Minimizing yield loss of wheat (*Triticum aestivum* L.) by controlling leaf rust (*Puccinia triticina* L.) with an appropriate combination of fungicides

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ABSTRACT

Background and Objective: Wheat is the most significant grain crop in the world and in Bangladesh, and leaf rust is a major disease of this crop. Every year it occurs in almost all wheat-growing areas. So it needs to know the chemical fungicide for managing this disease.

Methodology: An experiment with seven fungicides, namely Tilt 250 EC (propiconazole), Folicur 250 EC (tebuconazole), Nativo 75 WG (a combination of tebuconazole with trifloxystrobin), Positive 300 SE (a combination of propiconazole with difenoconazole), Awal 72 WP (a combination of hexaconazole with zineb), Rovral 50 WP (iprodione) and Goldman 80 WP (mancozeb) was conducted following randomized complete block design with three replications for three consecutive years.

Main Results: The experiment gave similar results in three years (2017–2018, 2018–2019, and 2019–2020) on different agronomic and disease parameters. The lowest (2%) diseased leaf area and area under the diseased progressed curve (AUDPC) were obtained when treating the plot with fungicides Tilt 250 EC, Folicur 250 EC, Nativo 75 WG, Positive 300 SE, and Awal 72 WP with the highest 97–98% of disease control. The mean of a thousand-grains weight and grain yield were obtained highest from the treated plot with Folicur 250 EC followed by Tilt 250 EC, Positive 300 SE, and Nativo 75 WG.

Conclusions: Spraying with fungicides Tilt 250 EC, Folicur 250 EC, Nativo 75 WG, Positive 300 SE, and Awal 72 WP provides the best results to manage leaf rust disease to a great extent.

Keywords: Wheat, leaf rust, fungicide, disease control, sub-tropical region

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INTRODUCTION

Wheat (*Triticum aestivum*) is an important cereal crop largely consumed worldwide, producing about 770 million tons in 2017 (FAO, 2019). The world population feeds this food as a source of energy and proteins, which helps to maintain their good health (Peña-Bautista *et al.,* 2017). In Bangladesh, 13.75 million tons of wheat were produced from 4.53 million hectares of land with an average yield of about 3.04 tons per hectare (BBS, 2019), facing different biotic organisms and abiotic factors resulting in reduced yield of wheat. There were around 20 different diseases (Ahmed, 1994; Alam *et al.,* 1994) and Simón *et al*. (2021) reported 31 pests and pathogens, leaf rust of wheat is an important disease that causes huge yield loss each year (Figure 1). Leaf rust of wheat caused by *Puccinia triticina* (formerly known as *Puccinia recondita*) is one of the most recognized wheat diseases in the world (Roelfs *et al.,* 1992). Three types of rust disease (leaf, stem, and stripe rust) are the major problem for sustainable wheat production worldwide (Saari and Prescott, 1985; Abeb, 2021).

Though *Puccinia triticina* mainly attacks the leaf blades, it also infects the leaf sheath and glumes in different highly susceptible varieties (Huerta-Espino *et al.,* 2011), causing lower numbers of kernels which result in lower kernel weights, i.e., 2 to 41% (Bajwa *et al.,* 1986; Roelfs *et al.,* 1992; Marasas *et al.,* 2004; Kolmer *et al.,* 2005). An early infection usually causes higher yield loss (60–70%), and around 7 and 30% yield loss occurs when it infects at the time of spike emergence and the soft dough stage (Huerta-Espino *et al.*, 2011). In Kansas, the loss of winter wheat alone was estimated at 13.9, 4.7, and 1.37% in 2007, 2008, and 2009 respectively (Appel *et al.,* 2009). Yield losses were estimated at up to 50% in Egypt, 30% in Tunisia, 10% in northwestern India (Nagarajan and Joshi, 1978; Abdel-Hak *et al.,* 1980; Deghais *et al.,* 1999), and in Ethiopia, it attains up to 75% depending on the susceptibility of a variety and growing location (Tesfaye *et al*., 2020). Hassan *et al.* (1973) reported that leaf rust intensities in Pakistan ranged from 40 to 50%, with 100% infection occurring on susceptible wheat varieties in 1973 with a severe leaf rust epidemic in 1978 causing a loss of $86 million in Pakistan (Hussain *et al.,* 1980). During 1971–1972 and 1972–1973, there were severe outbreaks of leaf rust resulting in losses of 5.9 and 2.0% respectively, which were estimated for varieties Kalyansona and Sonalika (Joshi *et al.,* 1975). In Bangladesh, leaf rust occurs almost every year depending on variety, sowing dates, and spots and causes significant yield loss if a susceptible variety is planted late. However, 74% of the surveyed field were found with leaf rust infection in the 2018–2019 cropping season (Mustarin *et al.,* 2021).

