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Effect of wheat cultivars, fertilizers, and fungicides on *Fusarium* foot rot disease of wheat

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Abstract: *Fusarium culmorum* is a principal causal agent of root, crown, and foot rot disease in the wheat-growing areas of Turkey. The effects of different fertilization practices, fungicide sprays, and cultivar reactions of 12 wheat varieties were investigated for disease development in greenhouse conditions in 2006–2007. The fertilizers used in the experiments significantly reduced disease by 27.5%–54.7% compared to the nonfertilized control. The plants fertilized with calcium ammonium nitrate (26% N) or composite NPK (15%, 15%, 15%) showed fewer disease symptoms than those fertilized with NPK (20%, 20%, 0%) in the presowing applications. On the other hand, foot rot severity was lower with ammonium nitrate (33% N) than urea (46% N) when applied as a supplement in the 25th and 45th growth stages of the Zadoks scale. Furthermore, fungicide sprays and seed dressing treatments also decreased foot rot symptoms. Seed treatment with tebuconazole lowered disease severity in the subcrown internode compared to the control and it was overall the most effective fungicide with 47.8% efficacy. When plants were sprayed with fluquinconazole, tebuconazole, or epoxyconazole + carbendazim (two times at Zadoks growth stages 31 and 45), disease severity decreased by 96.3%, 93.9%, and 91.0%, respectively. In the cultivar reaction tests, no stable or considerable tolerance was observed in the 12 wheat varieties against foot rot. It may be concluded from this study that fertilizer forms and fungicide preference can play an important role where *Fusarium* foot rot is the main problem in wheat-growing areas.

Key words: Disease severity, fertilizers, fungicides, *Fusarium*, wheat

1. Introduction

Fusarium is an important pathogenic genus of wheat causing crown and foot rot as well as seedling and head blight. Crown and foot rot disease of winter wheat and barley is caused by a complex of *Fusarium culmorum*, *F. pseudograminearum*, *F. avenaceum*, *F. acuminatum*, *F. crookwellense*, *F. poae*, and *Microdochium nivale* (Wiese, 1987). These pathogens may occur singly, but they often coexist in the same field and even within individual plants, and the dominant pathogens at a specific location can change from year to year. Infected crowns and roots are brown and rotted, and a brown to reddish-brown discoloration of the stem may extend up the internodes. In the early stages of disease development under favorable conditions, light discoloration may become visible inside the leaf sheaths. After that, the disease may eventually proceed up to the top. The foot rot pathogens are often associated with considerable yield losses because of premature senescence and reduced grain filling (Cook, 1968; Mihuta-Grimm and Forster, 1989; Smiley and Patterson, 1996).

Wheat management strategies such as fertilization, cropping of resistant or tolerant cultivars, and fungicide use can affect the disease progress by changing the predisposition of the plants or suppressing pathogen populations in the soil. Colbach et al. (1996) reported that sowing date had a negative effect on the incidence of foot rot caused by *Microdochium nivale* but it had a positive effect on disease incidence of *Fusarium* species in winter wheat. However, soil structure, the forms of the fertilizers, and wheat residues did not change foot rot symptom development substantially. Martin et al. (1991) demonstrated that excess nitrogen and an application of a plant growth regulator (ethepon) increased the incidence of *Fusarium* species (47.9%) from wheat seeds but fungicide sprays (propiconazole + chlorothalonil) did not show any effect on disease incidence. In a similar study by Dawson and Bateman (2000), neither fluquinconazole nor prochloraz had any effect on the disease development of take-all (*Gaeumannomyces graminis* var. *tritici*) but these fungicides suppressed the root rot symptoms caused by *F. culmorum*, *Alternaria infectoria*, and *Idryella bolleyi* in winter wheat. In a different study on screening the resistance of wheat cultivars against *F. culmorum*, Wisniewska and Kowalczyk (2005) screened 12 Polish spring wheat cultivars and 18 wheat accessions from

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CIMMYT for *F. culmorum* resistance and they found, in a 5-year-long assay, that *Fusarium*-damaged kernels were lower in the CIMMYT accessions (16.7%) than in the Polish spring cultivars (28.3%).

