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Reduction of Winter Wheat Yield Losses Caused by Stripe Rust through Fungicide Management

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Abstract

Stripe rust of winter bread wheat (*Triticum aestivum* L.) causes substantial grain yield loss in Central Asia. This study involved two replicated field experiments undertaken in 2009–2010 and 2010–2011 winter wheat crop seasons. The first experiment was conducted to determine grain yield reductions on susceptible winter wheat cultivars using single and two sprays of fungicide at Zadoks growth stages Z61–Z69 in two farmers' fields in Tajikistan and one farmer's field in Uzbekistan. In the second experiment, four different fungicides at two concentrations were evaluated at Zadoks growth stage Z69. These included three products from BASF – Opus (0.5 l/ha and 1.0 l/ha), Platoon (0.5 l/ha and 1.0 l/ha) and Opera (0.75 l/ha and 1.5 l/ha) – and locally used fungicide Titul 390 (0.5 l/ha and 1.0 l/ha). One and two sprays of fungicides did not differ significantly ($P > 0.05$) in increasing grain yield. Stripe rust reduced grain yield and 1000-kernel weight (TKW) from 24 to 39% and from 16 to 24%, respectively. The benefits from the two concentrations of the same fungicide did not consistently resulted in significantly higher grain yield, suggesting that the lower concentrations could be more cost effective. Our study provides important information about the selection of fungicides, spray concentrations and number of spray to control stripe rust and increase grain yield. The findings could play an important role in developing stripe rust management approaches such as fungicide rotation and strategic fungicide applications in Central Asian countries.

Introduction

Stripe (yellow) rust, caused by *Puccinia striiformis* f. sp. *tritici*, has been an important disease constraint to winter bread wheat production in Central Asia over the last 15 years (Absattarova et al. 2002; Nazari et al. 2008; Ziyaev et al. 2011; Sharma et al. 2013). Morgounov et al. (2012) analysed trends in the incidence of wheat rusts between 1970 and 2010 and reported substantial increases in stripe rust severities between 2001 and 2010 in Central and West Asia. The increasing trend in stripe rust severities in the recent years is also reflected through the occurrence of four epidemics in different parts of Central Asia in the past 6 years, 2009–2014 (Ziyaev et al. 2011; Sharma et al. 2013, 2014). These recent epidemics resulted in substantial but varying yield losses due to stripe rust in different years (R.C. Sharma, Unpublished data).

There is a lack of recent empirical evidence on yield loss occurring due to stripe rust under epidemics in Central Asian countries. Past preliminary results show that stripe rust could reduce grain yield by 10–90% in the Central Asian countries (Dzhunusova et al. 2009; Moghaddam et al. 2009; Rahmatov et al. 2009;

Sarbayev and Kydyrov 2009; Ziyaev et al. 2011). However, these loss estimates were not performed through properly designed experiments using the plots with disease compared with the plots protected by fungicide spray on the same field.

As the leading winter wheat varieties in the region are either susceptible to or possess low levels of resistance to stripe rust (Sharma et al. 2009), different fungicides are widely used to control the disease, which is done without the knowledge of their efficacy to control disease under field conditions. Different commercial products and their concentrations are known to differ in their efficacy (Conner and Kuzyk 1988). This underlines a knowledge gap on actual yield reductions caused by stripe rust and effectiveness of the fungicides in disease control. Therefore, this study was conducted to evaluate effectiveness of fungicides agents on controlling stripe rust and estimate grain yield reductions.

Materials and Methods

Yield loss estimates

Tajikistan

The study was conducted in *Sharor* and *Durbat* villages in Hissor district of Tajikistan in 2009–2010 (2010) and 2010–2011 (2011) cropping seasons, respectively, using a stripe rust susceptible winter wheat variety 'Navruz'. Individual experiment plots of 30 m^2 size were laid out in the Randomized Complete Block with four replications. The three treatments included non-protected control, and one spray and two sprays of Folicur® (tebuconazole at 430 a.i. g/l) at the rate of 0.5 l/ha in 250 litres water. The first spray of the fungicide was applied when 20% leaves showed initial signs of infection (Zadoks growth stage Z61) in 2010 and 1 week after heading (Zadoks growth stage 69) in 2011. The second spray was provided 2 weeks after the first spray. The crop management practices were adopted according to the recommendations made for commercial winter wheat production by the farmers in the community where the experiment was conducted. The disease scores were recorded in control plots between growth stages Z61 and Z75 in 2010 and between Z69 and Z77 in 2011.