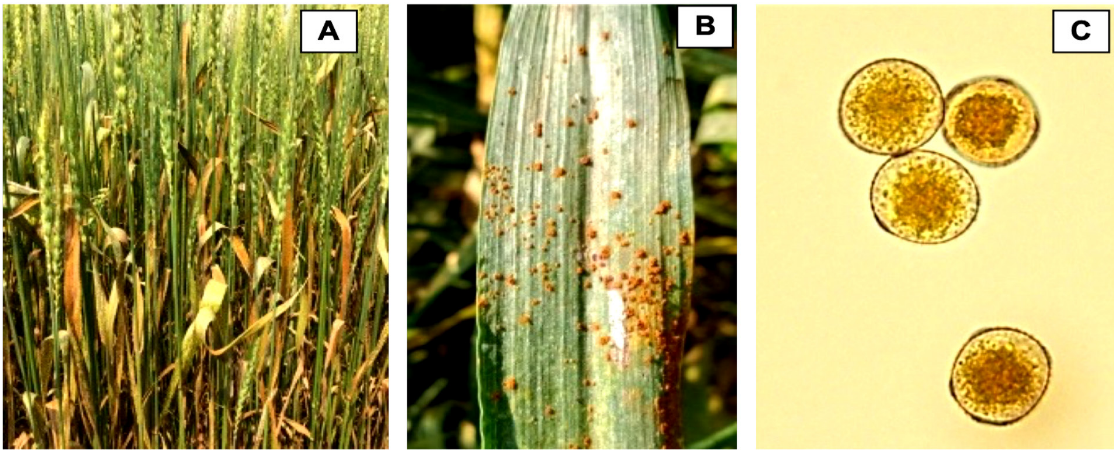

Figure 1 Symptoms of leaf rust on wheat leaf: (A) severely infected plot, (B) leaf rust pustule on the wheat leaf, and (C) microscopic spores of *Puccinia triticina*

In the 1960s' systemic fungicides were introduced, and people started to use them to control plant disease to reduce yield loss with the increase in crop production and net returns (Hewitt, 1998). The use of fungicides results in three times higher crop production (Ordish and Dufour, 1969). Cook and King (1984) reported that the use of fungicides was beneficial and provided double economic returns in an experiment conducted in 1982 in England. Fungicide played a vital role in controlling *Septoria* and powdery mildew and resulted in a 400 to 2,700 kg ha^{-1} increase per acre (Jorgensen *et al.,* 2000). Wegulo *et al.* (2009) reported that in a study in Nebraska, fungicides decreased by 42% crop loss, and in a similar experiment Kelley (2001) found that yield of winter wheat was increased by 77% by the application of fungicide propiconazole. The complex disease of *Septoria tritici* blotch, tan spot, and leaf rust of wheat was controlled by using fungicides which led to increasing crop production and good economic returns in every wheat variety (Puppala *et al.,* 1998). During the 1976–1977 cropping season, a severe leaf rust epidemic was reported on the bread wheat in northwestern Mexico. An emergency fungicide control program was implemented to prevent losses (Dubin and Torres, 1981; Huerta-Espino *et al.,* 2011). In Canada, foliar fungicides minimized wheat yield loss by controlling leaf rust and *Fusarium* head blight. In South America, potential yield losses can exceed 50% if fungicides are not applied in areas with favourable weather conditions.