F. culmorum is a main causal agent of root, crown, and foot rot disease in the wheat-growing areas of the Çukurova region. Akgül and Erkılıç (2007) conducted a survey to investigate the prevalence and severity of the disease. Their study showed that disease prevalence and severity values were 100% and 12.5%, respectively. Moreover, most of the *Fusarium* species isolated from the brown-colored foot tissues of the Çukurova wheat fields in 2004–2005 were *F. culmorum*. Because of monoculture cereal farming, the disease has reached a noticeable level in recent years. For this reason, wheat growers have been seeking control methods to combat the disease effectively. It has been suggested that the use of wheat management strategies in Çukurova including fertilization, cultivar selection, and fungicide applications could reduce foot rot severity according to the findings of previous similar studies. The objectives of this study were (i) to evaluate the reactions of some regional bread wheat cultivars to *F. culmorum*, and (ii) to determine the effect of fertilization programs (commonly adopted in the Çukurova region) and fungicide applications (seed-spray applications) on disease development under greenhouse conditions in Adana, Turkey.

2. Materials and methods

2.1. Materials

The wheat cultivars used as plant materials in the cultivar reaction experiments were the 12 bread wheat varieties Adana-99, Balatilla 2000, Ceyhan-99, Cham-1, Cumhuriyet-75, Dariel, Galil, Genç-99, Golia-99, Pamukova-97, Pandas, and Sagittario, but Adana-99 was used in all of the experiments because it is the most preferred cultivar in Adana. The fertilizer calcium ammonium nitrate (CAN, 26% N) and two kinds of nitrogen, phosphorus, and potassium composite fertilizers (NPK, 15%, 15%, 15% N and NP, 20%, 20%, 0% N) were used in the seedbed application. In addition, urea (46% N) and ammonium nitrate (AN, 33% N) were used for postemergence application in fertilizer experiments. The experimental fungicides used in the seed treatments and postemergence sprays and their application doses are specified in Table 1. All fungicides except Dynasty CST are registered in Turkey.

Table 1. The experimental fungicides and their application dosages.

Fungicides used in seed treatments			
Active ingredients	Trade name	Application dose (mL or g kg seed^{-1})	Manufacturer
Azoxystrobin (75 g L^{-1}) + fludioxonil (12.5 g L^{-1}) + metalaxyl-M (37.5 g L^{-1})	Dynasty CST	2.5	Syngenta
Carboxin (200 g L^{-1}) + thiram (200 g L^{-1})	Vitavax 200 FF	5.0	Uniroyal
Difenoconazole (30 g L^{-1})	Dividend 030 FS	1.0	Syngenta
Fludioxonil (25 g L^{-1}) + metalaxyl (10 g L^{-1})	Maxim XL 035 FS	3.0	Syngenta
Prothioconazole (150 g L^{-1}) + tebuconazole (250 g L^{-1})	Lamardor 400 FS	0.2	Bayer
Tebuconazole (60 g L^{-1})	Raxil 060 FS	0.5	Bayer
Tolclofos methyl (200 g kg^{-1}) + thiram (200 g kg^{-1})	Rizolex-T 50 WP	3.0	Sumitomo
Foliar fungicides			
Active ingredients	Trade name	Application dose (mL or g ha^{-1})	Manufacturer
Difenoconazole (150 g L^{-1}) + propiconazole (150 g L^{-1})	Armure 300 EC	500	Syngenta
Epoxyconazole (125 g L^{-1}) + carbendazim (125 g L^{-1})	Duett	1000	BASF
Fluquinconazole (100 g L^{-1})	Flamenco	1000	Bayer
Prochloraz (450 g L^{-1})	Sportak	1000	Bayer
Tebuconazole (25%)	Folicur 25 WP	750	Bayer

