Foliar Fungicides to Control Wheat Stem Rust, Race TTKS (Ug99), in Kenya

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ABSTRACT

Wanyera, R., Macharia, J. K., Kilonzo, S. M., and Kamundia, J. W. 2009. Foliar fungicides to control wheat stem rust, race TTKS (Ug99), in Kenya. *Plant Dis.* 93:929-932.

The emergence of a new virulent race of stem rust (*Puccinia graminis* f. sp. *tritici*) of wheat (*Triticum aestivum*), TTKS (Ug99), calls for urgent measures to contain the disease, which is a serious threat to wheat production in Kenya. Nine commercial fungicides were evaluated for control of stem rust in the field in three locations in 2005 and 2006. Ten treatments, including untreated control, were applied on field plots in a randomized complete block design with four replications. Assessment of stem rust severity was done at growth stage (GS) 55 (heading), GS 65 (flowering), and GS 75 (late milk) and expressed in terms of mean rust severity and area under the disease progress curve (AUDPC). In general, fungicide treatment significantly ($P \leq 0.05$) reduced rust severity, AUDPC, and losses in grain yield and 1,000-kernel weight for cv. Duma compared with the untreated control. Stem rust was severe in both years across all sites, resulting in significantly less grain yield in the control treatment. The 1,000-kernel weight was significantly less at two locations in 2006. Fungicides azoxystrobin at 200 g/liter + cyproconazole at 80 g/liter (AmistarXtra 280 SC), tebuconazole (Folicur 250 EC), tebuconazole + tridimenol (Silvacur 375 EC), and tebuconazole (Orius 25 EW) were more effective in reducing stem rust across the sites. Fungicides trifloxystrobin + propiconazole (Stratego 250 EC), hexaconazole (Cotaf 5 EC), epoxiconazole + carbendazim (Swing 250 EC), cyproconazole at 80 g/liter + propiconazole at 250 g/liter (Artea 330EC), and epoxiconazole at 125 g/liter + carbendazim at 125 g/liter (Soprano C 250 EC) were inconsistent in the reduction of the disease. The results suggest that fungicides can be used effectively in reducing stem rust severity and increasing yield of susceptible wheat cultivars in stem-rust-prone areas.

Stem rust, caused by *Puccinia graminis* f. sp. *tritici* Erikss. & Henning, is a serious disease of wheat (*Triticum aestivum* L.), occurring frequently in warm and moist environments, which is typical of the wheat-growing areas in Kenya. Although the disease has been under control through widespread use of resistant cultivars, the reemergence of a new virulent race, TTKS (Ug99), has reversed the gains made by breeders, posing a new and significant threat to wheat in the Eastern Africa region (3,13). The growing of wheat in diverse agroecological zones throughout the year (4) in Kenya creates a significant pool of airborne urediniospores which, coupled with favorable climatic conditions and the presence of host plants, favors rapid build-up of inoculum and occurrence of epidemics. All the current commercial wheat cultivars are highly susceptible to the new race, and it is not possible to grow a profitable crop of wheat without the application of a fungicide. Widespread deployment and cultivation of resistant cultivars had

generally provided adequate protection without the need for fungicides in the past (3,5). However, the ineffectiveness of resistance to the new race necessitates new interventions in the management of the disease as efforts to incorporate new sources of varietal resistance continue.

Fungicides can play a role in an integrated management of the disease until new cultivars with genetic resistance are available (5). No studies have been conducted to determine the effects of foliar fungicides on stem rust severity and crop yield in the Eastern Africa region, though a few studies have been done elsewhere (2). The lack of fungicides specifically labeled for control of stem rust in Kenya constrains immediate release of recommendations for fungicide use in stem rust control. The objective of this study was to screen the fungicides currently available in Kenya for efficacy against stem rust of wheat. This article reports field experiments conducted under natural infection to determine the effect of foliar fungicides on wheat stem rust, grain yield, and 1,000-kernel weight.