Therefore, the costs of annual fungicide applications from 1999 to 2003 were estimated at more than $50 million (Huerta-Espino *et al.,* 2011). Leaf rust is also an important disease in South Africa. However, to control stripe rust, low infection levels have been observed in farmers' fields due to lower inoculum levels resulting from fungicide applications, host resistance, and a non-conducive environment (Terefe *et al.,* 2009). DeWolf (2014) and Martinez-Espinoza (2014) mentioned the effectiveness of propiconazole, tebuconazole, propiconazole + azoxystrobin, and tebuconazole + trifloxystrobin against wheat rust. These results were also accordant with Iqbal *et al*. (2015). Hence, to maximize more fungicide options in the market and identify effective fungicides, frequent verification and evaluation of new fungicides against wheat leaf rust are important to sustain wheat production and productivity. To test the effectiveness of different fungicides for the management of wheat leaf rust caused by *Puccinia triticina* this study was undertaken.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at Bangladesh Wheat and Maize Research Institute (BWMRI), Nashipur, Dinajpur, Bangladesh, during the month from November to March of three consecutive cropping seasons during 2017–2018, 2018–2019, and 2019–2020.

Weather Conditions during Wheat Seasons

Three years of weather conditions during the crop growth stages are presented in Figure 2. In the first season, wheat was sown on 19 December 2017, the second season was sown on 9 December 2018, and the third season was sown on 20 December 2019. In all three seasons, the temperature was low (10–15 °C during germination to the vegetative stage, whereas, at the reproductive stage, the temperature was high (25–35 °C).

Experimental Design, Treatments, and Field Management

With three replications, the experiment was arranged in a randomized complete block design. The trial contained eight treatments (Tilt 250 EC, Folicur 250 EC, Positive 300 SE, Goldman 80 WP, Rovral 50 WP, Awal 72 WP, Nativo 75 WG, and unsprayed control). The fungicides were applied at the recommended rate (Table 1).

To protect the flow of chemicals to the subsequent experimental plots during the application of fungicide, the plots under application were sheltered with plastic sheets supported by four wooden poles. Trail fungicides were sprayed twice, once at the heading stage, and another was applied 15 days after the first spray. The susceptible variety 'Morocco' was sown in 1.2 × 2.5 m plots with 20 cm row-spacing on 19 December 2017, 9 December 2018, and 20 December 2019. The seed rate was 120 kg ha^{-1}. Spacing between each plot was 1 and 2 m, and replication respectively was followed. The recommended dose of fertilizers were 100, 27, 40, and 20 kg ha^{-1} of N, P, K, and S respectively, and 1 kg ha^{-1} of B. A full amount of other fertilizers and two-thirds of N were applied as basal during final land preparation. The remaining one-third of N fertilizer was applied immediately after the first irrigation (at the crown root initiation stage). The second and third irrigations were applied at the booting stage and grain-filling stage.