2.2. Methods

2.2.1. Pathogenicity tests

Eight isolates of *F. culmorum* (*Fc*. 8-1, 26-2, 30-2, 31, 36, 43, 44, and 50) were isolated from the highly symptomatic subcrown internodes of wheat plants in the Çukurova region of Turkey. The surfaces of the infected tissues were sterilized with 1.5% sodium hypochloride (NaOCl) solution for 2 min, rinsed two times with sterile distilled water, and plated onto potato dextrose agar (PDA, Merck) supplemented with 150 mg L^{-1} streptomycin sulfate. Their virulence was determined by pathogenicity tests done to select the most virulent isolate to use in further experiments. For inoculum production, boiled wheat grains were placed in screw-cap glass bottles and autoclaved twice at 121 °C and 1 atm for 20 min. The PDA discs colonized by *Fc.* isolates were inoculated into the glass bottles containing the autoclaved grain and these bottles were incubated at 24 °C in the dark for 15 days. At the end of the colonization period, the grain was air-dried briefly and used immediately. Solarized disease-free field soil (53.6% clay, 21.5% silt, 24.9% sand, and pH 7.2), fermented cow manure, and a sand mixture (1:1/2:1/2 v/v/v) were added to the pots and watered, at which time 20 Adana-99 wheat seeds were placed onto the soil surface. The seeds were covered with 1 cm of soil, 10 g of inoculum was mixed into this layer, and additional soil was added again to cover the inoculum (Dodman et al., 1985; Smiley et al., 2005). The entire pot was moistened by the addition of water to the surface of the pot 7 days after inoculation. The soil was kept moist during the whole experiment by adding appropriate amounts of water. For each isolate, four replicates (one pot for each replicate) were done and each of the replicates consisted of 20 wheat plants. Disease assessment was done at the end of the growing season on the coleoptiles, subcrown internodes, and whole stems by using a 0–4 scale where 0 = completely healthy, 1 = coleoptiles and/or subcrown internode partially or wholly necrotic but no necrosis in the leaf bases, 2 = coleoptiles and/or subcrown internode and leaf sheaths partially or completely necrotic, 3 = necrotic area covered to second internode, and 4 = necrotic area covered third internode (Wildermuth and McNamara, 1994). Disease severity was calculated using the scale values according to the Towsend–Hauberger formula, as follows: (∑ (number of plants in a disease scale category × disease scale category) / (total number of plants × maximum disease scale category)) × 100). The most virulent isolate was selected on the basis of disease severity averages.

2.2.2. Screening reactions of some bread wheat cultivars to *Fusarium* foot rot

In the first part of the greenhouse studies, 12 different bread wheat varieties were tested for resistance to *F. culmorum* in the pot experiments. A highly virulent isolate of *F. culmorum* (*Fc*. 30-2), which was previously tested for pathogenicity, was used in all of the greenhouse studies. The seeds of these varieties were not treated with any fungicides but inoculated with the *Fc*. 30-2 pathogen as stated before. Disease symptoms were evaluated as stated in the pathogenicity tests.

2.2.3. Effect of different fertilization programs on disease development

Adana-99, the most preferred bread wheat variety in the Çukurova region of Turkey, was used in the experiment. Generally, 150 kg of pure nitrogen per hectare is the optimum dosage for reasonable growing of wheat plants in Turkey. This amount of nitrogen is divided into 3 equal parts and given to the soil in 3 different growth stages. In this experiment, application dosages of fertilizers (Table 2)

Table 2. The experimental fertilization programs and their application dosages.

Fertilization program	Fertilizer amounts					
	(kg ha^{-1})			(g pot^{-1})		
	Presowing	Stem elongation	Prepollination	Presowing	Stem elongation	Prepollination
CAN + AN + AN	192	152	152	0.665	0.765	0.765
CAN + urea + urea	192	109	109	0.665	0.376	0.376
NP + AN + AN	250	152	152	0.865	0.765	0.765
NP + AN + urea	250	152	109	0.865	0.765	0.376
NPK + AN + AN	333	152	152	1.153	0.765	0.765
NPK + AN + urea	333	152	109	1.153	0.765	0.376

CAN = calcium ammonium nitrate (26% N), AN = ammonium nitrate (33% N), urea is 46% N, NP is (20%, 20%, 0% N), and NPK is (15%, 15%, 15% N).

were calculated by proportioning of a 1-ha dose for each pot's soil surface (350 cm^2). In the presowing application, small amounts of the CAN, NPK, and NP fertilizers were weighed for each pot and mixed into the pot soil before seeding and pathogen inoculation, but the supplemental fertilizers (AN and urea) were applied as a water solution at the stem elongation and prepollination periods, the 25th and 45th growth stages of Zadoks scale, respectively (Zadoks et al., 1974). Pathogen inoculation (*Fc*. 30-2), seeding, and disease evaluation were done as previously described in the pathogenicity tests.