MATERIALS AND METHODS

Field experiments were conducted in 2005 and 2006 in three locations represented by trial sites at (i) Kenya Agriculture Research Institute (KARI)-Njoro (0° 20' S, 35° 56') at 2,185 m above sea level

(MASL) with mean minimum and maximum temperatures of 9.7 and 23.5°C, respectively, and mean average rainfall of 900 mm; (ii) Eldoret (0° 31' N, 35° 15' E) at 2,180 MASL, with mean annual rainfall of 1,250 mm and minimum and maximum temperatures of 12 and 23°C, respectively; and (iii) Mau-Narok (0° 39' S, 35° 57' E) at 2,900 MASL, with an annual rainfall of 1,200 to 1,400 mm and minimum and maximum temperatures of 6 to 14 and 22 to 26°C, respectively.

Nine commercial fungicides labeled for the control of stripe rust, leaf rust, and other leaf diseases of wheat were evaluated for control of stem rust in field experiment. The experimental units were eight-row field plots of 9 m² with an inter-row spacing of 20 cm. The test cultivar was the widely grown bread wheat Duma, which is highly susceptible to stem rust. The cultivar is moderately resistant to stripe rust (*P. striiformis* Westend. f. *tritici* Erikss.). A randomized complete block design with four replicates was used in all the locations. An experimental seed-drill planter was used at a seeding rate of 100 g/plot. Planting was done on 19 May at KARI-Njoro, 4 June at Eldoret, and 22 August at Mau-Narok in 2005. In 2006, the planting dates were 18 May at Eldoret, 30 May at KARI-Njoro, and 19 September at Mau-Narok.

The experimental fields were fertilized with Di-ammonium phosphate (18% N, 46% P, 0% K) at the recommended rate of 150 kg/ha at planting. A preemergent herbicide, Stomp 500 E (pendimethalin), labeled for weed control in wheat was applied soon after planting at 3 liters/ha. Buctril MC (bromoxynil + MCPA) labeled for control of broad-leaved weeds was applied at 1.25 liters/ha at growth stage (GS) 24 (tillering). Metasystox 250 EC (oxy-demeton-s-methyl) was applied at 0.5 liters/ha to control cereal aphids at GS 24 (tillering), GS 65 (flowering), and GS 73 (milk) (15).

The fungicides tested were (i) epoxiconazole + carbendazim (Swing 250 EC), (ii) cyproconazole at 80 g/liter + propiconazole at 250 g/liter (Artea 330 EC), (iii) tebuconazole + tridimenol (Silvacur 375 EC), (iv) tebuconazole (Folicur 250 EC), (v) trifloxystrobin + propiconazole (Stratego 250 EC), (vi) epoxiconazole at 125 g/liter + carbendazim at 125 g/liter (Soprano C 250 EC), (vii) tebuconazole (Orius 25 EW), (viii) hexaconazole (Cotaf 5 EC), and (ix) azoxystrobin at 200 g/liter

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Accepted for publication 17 May 2009.

+ cyproconazole at 80 g/liter (AmistarXtra 280 SC), all at the rate of 1.0 liter/ha. The untreated plots served as the control. The fungicides were applied twice using a knapsack sprayer at a recommended water volume of 200 liters/ha at GS 55 (heading) and GS 65 (flowering) (15). Stem rust severities based on the modified Cobb scale (8) were scored three times on whole plots at GS 55, 65, and 73 or 77 (late milk) before fungicide application and at two 14- to 18-day intervals following the application, according to the schedule in Table 1. However, the third reading at Eldoret in 2006 was delayed due to logistical problems. Area under the disease progress curve (AUDPC) was calculated by a computer program developed at the International Center for Maize and Wheat Improvement (CIMMYT) that calculates the area of the curve created by the disease scores taken three times during the crop cycle (Tables 2, 3, and 4).

Every plot was harvested using a Hans-Ulrich Hege plot combine harvester (Saatzuchtmaschinen, Hohebuch). Grain weight measurements were taken after harvest and cleaning at 13 to 14% moisture content. A sample of grain was taken from each plot for determination of kernel weight based on the weight of 1,000 grains (1,000-kernel weight). Data on disease severity, grain yield, and 1,000-kernel weight were analyzed according to the analysis of variance procedure using the SAS statistical package (PROC-ANOVA) (10). Differences in treatment effect were compared at ($P \leq 0.05$) using the least significant difference test (11).

RESULTS

Rust severity. In 2005, the onset of stem rust disease was early in the growing season at KARI-Njoro, resulting in a severe infection of 77.5% at GS 77 in the

untreated plots. In the same year, stem rust severities at Eldoret and Mau-Narok were moderate, 30.0 and 35.0%, respectively, at GS 77 (Tables 2, 3, and 4). In 2006, disease severity in untreated plots was 28.8% at KARI Njoro, 45.0% at Eldoret, and 40.0% at Mau-Narok (Tables 2, 3, and 4). There were no other diseases observed in the experimental plots.