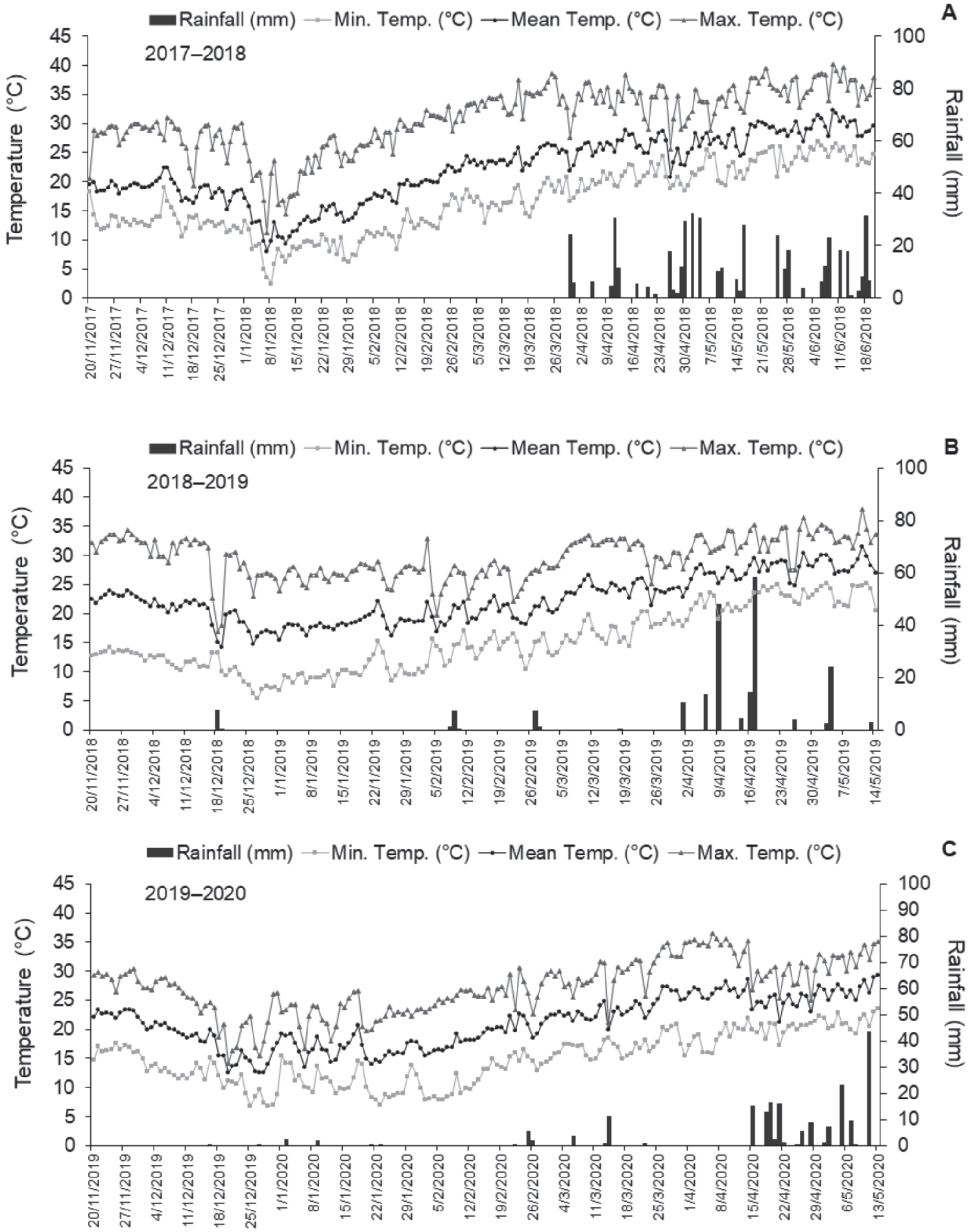

Figure 2 Weather conditions during the crop growth stage in three wheat seasons: (A) 2017–2018, (B) 2018–2019, and (C) 2019–2020. Max. Temp. = maximum temperature, Min. Temp. = minimum temperature, Mean Temp. = mean temperature.

Table 1 Fungicides with recommended rates used to control leaf rust diseases of wheat in the experiment

SL No.	Trade name	Content of ingredients	Manufacture company	Application rate
1	Tilt 250 EC	Propiconazole 250 g/L	Syngenta Bangladesh Limited	0.5 mL/L
2	Folicur 250 EC	Tebuconazole (25%)	Bayer CropScience Limited	0.5 mL/L
3	Positive 300 SE	Difenoconazole (15%) + Propiconazole (15%)	McDonald Bangladesh (Pvt) Limited	1 mL/L
4	Goldman 80 WP	Mancozeb (75%)	Mary Gold Agro Science	2 g/L
5	Rovral 50 WP	Iprodione (50%)	FMC Chemical International AG	2 g/L
6	Awal 72 WP	Zineb (68%) + Hexaconazole (4%)	Indofil Bangladesh Industries Private Limited	2 g/L
7	Nativo 75 WG	Tebuconazole (50%) + Trifloxystrobin (25%)	Bayer CropScience Limited	0.6 g/L
8	Control	-	-	-