2.2.4. Effect of seed treatments and fungicide sprays on disease development

The fungicides and their application dosages used in both the seed treatments and the spray applications are listed in Table 1. In the seed treatments, Adana-99 wheat seeds were subjected to seven fungicidal treatments according to the manufacturers' instructions, were seeded in the pot mixture, and pathogen inoculation was done immediately. The control seeds were not treated with any fungicides but were inoculated with the *Fc*. 30-2 pathogen. In the fungicide spray experiments, nontreated wheat seeds were seeded in pots and the pathogen inoculation was done as previously. After seed emergence, the plants were sprayed with 5 fungicide suspensions (at the 31st and 45th growth stages of the Zadoks scale) using a hand-pressurized sprayer. The control plants were sprayed with tap water.

2.2.5. Experimental design and statistical analysis

All of the pot experiments were arranged in a completely randomized plot design of 4 replications with 3 pots in each replicate. All of the experiments were repeated 2 years successively. The data from each experiment were statistically analyzed using variance analysis, and Duncan's multiple range test (P = 0.05) was used for statistical separation of the means. The efficiency of each treatment was calculated using the Abbott formula, which is ((control – treatment)/control) × 100) (Gomez and Gomez, 1984).

3. Results

3.1. Pathogenicity test results

According to the laboratory reisolation results and symptomatic discolorations, all of the *F. culmorum* isolates were understood to be pathogenic on the Adana-99 wheat plants. They were successfully reisolated from the plants with an 82.1% reisolation rate. The calculated disease severity of the plants, caused by 8 *Fc* isolates, ranged from 43.6% to 64.5% (Figure), and the most virulent isolate was determined to be *Fc*. 30-2 (64.5%).

3.2. Susceptibility of bread wheat cultivars to *Fusarium* foot rot

Twelve bread wheat cultivars were tested to determinate their susceptibility levels to the *F. culmorum* isolate *Fc*.

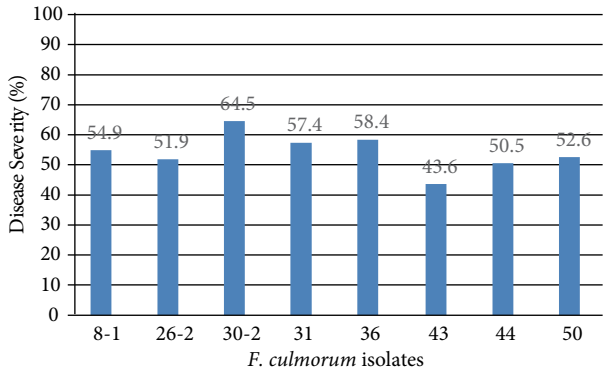


Figure. Disease severity of plants caused by *F. culmorum* isolates in a pathogenicity test.

30-2 in 2006 and 2007. The disease severity levels ranged from 6.3% to 36% in these years. In the first year, the disease severity levels of the cultivars were higher than those of the second year. The lowest disease severity was from Adana-99 (22.7%) in 2006 and Dariel (6.3%) in 2007. On the other hand, the highest disease severity was from Pandas (36%) in the first year and Balatilla 2000 (26%) in the second year (Table 3). However, no stable or considerable tolerance was observed in the 12 different wheat cultivars against foot rot disease.

Table 3. Susceptibility of bread wheat cultivars to *F. culmorum* foot rot.

Wheat cultivars	Disease severity (%)	
	2006	2007
Adana-99	22.7 a*	17.2 bcd
Balatilla 2000	25.9 abc	26.0 e
Ceyhan-99	24.0 abc	16.0 bc
Cham-1	29.2 bc	18.7 bcd
Cumhuriyet-75	26.7 abc	24.2 de
Dariel	29.5 bc	6.3 a
Galil	27.3 abc	16.6 bc
Genç-99	24.7 abc	20.4 cde
Golia-99	24.3 abc	18.8 bcd
Pamukova-97	29.8 c	14.4 bc
Pandas	36.0 d	11.8 ab
Sagittario	22.9 ab	12.6 ab

* = Mean values within a column are significantly different based on Duncan's multiple range test (P = 0.05).

3.3. Effect of different fertilization programs on disease severity

The fertilization programs affected *Fusarium* foot rot severity with rates of 20.7%–32.1% in 2006 and 13.8%–21.0% in 2007 (Table 4). The lowest disease severity was observed in the plants fertilized with the NPK + AN + AN program (20.7%) and the CAN + AN + AN program (13.6%) in these years. However, the most severe disease symptoms were seen on the plants fertilized with the CAN + urea + urea program, at 32.1% in 2006 and 21.0% in 2007. Among the presowing fertilizers, the composite NPK and CAN had better results than NP in reducing the *Fusarium* foot rot symptoms. However, the postemergence fertilizers ammonium nitrate and urea significantly changed the disease progress. Therefore, urea-treated plants revealed more severe disease symptoms than the ones treated with ammonium nitrate. Generally, the use of urea led to increased disease development in most of the combinations in the experiment.