Effect of fungicide on stem rust severity. In both 2005 and 2006, fungicide treatments for AUDPC were significant ($P \leq 0.05$) at KARI-Njoro. Differences in AUDPC for stem rust were observed among fungicides at Eldoret and Mau-Narok in 2006. In 2005, nonsignificant ($P \geq 0.05$) effects of fungicide treatments for AUDPC were obtained at Eldoret and Mau Narok (Tables 2, 3, and 4). AUDPC values indicated that AmistarXtra 280 EC, Orius 25 EW, Folicur 250 EC, and Silvapur 375 EC reduced rust severity across the three locations.

Table 1. Schedule on planting, fungicide application, disease assessment, and harvesting at Kenya Agricultural Research Institute (KARI)-Njoro, Eldoret, and Mau-Narok locations in Kenya

Activity, GS ^z	2005			2006		
	KARI-Njoro	Eldoret	Mau-Narok	KARI-Njoro	Eldoret	Mau-Narok
Planting	May 19	June 4	August 22	3-May 3	May 18	September 14
Fungicide application						
GS55	August 4	August 10	November 15	August 9	August 3	...
GS 65	August 18	August 26	November 30	August 23	August 18	...
GS 65	...	...	...	...	...	December 15
GS 73	...	...	...	...	...	January 2, 2007
Disease assessment						
GS 55	August 4	August 10	November 15	August 9	August 3	...
GS65	August 18	August 26	November 30	August 23	August 18	November 8
GS 65	...	...	...	...	...	December 15
GS 73	...	...	...	...	...	January 2, 2007
GS77	September 1	September 13	December 14	September 8	September 12	January 16, 2007
Harvesting	November 12	November 4	March 26, 2006	November 6	October 31	April 6, 2007

^z GS = growth stage.

Table 2. Effect of fungicide treatments on stem rust severity, area under the disease progress curve (AUDPC), grain yield, and 1,000-kernel weight on wheat cv. Duma at Kenya Agricultural Research Institute-Njoro^u

Treatment ^v	2005								2006							
	MRS ^v				Grain yield ^w				MRS ^v				Grain yield ^w			
	1st	2nd	3rd	AUDPC ^z	t/ha	G (%)	Wt. (g)	G (%)	1st	2nd	3rd	AUDPC ^z	t/ha	G (%)	Wt. (g)	G (%)
Untreated	23.8 a	57.5 a	77.5 a	709 b	0.6 b	—	29.8 d	—	10.3 a	11.3 a	28.8 a	518 a	0.8 b	—	36.9 b	—
Swing 250 EC	25.0 a	47.5 a	42.5 b	792 a	0.9 ab	31.5	33.2 cd	10.1	5.0 a	7.8 bc	6.3 cd	191 cd	2.0 a	61.5	45.1 a	22.2
Artea 330 EC	32.5 a	15.0 b	22.5 cd	210 c	1.4 a	55.8	37.6 a	20.6	11.2 a	13.8 a	15.0 bc	271 bc	2.2 a	65.1	42.0 a	13.8
Silvacur 375 EC	27.5 a	12.5 b	15.0 de	290 c	1.2 ab	47.9	36.7 ab	18.6	6.3 a	2.0 bc	7.5 cd	116 d	2.6 a	71.3	45.2 a	22.5
Folicur 250 EC	17.5 a	8.8 b	11.3 e	154 c	1.0 ab	37.1	36.4 abc	18	12.5 a	1.0 c	6.3 cd	154 cd	2.3 a	66.9	45.2 a	22.5
Stratego 250 EC	22.5 a	21.3 b	32.5 bc	381 bc	1.4 a	57.3	36.6 abc	18.5	6.3 a	5.5 abc	8.8 cd	191 cd	2.5 a	70.2	43.3 a	17.3
Soprano 250EC	31.25 a	40.0 a	62.5 a	815 a	0.8 ab	26.5	33.2 bcd	10.2	12.5 a	10.3 ab	12.5 bc	292 bc	1.9 a	60.3	42.4 a	14.9
Orius 25 EW	20.0 a	10.0 b	11.3 e	189 c	1.2 ab	49.6	37.0 a	19.2	11.3 a	2.0 bc	8.8 cd	156 cd	2.0 a	62.3	44.8 a	21.4
Cotaf 5 E	20.0 a	10.0 b	16.3 de	225 c	1.3 ab	51.6	35.9 abc	16.7	7.5 a	12.5 a	18.8 ab	376 ab	0.5 b	38.8	35.6 b	—3.5
AmistarXtra 280SC	17.5 a	10.0 b	12.5 de	210 c	1.4 a	55.1	36.9 a	19.3	7.8 a	1.0 c	4.0 d	105 d	2.2 a	66.2	44.9 a	21.7
Mean	23.8	19.5	25.2	363	1.2	45.8	35.9	16.8	8.9	6.2	9.8	206	2	62.5	43.2	17
LSD (0.05)	1.6	1.6	1.1	32.3	0.6	—	3.6	—	1.2	1.5	1.2	4.9	0.9	—	4.2	—