At maturity, all plants in individual plots were hand harvested, threshed and grain yield recorded. From each plot bag, 1000 kernels were randomly counted and weighed to record 1000-kernel weight (TKW). Grain yield reduction was calculated as yield difference between fungicide sprayed and non-sprayed treatments, expressed in percentage of the sprayed plots using the formula, reduction (%) = $\{(Y_{sp} - Y_{nsp}) \div (Y_{sp})\} \times 100$, where Y_{sp} and Y_{nsp} represent grain yield under fungicide sprayed and non-sprayed conditions, respectively.

Uzbekistan

The study was conducted in Fergana in 2010 using a stripe rust susceptible, widely grown winter wheat variety 'Kroshka' (Ziyaev et al. 2011). The experimental design was similar to that explained above for Tajikistan. The fungicide Titul 390® (propiconazole at 390 a.i. g/l) was sprayed at the rate of 0.5 l/ha in 250 litres of water. The first spray was applied with initial symptom of stripe rust infection which occurred at Zadoks growth stage Z49. The second spray was provided 2 weeks after the first spray. The wheat crop management practices were adopted according to the recommendations made for commercial winter wheat productions by the local farmers. The disease scores were recorded in the control plots between growth stages Z69 and Z79. At maturity, plots were individually harvested, threshed and grain yield recorded. From each plot, 1000 kernels were randomly counted and weighed to record TKW.

Evaluation of effectiveness of different fungicides

This study was conducted in Karshi and Surkhandarya, Uzbekistan, in 2009–2010 (2010) and 2010–2011 (2011) cropping season, respectively. Stripe rust susceptible winter wheat cultivars 'Bobur' and 'Krasnodar-99' were used in 2010 and 2011, respectively. The experiment was conducted in a farmer's field in a randomized complete block design with three replicates, using individual plot of 10 m^2 size. Four fungicides were Opus® (epoxiconazole at 125 a.i. g/l), Platoon® (pyraclostrobin at 200 a.i. g/l), Opera® (pyraclostrobin at 50 a.i. g/l) and Titul 390® (propiconazole at 390 a.i. g/l) plus one non-sprayed control. Titul was selected as a product being used locally in Uzbekistan. Opus® at the rate of 0.5 l/ha and 1.0 l/ha, Platoon® at the rate of 0.5 l/ha and 1.0 l/ha, Titul 390® at the rate of 0.5 l/ha and 1.0 l/ha and Opera® at the rate of 0.75 l/ha and 1.5 l/ha were used. The fungicides were mixed in water at the rate of 250 l/ha and sprayed when the leaves showed initial symptoms of stripe rust which occurred at Zadoks growth stage Z69. These concentrations were chosen based on the discussion among the research team members and with other researchers who had experience in fungicide control of wheat stripe rust. The individual plots were harvested as 6 m^2 from the middle of the 10 m^2. The disease scores were recorded in the control plots between growth stages Z69 and Z79.

At maturity, plots were individually harvested, threshed and grain yield recorded. From each plot bag, 1000 kernels were randomly counted and weighed to record TKW. Per cent grain yield reduction was estimated as explained earlier.

Data were analysed using Genstat (2013) statistical software. Analysis of variance was used to determine the difference among the treatments. The significance among treatment mean effects was tested based on least significant difference (LSD) at 5% probability level.

Results

Yield loss estimates: frequency of fungicide application

In both years (2010 and 2011), natural epidemics of stripe rust occurred in Tajikistan and Uzbekistan trials. Stripe rust severities in control plots in Tajikistan were 70% at growth stage Z75 and 60% at growth stage Z77 in 2010 and 2011, respectively. In Uzbekistan, disease severity in the control plots was 80% at growth stage Z79 in 2010. The level of severity of other foliar diseases in the experimental plots was negligible.

There was significant effect of fungicide spray on grain yield and TKW in Tajikistan and Uzbekistan in each trial (individual ANOVA not presented). Number of spray × location interaction was significant for grain yield but not for TKW (Table 1). Fungicide spray resulted in significantly higher grain yield and TKW compared to the control in all three trials (Table 2). However, the differences between the effects of one spray and two sprays on grain yield and TKW were non-significant in all three trials. Grain yield and TKW reductions due to stripe rust ranged from 24 to 39% and from 16 to 24%, respectively.