Disease Assessments

The disease severity of leaf rust was scored three times from the middle rows, ranging from 6 days of application of the second fungicide at 7 days intervals as percent diseased leaf area (% DLA) on 10 flag leaves of 10 main tillers selected randomly in each plot. The severity of leaf rust was scored according to the modified Cobb scale (Stubbs *et al.,* 1986). From the severity data, the area under the disease progress curve (AUDPC) for each treatment was calculated as described by Campbell and Madden (1990) as follows:

$$AUDPC = \sum_{i=1}^{n} [(Y_{i=1} + Y_i) \times 0.5][T_{i+1} + T_i]$$

where AUDPC is the area under the disease progress curve, Y_i is the disease severity at the i^{th} observation, T_i is the time (days) of the i^{th} observation, and n is the total number of observations.

Grain yield data were collected at the plot base, and the percent yield loss due to the disease was calculated by the following equation (Peterson *et al.*, 1948).

$$\text{Yield reduction (\%)} = [(1 – yd) / yh] \times 100$$

where yd is the yield of untreated plants, and yh is the yield of the treated plant. At harvest, thousand-grain weights were also calculated.

The efficacy of fungicide was determined according to the following equation (Rewal and Jhooty, 1985).

$$\text{Fungicide efficacy (\%)} = [(C – T) / T] \times 100$$

where C is the infection (%) in the control and T is the infection (%) in the treatment.

Economic Assessment of All Disease Control Treatments

The gross return for each treatment for harvested product t ha^{-1} (grain and straw) was calculated for each treatment in farmgate price. The benefit-cost ratio (BCR) was calculated from the gross return divided by the total cost. Annual cropping system economic performance was calculated from the sum of the returns and the sum of the costs for each crop in each one-year cycle.

Data Analysis

The recorded data were analyzed statistically using R software for analysis of variance (ANOVA). Fisher's least significant difference (LSD) test at P < 0.05 (Gomez and Gomez, 1984; Steel and Torrie, 1986) was used to compare pairs of treatment means.

RESULTS AND DISCUSSION

Percent Diseased Leaf Area

The experiment among the seven-fungicide tested gave the same trend in three consecutive years on the percent diseased leaf area against leaf rust (Table 2). The result of the current study related to managing the severity of leaf rust in wheat through fungicides was also confirmed by Abeb (2021) and Barro *et al*. (2017). The highest %DLA was obtained from the treatment control which was 80% in both seasons (2017–2018 and 2018–2019), and in the 2019–2020 cropping season it was 85.30%, followed by the sprayed fungicide Goldman 80 WP (35% in 2017–2018 and 2018–2019, and 45.0% in 2019–2020) and Rovral 50 WP (25% in 2017–2018, 21% in 2018–2019, and 20% in 2019–2020). Statistically, there was a significant difference (P < 0.05). The low %DLA was obtained from sprayed fungicide Tilt 250 EC, Folicur 250 EC, Positive 300 SE, Awal 72 WP, and Nativo 75 WG with statistical similarity (Table 2). In the case of the mean %DLA, the lowest %DLA was found with the plot sprayed with Tilt 250 EC, Folicur 250 EC, Positive 300 SE, Awal 72 WP, and Nativo 75 WG (2%) followed by the plot sprayed with Rovral 50 WP (22%) and Goldman 80 WP (38%). The highest %DLA was found with the unsprayed control plot. Bhatta *et al*. (2018) investigated the effects of foliar fungicide (Prosaro 421 SC prothioconazole + tebuconazole) and reported that fungicide significantly decreased disease severity.