^u Treatment means within columns followed by the same letter are not significantly different at $P \leq 0.05$ according to least significant difference (LSD) test; — = no data.

^v MRS = mean rust severity (modified Cobb scale); 1st, 2nd, and 3rd disease notes were recorded at growth stages 55, 65, and 77, respectively.

^w Yield gain (G) (%) = (fungicide-treated – untreated) $\times$ 100/treated.

^x TKW = 1,000-kernel weight; gain (G) (%) = (fungicide-treated – untreated) $\times$ 100/treated.

^y Active components of the fungicides are as follows: Swing 250 EC, epoxiconazole + carbendazim; Artea 330 EC, cyproconazole at 80 g/liter + propiconazole at 250 g/liter; Silvapur 375 EC, tebuconazole + tridimenol; Folicur, tebuconazole; Stratego 250 EC, trifloxystrobin + propiconazole; Soprano C 250 EC, epoxiconazole at 125 g/liter + carbendazim at 125 g/liter; Orius 25 EW, tebuconazole; Cotaf 5E, hexaconazole; and AmistarXtra 280SC, azoxystrobin at 200 g/liter + cyproconazole at 80 g/liter. Soprano 250 EC, Orius 25 EW, and Cotaf 5E are generic chemicals.

^z Area under the disease progress curve (AUDPC) = values are means of four replications.

The trend of reduction on stem rust severity was maintained after the first and second fungicide application. However, the reductions were more pronounced in the latter. Overall, the pattern of stem rust suppression by fungicide treatments was observed at all locations for the 2 years. The lowest mean rust severities after the second treatment were obtained in plots sprayed with AmistarXtra 280 SC followed by Folicur 250 EC, Orius 25 EW, and Silvacur 375 EC.

Effect of fungicide on grain yield. In 2005, fungicide treatments with reduced

stem rust severity yielded significantly ($P \leq 0.05$) more grain at Eldoret and Mau-Narok (Table 3 and 4) whereas only Artea 330 EC, Stratego 250 EC, and AmistarXtra 280 SC significantly ($P \leq 0.05$) increased grain yield at KARI-Njoro (Table 2). Similarly, in 2006, treatments that had reduced stem rust severity significantly ($P \leq 0.05$) increased grain yield, except for Cotaf 5 E at KARI-Njoro and Eldoret; and Swing 250 EC and Soprano C 250 EC at the later site. The mean grain yield among the treatments ranged from 1.3 to 2.6 t/ha. The highest yield, 2.6 t/ha, was

obtained in plots of AmistarXtra 280 SC, which was 50% higher than the untreated control.

Effects on kernel weight. All fungicide treatments that had significantly ($P \leq 0.05$) higher grain yield also had higher 1,000-kernel weight. In 2005, 1,000-kernel weights from treated plots at all locations were significantly ($P \leq 0.05$) higher than those from untreated control plots. The trend for both grain yield and 1,000-kernel weight in 2006 was similar, except at Eldoret and Mau-Narok (Table 2, 3, and 4).

