
Benomyl	5.5	60.6
Triadimenol	1.2	58.7
Propiconazole	0.6	68.5
Nuarimol	3.4	42.6
Furmecyclox	1.1	53.1
Triadimefon	1.2	58.7
Thiabendazole	5.5	40.0
Bitertanol	1.2	60.0
$LSD_{0.05}$	···	11.7

[a] Percentage of infected spikes after boot-injection inoculation (n = 200 for each fungicide application).

Table 4. Effect of boot inoculation timing on the control of Karnal bunt obtained by two applications of systemic fungicides

Treatment	Rate (a.i./ha)	Incidence of infected spikes (%) for each time of fungicide application[a]			
		48 hr Before inoculation[b]	24 hr Before inoculation[c]	24 hr After inoculation[c]	72 hr After inoculation[b]
Untreated	···	76.2	78.2	83.3	57.0
Benomyl	500 g	85.1	77.4	71.0	63.8
Bitertanol	570 g	85.3	53.7	53.5	52.0
Carboxin + PCNB	1,500 g + 750 g	···	75.9	54.5	···
Etaconazole	250 g	47.8	22.8	40.4	8.5
Furmecyclox	570 g	84.9	62.8	66.8	61.0
Imazalil	1 L	89.5	64.6	60.8	55.6
Nuarimol	95 ml	73.2	54.7	72.6	49.6
Oxycarboxin	1.13 kg	···	72.3	74.6	···
Propiconazole	250 g	47.4	34.2	37.4	7.6
Thiabendazole	600 g	87.7	63.1	69.2	46.5
Triadimefon	570 g	81.2	64.8	60.3	49.5
Triadimenol	570 g	74.0	64.6	70.7	40.3
$LSD_{0.05}$		13.0	11.9	12.7	11.2

[a] Percentage of infected spikes after boot-injection inoculation ($n = 100$ for each time of fungicide application).
[b] Wheat planted 7 November 1984.
[c] Wheat planted 28 November 1984.

dwarf bunt was controlled by seed treatment (13). Benomyl, thiabendazole, and triadimenol showed activity as seed treatments against both dwarf and common bunt (7,12,13) but did not control Karnal bunt (Table 3). We hoped to provide protection of the wheat through flowering from Karnal bunt infection by applying a systemic fungicide to the seeds. This would require long persistence, similar to the protection conferred by ethirimol seed treatment to cereals against powdery mildews (6). Chemical seed treatment has no value as a protectant against Karnal bunt for two reasons: 1) systemic fungicides did not persist long enough to inhibit floret infection and 2) the inoculum for Karnal bunt is primarily soilborne and not seedborne like that of dwarf bunt (11). The teliospores residing on the seed have little or no immediate infection potential. It should be realized, however, that seed treatments that destroy seedborne teliospores would prevent the introduction of this pathogen into new areas.

Applying fungicides directly to the glumes, the presumed site of Karnal bunt infection (8), is probably necessary for efficacy with either contact or systemic fungicides. The contact fungicides must be applied to the emerged spikes before the release of sporidia from the soilborne teliospores. The time of application of systemic compounds presumably could be less critical; however, these fungicides are primarily xylem-mobile and concentrate in tissues with high transpiration rates (6). Consequently, higher concentrations would occur in the rapidly transpiring leaves rather than the glumes unless the fungicides were applied directly to the emerged spikes. Etaconazole and propiconazole, the only systemic fungicides showing high activity against Karnal bunt, were most effective when applied to exposed spikes. They provided best control when applied 72 hr after inoculation, when the inoculated spikes were completely emerged and exposed. Conversely, least control was obtained when these fungicides were applied 48 hr before inoculation, when most of the inoculated spikes were still enclosed within the boot. Thus, it appears that to inhibit floret infection by *T. indica*, a relatively high concentration of fungicide must be present on or in the glumes.

An unfortunate consequence of applying systemic chemicals to wheat at late growth stages is the high level of residue in the grain at harvest. The systemic fungicide concentration needed for activity against *T. indica* may result in excessive residues. Contact fungicides, because they do not redistribute systemically within the spike, would probably have insignificant residues, because the residual chemical would be removed when the grain is threshed.

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