Table 4. Effect of the fertilization programs on *F. culmorum* foot rot of wheat.

Fertilization program	Disease severity (%)	
	2006	2007
NPK + AN + AN**	20.7 a*	14.6 a
NPK + AN + urea	30.5 c	18.4 bc
NP + AN + AN	33.1 c	16.5 ab
NP + AN + urea	25.6 b	19.2 bc
CAN + AN + AN	25.4 b	13.8 a
CAN + urea + urea	32.1 c	21.0 c

* = Mean values within a column are significantly different based on the Duncan multiple range test (P = 0.05).
** = CAN (calcium ammonium nitrate, 26% N), AN (ammonium nitrate, 33% N), urea (46% N), NP (20%, 20%, 0% N), and NPK (15%, 15%, 15% N).

3.4. Efficacy of fungicidal seed treatments on disease development

Seven commercial fungicides were tested to estimate their disease suppression potential against *Fusarium* foot rot in wheat. The fungicide seed treatments in the pot experiments done in 2006–2007 reduced disease severity to some extent (up to 47.8%), but could not suppress it completely. The control plants showed more severe disease symptoms than the fungicide-treated ones. The mean disease severity of the untreated control was 24.5% in the first year and 21.1% in the second year (Table 5). Among the fungicides, tebuconazole (Raxil 060 FS) was the most effective in reducing disease symptoms with efficacy rates of 47.8% and 47.4%. However, prothioconazole + tebuconazole (Lamardor 400 FS) did not show a putative effect on disease control (11.4%–17.1%), despite containing dual active ingredients and being in the same chemical group. The other fungicides (azoxystrobin + fludioxonil + metalaxyl-m (Dynasty CST), fludioxonil + metalaxyl (Maxim XL 035 FS), and tolclofos-methyl + thiram (Rizolex-T WP 50) had a moderate effect on disease development when compared to tebuconazole (Raxil 060 FS) and their effects ranged from 13.1% to 35.5% in two successive years. On the other hand, carboxin + thiram (Vitavax 200 FF) and difenoconazole (Dividend 030 FS) did not perform with consistent efficacy, at 48.6%– 9.5% and 1.6%–19.4%, respectively.

Table 5. Effect of fungicide seed treatments on *F. culmorum* foot rot of wheat.

Active ingredients	Disease severity (%)		Efficacy (%)	
	2006	2007	2006	2007
Azoxystrobin (75 g L^{-1}) + fludioxonil (12.5 g L^{-1}) + metalaxyl-M (37.5 g L^{-1})	20.4 bc*	13.6 ab	16.7	35.5
Carboxin (200 g L^{-1}) + thiram (200 g L^{-1})	12.6 a	19.1 bc	48.6	9.5
Difenoconazole (30 g L^{-1})	24.1 c	17.1 abc	1.6	19.4
Fludioxonil (25 g L^{-1}) + metalaxyl (10 g·L^{-1})	21.3 bc	15.5 abc	13.1	26.5
Prothioconazole (150 g L^{-1}) + tebuconazole (250 g L^{-1})	21.7 bc	17.5 abc	11.4	17.1
Tebuconazole (60 g L^{-1})	12.8 a	11.1 a	47.8	47.4
Tolclofos-methyl (200 g kg^{-1}) + thiram (200 g kg^{-1})	18.9 b	13.7 ab	22.9	35.1
Untreated control	24.5 c	21.1 c	–	–

* = Mean values within a column are significantly different based on Duncan's multiple range test (P = 0.05).

3.5. Efficacy of fungicide sprays on disease development

The fungicide sprays were more effective than the seed treatments alone in reducing the disease severity of *Fusarium* foot rot. Fluquinconazole (Flamenco), tebuconazole (Folicur WP 25), and epoxyconazole + carbendazim (Duett) were the most effective fungicides with the highest efficiency rates (96.3%, 93.9%, and 91.0% in 2006 and 61.9%, 74.5%, and 61.0% in 2007, respectively). These fungicides were in the same statistical group when compared to the control and others (Table 6). The efficiency rates of the prochloraz (Sportak) and difenoconazole + propiconazole (Armure) mixtures were insignificant compared to the control in the first year, but their effects were significant in the second year. However, they could not show a putative effect on controlling disease symptoms although they had 35.5% and 33.3% efficiency rates.