Table 3. Effect of fungicide treatment on stem rust severity, area under the disease progress curve (AUDPC), grain yield, and 1,000-kernel weight on wheat cv. Duma at Eldoret^a

Treatment ^y	2005								2006							
	MRS ^v			AUDPC ^z	Grain yield ^w		TKW ^x		MRS ^v			AUDPC ^z	Grain yield ^w		TKW ^x	
	1st	2nd	3rd		t/ha	G (%)	Wt. (g)	G (%)	1st	2nd	3rd		t/ha	G (%)	Wt. (g)	
Untreated	12.5 a	30.0 a	30.0 a	643 a	0.7 c	—	25.0 d	—	12.5	14.0 ab	45.0 a	975 a	2.3 ab	—	40.7	
Swing 250 EC	5.0 a	5.0 cd	5.0 bc	195 a	2.1 b	67	37.3 ab	32.8	13.8	5.3 bc	18.8 cd	510 ab	2.2 b	8.4	43.3	
Artea 330 EC	7.5 a	20.0 cd	5.5 bc	425 a	1.8 b	62	35.9 bc	30.3	7.5	4.3 bc	13.8 cd	335 b	2.4 ab	2.1	41.1	
Silvacur 375 EC	7.5 a	7.5 bcd	5.5 bc	235 a	2.1 b	66.4	36.1 bc	30.7	6.8	5.3 bc	12.5 cd	357 b	2.7 ab	14	43.3	
Folicur 250 EC	7.5 a	3.0 cd	7.5 bc	195 a	2.3 b	69.4	35.8 bc	30.1	13.8	6.5 bc	11.3 cd	381 b	2.5 ab	7.5	42.9	
Stratego 250 EC	10.0 a	5.0 cd	10.0 b	257 a	1.5 b	54.6	33.0 c	24.1	13.8	5.5 bc	25.0 cd	221 b	2.3 ab	2.6	41.9	
Soprano 250EC	7.5 a	12.5 bc	12.5 b	580 a	1.6 b	55.1	33.7 bc	25.8	6.3	2.0 c	7.5 d	652 ab	2.2 b	6.4	40.6	
Orius 25 EW	5.0 a	2.5 d	5.0 bc	172 a	2.2 ab	68.5	34.1 bc	26.6	6.3	6.3 bc	25.0 bc	618 b	2.4 ab	0.9	41.8	
Cotaf 5 E	7.5 a	7.5 cd	5.5 bc	221 a	2.2 ab	67.4	35.1 bc	28.6	7.5	21.3 a	37.5 ab	1,020 a	2.2 b	7.4	40.4	
AmistarXtra 280SC	10.0 a	3.0 cd	3.0 c	156 a	3.0 a	76.3	40.1 a	37.5	7.5	3.3 c	11.3 cd	335 b	2.9 a	18.2	42.9	
Mean	8	7.3	6.6	271	2.1	65.2	35.7	29.6	9.2	6.6	18.1	492	2.4	7.5	42	
LSD (0.05)	1.6	1.6	1.3	571	0.8	—	3.6	—	1.3	1.5	1.8	517	0.6	—	3.3	

^a Treatment means within columns followed by the same letter are not significantly different at $P \leq 0.05$ according to least significant difference (LSD) test; — = no data.

^v MRS = mean rust severity (modified Cobb scale); 1st, 2nd, and 3rd disease notes were recorded at growth stages 55, 65, and 77, respectively.

^w Yield gain (G) (%) = (fungicide-treated – untreated) $\times$ 100/treated.

^x TKW = 1,000-kernel weight; gain (G) (%) = (fungicide-treated – untreated) $\times$ 100/treated.

^y Active components of the fungicides are as follows: Swing 250 EC, epoxiconazole + carbendazim; Artea 330 EC, cyproconazole at 80 g/liter + propiconazole at 250 g/liter; Silvacur 375 EC, tebuconazole + tridimenol; Folicur, tebuconazole; Stratego 250 EC, trifloxystrobin + propiconazole; Soprano C 250 EC, epoxiconazole at 125 g/liter + carbendazim at 125 g/liter; Orius 25 EW, tebuconazole; Cotaf 5E, hexaconazole; and AmistarXtra 280SC, azoxystrobin at 200 g/liter + cyproconazole at 80 g/liter. Soprano 250 EC, Orius 25 EW, and Cotaf 5 E are generic chemicals.

^z Area under the disease progress curve (AUDPC) = values are means of four replications.