Table 1 Combined analysis of variance for three locations for grain yield and 1000-kernel weight in a study of grain yield reductions caused by stripe rust in Central Asia, 2010 and 2011

Source of variation	Df	Mean square	
		Grain yield	1000-kernel weight
Location	2	6.669**	201.50**
Replication within Location	9	0.021	3.37
Number of spray	2	4.322**	217.79**
Number of spray × Location	4	0.445**	6.94
Error	18	0.011	2.46

**Significant at P = 0.01.

Table 2 Response of stripe rust susceptible wheat varieties to fungicide sprays and estimates of grain yield reductions estimated by one and two sprays of fungicide in field experiments conducted in Tajikistan in 2010 and 2011 and in Uzbekistan in 2010

Location	Grain yield (t/ha)					Grain yield increase estimates (%)		Grain yield loss estimates (%)		1000-kernel weight (g)					1000-kernel weight loss estimates (%)	
	Control	One spray	Two sprays	$LSD_{0.05}$	CV (%)	One spray	Two sprays	One spray	Two sprays	Control	One spray	Two sprays	$LSD_{0.05}$	CV (%)	One spray	Two Sprays
Sharor, Tajikistan, 2010	2.015 b[a]	2.730 a	2.880 a	0.222	2.8	35	43	26	30	33.6 b	42.3 a	44.4 a	2.3	3.3	20	24
Durbat, Tajikistan, 2011	2.090 b	2.680 a	2.750 a	0.231	5.3	28	32	22	24	36.0 b	41.8 a	43.1 a	3.5	5.0	14	16
Fergana, Uzbekistan, 2010	2.685 b	4.357 a	4.402 a	0.17	2.6	62	64	38	39	29.3 b	34.8 a	35.2 a	2.2	3.8	16	17
Mean	2.263 b	3.256 a	3.344 a	0.098	3.5	44	48	30	32	33.0 b	39.6 a	40.9 a	1.3	4.1	17	19

[a] For a given trait in a row, the means followed different letters for the same location differ significantly based on $LSD_{0.05}$.

Table 3 ANOVA for grain yield and 1000-kernel weight in a study on the effect four fungicides in two concentrations and an unprotected control in 2 years, 2010–2011

Source	Df	Mean square	
		Grain yield	1000-kernel weight
Year	1	54.703**	–[a]
Replication within year	10	0.674	–
Fungicide treatment	(8)	1.410**	70.06**
Control vs. fungicide	1	7.478**	260.87**
Concentration	1	1.446**	175.19**
Product	3	0.757**	39.94**
Product × Concentration	3	0.029	1.55
Fungicide × Year	(8)	0.299**	–
Control vs. fungicide × Year	1	0.406*	–
Concentration × Year	1	1.145**	–
Product × Year	3	0.241*	–
Product × Concentration × Year	3	0.039	–
Error	80 (40)[b]	0.083	1.67

[a]Data are available for 2011 only.
[b]Error df is 80 for grain yield and 40 for 1000-kernel weight.
*Significant at P = 0.05.
**Significant at P = 0.01.

Fungicide evaluation

In both years (2010 and 2011), natural epidemics of stripe rust occurred as reflected through 80% and 70% disease severity in control plots in 2010 and 2011, respectively. Disease data were not recorded in the sprayed plots because there was no visual symptom of stripe rust in the plots sprayed with fungicide under both low and high concentrations. There were no other diseases present in the experimental plots to affect the result. There was significant effect of fungicide spray on grain yield and TKW (Table 3). The two concentrations of the fungicide products had significant effect on grain yield. However, the product × concentration interaction was non-significant. Fungicide × year interaction was significant on grain yield.

There were 13–39% and 18–42% grain yield increases over control from the application of different fungicides in 2010 and 2011, respectively (Table 4). In 2010, the two dosages of the individual fungicides did not produce significant differences in grain yield. However, in 2011, the higher dosage of each fungicide produced significantly higher grain yield than the lower rate. In 2010, Opera was most effective in increasing grain yield over the control, but did not differ significantly from Opus and Platoon. On the other hand, Titul was least effective among the four fungicides in increasing grain yield. In 2011, the higher dosage of Platoon produced the highest yield followed by Opera. Also, the higher dosage of Platoon and Opera resulted in significantly higher kernel weight than the other products. In 2011, the locally used fungicide Titul was as effective as Opus in terms of grain yield and TKW. The estimates of grain yield reductions were 11–28% and 15–30% in 2010 and 2011, respectively. There were 15–27% reductions in TKW, measured in 2011 only.