4. Discussion

In wheat cultivation systems, ideal seed selection, fertilization, and fungicide application (in the case of a high pathogen population) are indispensable practices for optimum crop production. In this study, it has been revealed that these practices can change the direction of *Fusarium* foot rot disease progress in wheat. Among the tested regional wheat cultivars, no stable or considerable tolerance was observed in two years of greenhouse studies. Despite ensuring homogeneous pathogen inocula, soil types, watering regimes, and greenhouse conditions, the disease severity percentages of the cultivars were not parallel with each other in successive years. Variability in seed nutrient reservoirs may have been a predisposing factor for plant-pathogen interactions in the initial growth stages of germinating wheat seedlings (Broscious and Frank, 1986; Bennett, 1993). Broscious and Frank (1986) stated in their study that foot rot disease severity was higher in wheat plants having lower seed weight and nutrient content. The wheat seeds used in this study may have had different levels of nutrient reservoirs and the year factor may have played an important role in predisposition to *F. culmorum* infections. Moreover, another factor affecting tolerance of the wheat varieties to disease may be the inoculum levels of the isolates. Ten grams (experimental rate) of *F. culmorum* inocula may have been too much per pot for the screening resistance experiment. Smiley et al. (2005) reported that genetic tolerance to *Fusarium* crown rot is important in years when the disease pressure is moderate, but it is ineffective when the disease pressure is high. Therefore, the inoculum level of the isolate may have affected the disease tolerance in this study.

Fertilization is one of the most indispensable practices in wheat cultivation and it is also a primary factor affecting yield quality and quantity. A balanced fertilization program provides a high-quality yield and it also increases the tolerance of plants to pathogen infections due to optimal nutrition (Engelhard, 1989). It has been stated by many authors that nitrogen fertilization has a considerable effect on the development of *Fusarium* foot rot in wheat (Daly, 1949; Tousson et al., 1960; Spratt and Gasser, 1970). The form of nitrogen is more important than its application dose on the disease development of many plants. It has been reported that the disease severity of *Fusarium* foot rot increased with the use of an ammonia-form (NH_4-N) nitrogen, while it decreased with a nitrate (NO_3-N) form (Smiley et al., 1972; Smiley and Cook, 1973; Huber and Watson, 1974). According to our fertilizer experiment results, the foot rot disease severity of the wheat plants was lower when ammonia–nitrate fertilizer was used and higher in the plants that were fertilized with urea. This corroborates the reported effects of nitrogen forms on wheat *Fusarium* foot rot disease. On the other hand, disease occurrence was also affected by the presowing fertilizer forms that were applied to the plants. Low-level occurrences were observed with the composite NPK

Table 6. Effect of the fungicide sprays on *F. culmorum* foot rot of wheat.

Active ingredients	Disease severity (%)		Efficacy (%)	
	2006	2007	2006	2007
Difenoconazole (150 g L^{-1}) + propiconazole (150 g L^{-1})	21.9 b*	15.4 b	10.6	33.3
Epoxyconazole (125 g L^{-1}) + carbendazim (125 g L^{-1})	2.2 a	9.0 a	91.0	61.0
Fluquinconazole (100 g L^{-1})	0.9 a	8.8 a	96.3	61.9
Prochloraz (450 g L^{-1})	22.9 b	14.9 b	6.5	35.5
Tebuconazole (25%)	1.5 a	5.9 a	93.9	74.5
Unsprayed control	24.5 b	23.1 c	–	–

* = Mean values within a column are significantly different based on Duncan's multiple range test (P = 0.05).