Table 4. Effect of fungicide treatment on stem rust severity, area under the disease progress curve (AUDPC), grain yield, and 1,000-kernel weight on wheat cv. Duma at Mau-Narok^a

Treatment ^y	2005								2006							
	MRS ^v			AUDPC ^z	Grain yield ^w		TKW ^x		MRS ^v			AUDPC ^z	Grain yield ^w		TKW ^x	
	1st	2nd	3rd		t/ha	G (%)	Wt. (g)	G (%)	1st	2nd	3rd		t/ha	G (%)	Wt. (g)	
Untreated	9.0 ab	11.5 a	35.0 a	367.3 a	1.3 c	—	38.2 b	—	5.0 a	35.0 a	40.0 a	833 a	2.1 b	—	34.5	
Swing 250 EC	10.0 ab	10.0 a	13.8 b	316.5 a	3.0 ab	54.8	46.6 a	18	1.0 a	12.5 bcd	11.3 c	262 cd	3.0 a	30	38.2	
Artea 330 EC	10.0 ab	17.5 a	9.0 b	392.0 a	3.4 a	60.5	44.0 a	13	4.0 a	32.5 a	32.5 ab	699 ab	2.4 ab	13.9	36.1	
Silvacur 375 EC	10.0 ab	8.0 a	6.5 b	236.8 a	3.3 a	59.8	43.7 a	12.6	0.8 a	16.3 abcd	18.8 bc	350 cd	3.0 a	30.5	38.7	
Folicur 250 EC	13.8 a	12.5 a	9.0 b	347.5 a	3.2 ab	57.9	45.1 a	15.3	0.8 a	5.3 d	11.3 c	180 d	2.9 a	28.6	37.2	
Stratego 250 EC	13.8 a	13.8 a	8.0 b	358.8 a	3.3 a	59.7	45.6 a	16.1	1.0 a	23.8 ab	32.5 ab	528 abc	2.5 ab	14.3	36.8	
Soprano 250EC	6.3 b	12.5 a	16.5 b	344.0 a	3.1 ab	56.6	44.1 a	13.4	0.5 a	15.0 bcd	21.3 bc	392 bcd	2.8 ab	25.5	38.1	
Orius 25 EW	10.0 ab	10.0 a	3.0 b	241.0 a	3.1 ab	56.3	44.4 a	14	0.8 a	13.8 bcd	13.8 c	309 cd	3.0 a	29.8	38.6	
Cotaf 5 E	6.3 b	11.3 a	7.8 b	264.5 a	3.1 ab	56.5	44.3 a	13.7	1.0 a	21.3 abc	30.0 ab	492 bcd	2.4 ab	13.6	36.7	
AmistarXtra 280SC	6.3 b	10.0 a	5.5 b	230.8 a	3.2 ab	37.9	44.2 a	13.5	1.0 a	8.8 cd	13.8c	264 cd	3.1 a	31.2	37.6	
Mean	9.5	11.9	11.4	309.9 a	3	55.6	44.7	14.4	1.2	16.6	20.6	386	2.8	24.2	37.6	
LSD (0.05)	1.0	1.7	1.9	7.2	1.0	—	3.2	—	1.3	1.8	1.4	322	0.7	—	4.9	

^a Treatment means within columns followed by the same letter are not significantly different at $P \leq 0.05$ according to least significant difference (LSD) test; — = no data.

^v MRS = mean rust severity (modified Cobb scale); 1st, 2nd, and 3rd disease notes were recorded at growth stages 55, 65, and 77, respectively.

^w Yield gain (G) (%) = (fungicide-treated – untreated) $\times$ 100/treated.

^x TKW = 1,000-kernel weight; gain (G) (%) = (fungicide-treated – untreated) $\times$ 100/treated.

^y Active components of the fungicides are as follows: Swing 250 EC, epoxiconazole + carbendazim; Artea 330 EC, cyproconazole at 80 g/liter + propiconazole at 250 g/liter; Silvacur 375 EC, tebuconazole + tridimenol; Folicur, tebuconazole; Stratego 250 EC, trifloxystrobin + propiconazole; Soprano C 250 EC, epoxiconazole at 125 g/liter + carbendazim at 125 g/liter; Orius 25 EW, tebuconazole; Cotaf 5E, hexaconazole; and AmistarXtra 280SC, azoxystrobin at 200 g/liter + cyproconazole at 80 g/liter. Soprano 250 EC, Orius 25 EW, and Cotaf 5 E are generic chemicals.