Table 4 Grain yield increases caused by different fungicides used to control stripe rust on a susceptible cultivar in Uzbekistan in 2 years, 2010 and 2011

Fungicide			2010			2011				
Name	Rate l/ha	Active ingredient concentration %	Grain yield (t/ha) t/ha	Grain yield increase over control (%)	Grain yield reduction (%)	Grain yield (t/ha) t/ha	1000-kernel weight g	Grain yield increase over control (%)	Grain yield reduction (%)	1000-kernel weight reduction
Water			2.528 d[a]			3.605 g	30.3 d			
Opus	0.50	0.025	3.140 abc	24	19	4.248 f	34.0 c	18	15	11
Opus	1.00	0.050	3.035 bc	20	17	4.672 cd	37.2 b	30	23	18
Platoon	0.50	0.040	3.190 abc	26	21	4.527 de	36.8 b	26	20	18
Platoon	1.00	0.080	3.227 abc	28	22	5.127 a	40.8 a	42	30	26
Opera	0.75	0.015	3.447 ab	36	27	4.453 e	36.6 b	23	19	17
Opera	1.50	0.030	3.508 a	39	28	4.961 b	41.4 a	38	27	27
Titul	0.50	0.078	2.852 cd	13	11	4.395 ef	34.3 c	22	18	12
Titul	1.00	0.156	2.967 c	17	15	4.717 c	37.6 b	31	24	19
$LSD_{0.05}$			0.451			0.154	1.6			
CV (%)			12.5			2.9	3.8			

[a]Means within a column followed different letters differ significantly based on $LSD_{0.05}$.

Discussion

Yield loss estimates: frequency of fungicide application

The single spray of Folicur and Titul effectively controlled stripe rust in Tajikistan and Uzbekistan, respectively, which was reflected through the absence of disease symptoms in the plots receiving one and two sprays of fungicide. As a result, there were non-significant differences in grain yield and TKW between one and two sprays in all three trials. The absence of number of spray × location interaction for grain yield and TKW suggested that the relative differences in these traits due to one and two sprays of the fungicide did not vary significantly across the trials. Even though the wheat varieties and the fungicides used in the experiments in Tajikistan and Uzbekistan differed, the comparison of the estimates of the relative differences between one spray and two sprays in different experiments was useful in getting an understanding of the consistency of the results over locations.

Stripe rust caused reductions in grain yield and TKW that varied among the three locations; this could be attributed to the different ways the epidemics might have developed across the locations. The estimates of stripe rust-induced grain yield reductions were lower in Tajikistan compared to Uzbekistan. In Tajikistan, the grain yield reduction was higher in 2010 (30%) compared to 2011 (24%). In Uzbekistan, where the experiment was conducted in 2010, a much higher grain yield reduction of 39% occurred. The higher grain yield reductions in 2010 could be attributed to the incidence of disease at earlier crop stage in 2010 compared to 2011. The occurrence of severe, wide-scale stripe rust epidemics in 2010 in Central and West Asia including Uzbekistan and Tajikistan was reported by Hodson and Nazari (2010), Ziyaev et al. (2011) and Sharma et al. (2013). A large proportion of grain yield reductions could be attributed to the reductions in TKW. The magnitudes of grain yield and TKW reductions recorded in this study are comparable to recently published reports from the neighbouring region of West and South Asia (Al-Maaroof et al. 2014; Eisa et al. 2014; Karaman et al. 2014).

Effect of fungicides

The effect of different fungicides differed in 2 years. Higher dosage of all fungicides, except Opus in 2010, resulted in higher grain yield than the lower concentrations. However, the differences between two concentrations were non-significant in 2010 due to higher level of experimental error compared to 2011. Even though there was no visual symptom of disease in the plots sprayed with lower and higher concentrations of the fungicide, there was difference in grain yield between the two concentrations. This indicates that some internal damage to plant tissues might still have occurred under low concentration of fungicide despite of the absence of visual symptom on the plants. There was a marked difference in effectiveness of Titul in the 2 years. Different fungicides caused a range (11–42%) of grain yield increases in 2 years. This finding broadly is in agreement with the previous study of Conner and Kuzyk (1988) who reported that the fungicides with different ingredients caused 17 to 79% grain yield increases over 3 years.