(15%, 15%, 15% N) and the calcium ammonia–nitrate (CAN, 26% N) fertilizers when compared to the other NPK (20%, 20%, 0% N) and the unfertilized control. Zielinska and Michniewicz (2001) found that an increase in calcium ions led to some hormonal changes in wheat cells that were grown on cell culture media in vitro. They also detected that calcium ions stimulated ethylene hormone but suppressed abscisic acid levels in wheat cells, and so *F. culmorum* infections could have been reduced by the synthesis of the pathogenesis-related proteins chitinase and β-1,3-glucanase in these cells. Gunfer et al. (1980) and Heitefuss (1989) reported in their studies that fertilizers supplemented with potassium raised plant defense mechanisms against cereal rust, powdery mildew, and foot rot diseases of wheat. Younts and Musgrove (1958) found that potassium induced nitrate uptake and organic nitrogen substances in plants. These reactions and fertilization programs may have changed the direction of the disease progress in wheat plants infected with *F. culmorum*.

The fungicides used in the seed treatments had significant effects on *Fusarium* foot rot disease development in the greenhouse experiments. Although different triazole fungicides were included in this experiment, tebuconazole was the most successful one with 47.8% effectiveness and its effect was stable in successive years (2006–2007). However, the effect of the prothioconazole + tebuconazole mixture was not so satisfactory despite containing two active ingredients. The experimental fungicides used in this study can penetrate wheat seeds and they can be transported from the seeds to the shoots. Difenoconazole and triadimenol have been found to reduce sporulation (50%) of *Puccinia recondita* and *Septoria tritici* fungi in the first 6.5 weeks after seed germination (Sundin et al., 1999). Likewise, Balmas et al. (2006) found that Folicur WG 25 (25% tebuconazole) reduced *F. culmorum* foot rot severity when wheat seeds were treated with this fungicide. Disease severity was 45% in the control and 37% in the fungicide-treated plants. The susceptibility of wheat seeds may be affected by fungicide applications. Although bromuconazole and cyproconazole are in the same chemical group (triazole), they have different effects on the seed germination of wheat. Demirci and Maden (2006) reported germination abnormalities in Gerek-79 wheat seeds treated with cyproconazole. No adverse effect was seen from the bromuconazole treatments but 95% abnormal germination was identified in the cyproconazole-treated seeds. In our experiments, tebuconazole reduced foot rot severity in the Adana-99 wheat cultivar but the prothioconazole + tebuconazole mixture did not cause a considerable reduction. It can be inferred from the previous studies that prothioconazole or its combination with tebuconazole may have adversely affected the wheat seedlings or predisposed them to pathogen infections. Moreover, the concentration of the prothioconazole + tebuconazole mixture (400 g L^{-1} triazole) of Lamardor 400 FS may have been too much for the Adana-99 wheat cultivar. In another study, Mihuta-Grimm and Forster (1989) determined that carboxin + thiram eradicated seed-borne inocula of *Fusarium*, but the field performance of this fungicide did not show a satisfactory effect on reducing the foot rot severity of wheat and barley. Smiley et al. (1990) reported that tolclofos-methyl + thiram decreased *F. culmorum* and *F. graminearum* foot rot severity (35%), although they also observed minor phytotoxicity due to the tolclofos-methyl.

Fungicide sprays were substantially successful against disease development when compared to seed treatments alone. Among the fungicides, the performances of fluquinconazole, tebuconazole, and epoxyconazole + carbendazim were satisfactorily good. Despite the high inoculum level in the pot mixture (10 g of inoculum per pot), the disease severity ranged from 61.0% to 91.0% in greenhouse conditions (over 2 years). However, the prochloraz and difenoconazole + propiconazole sprays did not perform well at controlling foot rot disease. Most of the active ingredients in the spray experiment belong to the triazole fungicide class; however, their efficacies were different from each other. Homdork et al. (2000) revealed that yield loss caused by *F. culmorum* and *F. graminearum* decreased by 31%–80% with tebuconazole spray applications in artificially inoculated wheat plants. In another study, mycotoxin accumulation in *Fusarium*-infected kernels was suppressed with tebuconazole and bromuconazole (by 49.2 and 67.2%, respectively) but no significant differences were identified with the use of epoxyconazole and kresoxym-methyl sprays (Menniti et al., 2003). The stability of the active ingredient in plant tissues, the plant cultivar, and the isolate virulence are known to affect disease progress in plants. These factors may have caused efficacy differences among the triazole fungicides applied to wheat plants.

The reduction in *Fusarium* foot rot disease by the different fertilization applications and fungicides clearly demonstrated the potential benefit of these control measures in pathogen-infested soils for wheat cultivation. It is therefore recommended that newly registered and differently acting fungicides should be tried for effective disease control.

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