^z Area under the disease progress curve (AUDPC) = values are means of four replications.

DISCUSSION

There is very little information published on the use of fungicide to control wheat stem rust, specifically related to the rust race TTKS that is prevalent in the Eastern Africa region. The occurrence of stem rust and the onset of epidemics differed from year to year and location to location. In this study, three locations, KARI-Njoro, Eldoret, and Mau-Narok, were selected because of their stem-rust-favorable weather conditions. Generally, these areas have hot days of 23 to 30°C, mild night temperatures below 15°C, and adequate moisture for night dews. Under such favorable conditions, the growth and spread of the stem rust pathogen can greatly reduce grain yield and 1,000-kernel weight in susceptible cultivars. Stem rust epidemics were high in 2005 and 2006 at KARI-Njoro. The rust development began early due to the warm and moist environmental conditions that prevailed. At Eldoret, rust severity was moderate in 2005 but high in 2006. Even though the Mau-Narok location experienced cooler weather and frequent rainfall during the growth seasons, rust severity was moderate before application of fungicides.

Stem rust caused 32 to 57% of grain yield loss and 17 and 24% of 1,000-kernel weight reduction in the experiments at the three locations in 2005 and 2006, respectively. These results are consistent with losses reported in other studies (1,5,7). Yield losses of 50% due to stem rust infection have been reported in a recent study (2). Previously, Pretorius (9) reported that yield losses caused by stem rust ranged from 7 to 35% depending on cultivar. Dill-Mackey et al. (2) induced severe stem rust epidemics in barley and wheat and observed yield losses of 50 to 58%. Mayfield (6) found a clear relationship between grain yield and disease severity by demonstrating that prevention of a 1% increase in rust severity saved a 2% loss in grain yield.

Different fungicides vary in their efficacy to control stem rust. Loughman et al. (5) reported that Folicur (tebuconazole) was more effective than Triad (triadimefon) or Impact (flutriafol) in disease reduction and yield increase. In the present study, all fungicide applications resulted in lower disease severity and higher yields than untreated check plots. However, AmistarXtra 280 SC, Folicur 250 EC,

Silvarcur 375EC, and Orius 25 EW were more effective than other treatments in reducing disease and increasing yield, while the effectiveness of Stratego 250 EC, Cotaf 5 EC, Swing 250 EC, Artea 330 EC, and Soprano C 250 EC was inconsistent. Therefore, growers should choose fungicides based on their efficacy.

Stem rust severity was lower in 2005 at Eldoret and Mau-Narok than at KARI-Njoro but treatments significantly increased grain yield. The yield increase by fungicide applications under low disease pressure could be due, in part, to the phytotoxic effect of fungicides. Such stimulatory effect of fungicide treatments on growth may result in significant yield increases even in the absence of the disease (14). Fungicide treatments, if applied under high and moderate disease pressure at critical growth stages, may reduce large yield losses by suppressing or eliminating stem rust pathogens (6). However, greater rust control and greater yield increases may have been possible using higher rates and more applications of fungicides as well as spraying at an earlier stage of the rust epidemic. Under field conditions, a stem rust severity level greater than 5% in hot-spot regions should be controlled to reduce yield losses (5). For this study, there was a sudden explosion of the disease within a few days due to ideal climatic conditions, which contributed to the high stem rust severities recorded at the KARI-Njoro location before the first fungicide application. This provided ideal conditions for assessing efficacies of the fungicides.

The impact of fungicide application in the management of stem rust was well illustrated at the three locations. Significant differences were found among fungicides in their ability to suppress disease development and protect the crop canopy, which is vital for dry matter accumulation and yield (12). The efficacy differences among the tested fungicides were probably related to their fungicidal activity. The study showed that stem rust can severely reduce wheat grain yield of susceptible cultivars. The adoption of effective fungicides to combat the stem rust pathogen as a short-term control strategy until resistant cultivars are developed should be encouraged. However, more research is required to identify the precise timing of fungicide sprays and doses.

ACKNOWLEDGMENTS

We thank the agrochemical companies and Global Rust Initiative (GRI) for partial funding of this study; and our colleagues in the pathology section, specifically D. Onyango and P. Kinyanjui, for their tireless support during the implementation of the experiments.

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