All fungicides controlled disease and increased grain yield; however, the chemicals differed in their effectiveness. Although not examined in this study, this difference in effectiveness of the fungicide could be due to different levels of control of internal tissue damage by different products. Also, the benefit of one or two sprays with the same fungicide did not consistently translate into increased grain yield. Therefore, it would be more cost effective to apply only one fungicide spray with the onset of stripe rust. Considering average grain production of 3.067 t/ha with a value of US $460 without fungicide application, one spray of 0.5 l/ha Opus®, 0.5 l/ha Platoon®, 0.75 l/ha Opera® and 0.5 l/ha Titul® would translate, based on our results in an additional 628 kg (20%), 792 kg (26%), 884 kg (29%) and 557 kg (18%) per hectare respectively (US $94, 119, 133 and 84, respectively). Similarly, one spray of 1.0 l/ha Opus®, 1.0 l/ha Platoon®, 1.5 l/ha Opera® and 1.0 l/ha Titul® would translate in an additional 787 kg (26%), 1111 kg (36%), 1168 kg (38%) and 776 kg (25%) per hectare, respectively (US $118, 167, 175 and 116, respectively). Assuming that all these fungicides would be available and marketed in Uzbekistan, spraying would be cost effective depending on the formulation and cost of each commercial product, grain yield level and stripe rust susceptibility of the wheat cultivar. If the price of commercial products remains below these indicative figures for additional benefit, the farmers will be able to afford the use of fungicides. Also, considering the >100% higher price paid for wheat seed than for food grain, farmers producing seed will be more motivated to use a fungicide.

There has been a continuous scourge of stripe rust on winter wheat in Central Asia in the past 15 years with four epidemics in the past 6 years, and substantial yield losses were reported (Hodson and Nazari 2010; Ziyaev et al. 2011; Sharma et al. 2013).

However, most of the yield losses in these previous studies were made through guesstimates. There is little documentation available through properly designed experiments to assess grain yield losses caused by stripe rust in Central Asia. Our studies, conducted over five sites in Tajikistan and Uzbekistan in 2 years, provide estimates-based evidence on stripe rust-induced grain yield reductions in Central Asia. There were wide-scale epidemics of stripe rust in 2010, but not in 2011. In 2011, epidemics occurred in specific rust-prone pockets where conditions are favourable for stripe rust development every year. These results demonstrate that cultivation of susceptible cultivars could result in stripe rust-induced grain yield reductions even in the years with limited epidemics.

Most of the widely cultivated winter wheat cultivars in Central Asia possess low levels resistance to stripe rust (Ziyaev et al. 2011; Sharma et al. 2013), and the farmers control the disease primarily through fungicide applications. Considering up to 42% yield increases through fungicide protection against stripe rust, the wheat farmers can greatly benefit from disease control. Further benefits could come from improvement in grain quality that could come from higher TKW. Also, straw quality is improved through fungicide spray, which is widely used as animal feed in Central Asia and other parts of the developing world. Another option of increasing profitability from wheat cultivation in Central Asia with persistent problem of stripe rust could come from planting of resistant cultivars. Recent reports suggest that stripe rust-resistant winter wheat varieties are increasingly becoming available in Central Asian countries (Ziyaev et al. 2011; Sharma et al. 2013).

Conclusion

All foliar fungicides evaluated in this study controlled stripe rust and increased grain yield and TKW. The benefit of one or two sprays with the same fungicide did not translate into increased grain yield and TKW. Therefore, it would be more cost effective to apply just one fungicide spray at the first appearance of disease symptom if the development period of disease is short and severity is not very high. The benefits from two concentrations of the same fungicide did not consistently resulted in significantly higher grain yield. Therefore, lower concentrations of different fungicides used in this study could be cost effective if the disease severity is not very high. The findings underline the need for caution when selecting a fungicide and the number of sprays to maximize profitability of a wheat crop grown under stripe rust epidemics in Central Asian countries. Our studies provide important information about selection of fungicides, spray concentrations and number of spray to control stripe rust. Such information, which is currently lacking, could play important role in developing integrated management strategy of wheat stripe rust.

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