Table 2 Effect of different fungicides on diseased leaf area and disease control in wheat

Fungicides	Diseased leaf area (%)				Disease control (%)
	2017–2018	2018–2019	2019–2020	Mean	
Tilt 250 EC	2.00 ± 0.20^{d}	2.00 ± 0.20^{d}	1.80 ± 0.10^{de}	2.00 ± 0.12	98
Folicur 250 EC	1.70 ± 0.20^{d}	1.50 ± 0.20^{d}	1.50 ± 0.10^{e}	2.00 ± 0.12	98
Positive 300 SE	2.00 ± 0.30^{d}	2.40 ± 0.20^{d}	2.00 ± 0.10^{de}	2.00 ± 0.23	97
Goldman 80 WP	35.00 ± 2.00^{b}	35.00 ± 2.00^{b}	45.00 ± 1.00^{b}	38.00 ± 5.77	53
Rovral 50 WP	25.00 ± 2.00^{c}	21.00 ± 1.00^{c}	20.00 ± 1.00^{c}	22.00 ± 2.89	73
Awal 72 WP	2.13 ± 0.21^{d}	2.40 ± 0.20^{d}	2.40 ± 0.20^{d}	2.00 ± 0.12	97
Nativo 75 WG	2.00 ± 0.20^{d}	1.90 ± 0.20^{d}	1.50 ± 0.10^{e}	2.00 ± 0.26	98
Control	80.00 ± 2.00^{a}	80.00 ± 1.00^{a}	85.30 ± 0.20^{a}	82.00 ± 3.05	0
LSD (0.05)	1.61	1.25	0.70	-	-
CV (%)	4.92	3.91	2.01	-	-
P-value	0.00001	0.0001	0.00001	-	-

Note: Values in the same column followed by different superscript letters significantly differ in LSD (least significant difference) test (P < 0.05). CV = coefficient of variation.

Disease Control

The result showed that there was a significant ($P < 0.05$) difference between fungicides sprayed and unsprayed plots on reducing disease (Figure 3). The highest 98% of disease control was obtained from fungicides such as Tilt 250 EC, Folicur 250 EC, and Nativo 75 WG, followed by 97% of disease control by spraying fungicide Positive 300 SE and Awal 72 WP, though these were not significantly differed. Fungicide Rovral 50 WP controlled rust by 73% and the lowest was found by sprayed fungicide Goldman 80 WP (53%; Table 2). Chen and Wood (2003) made an experiment and found azoxystrobin, propiconazole + trifloxystrobin, strobilurin, and azoxystrobin + propiconazole as effective control measures against the disease of barley and wheat rust. Iqbal *et al*. (2015) also reported fungicides triazoles were most effective for the control of wheat rust.

Figure 3 Effect of fungicides: (A) unsprayed plot and (B) sprayed plot

The Area under Diseased Progressed Curve (AUDPC)

Regarding the AUDPC tested seven fungicides also followed a similar trend during three years of experimentation (Figure 4). The highest AUDPC (1,421 in 2017–2018, 1,415 in 2018–2019, and 1,396 in 2019–2020) was in the control plot, while the lowest was in 2017–2018 and 2018–2019 cropping seasons with the treatment Folicur 250 EC (31 and 27, respectively) but in 2019–2020 was obtained from Nativo 75 WG (30). The second least AUDPC was obtained from Nativo 75 WG sprayed plot (33) in 2017–2018, Tilt 250 EC (32) in 2018–2019, and Folicur 250 EC (31) in 2019–2020; followed by Nativo 75 WG (33), in 2017–2018 and 2018–2019 but 2019–2020 it was from Tilt 250 EC sprayed plot (32). Positive 300 SE and Awal 72 WP treated plots also had the least AUDPC, which ranged between 39 and 43 from the 2017–2020 experiment years. Among the sprayed fungicide Goldman 80 WP treated plot had the highest AUDPC (656, 654, and 650 in 2017–2018, 2018–2019, and 2019–2020, respectively) followed by Rovral 50WP treated plot (372, 370, and 370 in 2017–2018, 2018–2019, and 2019–2020 respectively). Kalappanavar and Patil (1998) found propiconazole, along with tridimefon and hexaconazole, most effective for managing wheat leaf rust. Mesta *et al.* (2003) found propiconazole (0.1%) effective against some other diseases, such as the *Alternaria* blight of sunflowers. According to Galano *et al.* (2008), propiconazole application is more pronounced in most susceptible varieties to control net blotch (*Pyrenophorateres*) on malt barley. During the three consecutive cropping seasons of the experiment propiconazole, tebuconazole, propiconazole along with difenoconazole, hexaconazole, and tebuconazole along with trifloxystrobin were found very effective in reducing AUDPC.

Thousand-Grain Weight (g)

In the three years of experimentation (Table 3), a similar trend was also followed by using seven fungicides on thousand-grain weight. The maximum mean thousand-grain weight of three consecutive years was obtained from the treated plot with Folicur 250 EC (31.93 g) followed by Tilt 250 EC (31.62 g), Positive 300 SE (31.44 g), and Nativo 75 WG (30.79 g).

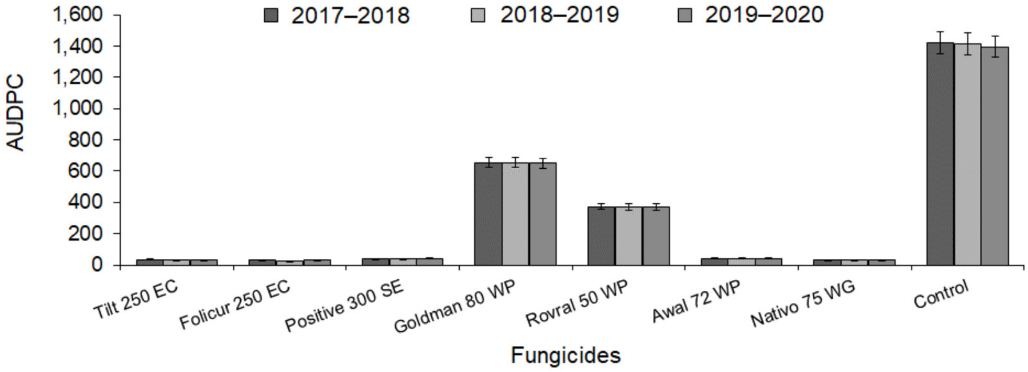

Figure 4 Effect of fungicide on the area under diseased progress curve (AUDPC) during 2017–2018, 2018–2019, and 2019–2020

Table 3 Effect of different fungicides on thousand-grain yield of wheat

Fungicides	Thousand-grain weight (g)				TGW increase (%)
	2017–2018	2018–2019	2019–2020	Mean	
Tilt 250 EC	30.80 ± 0.87^{bc}	31.27 ± 0.25^{a}	32.56 ± 0.20^{b}	31.62 ± 0.91	44
Folicur 250 EC	32.19 ± 1.25^{b}	30.11 ± 0.50^{b}	33.56 ± 0.20^{a}	31.93 ± 1.73	45
Positive 300 SE	34.44 ± 0.70^{a}	29.82 ± 0.35^{bc}	29.81 ± 0.23^{d}	31.44 ± 2.67	43
Goldman 80 WP	27.33 ± 0.58^{d}	25.01 ± 0.18^{e}	28.47 ± 0.03^{e}	26.83 ± 1.76	22
Rovral 50 WP	27.66 ± 0.59^{d}	27.00 ± 0.50^{d}	28.25 ± 0.08^{e}	27.55 ± 0.63	25
Awal 72 WP	28.22 ± 0.69^{d}	29.33 ± 0.06^{c}	27.75 ± 0.17^{f}	28.40 ± 0.81	29
Nativo 75 WG	30.31 ± 0.60^{c}	31.62 ± 0.21^{a}	30.59 ± 0.06^{c}	30.79 ± 0.69	40
Control	22.76 ± 1.40^{e}	22.84 ± 0.27^{f}	20.17 ± 0.29^{g}	21.97 ± 1.51	0
LSD (0.05)	1.653	0.587	0.323	-	-
CV (%)	3.231	1.182	0.638	-	-
P-value	0.00001	0.00001	0.00001	-	-

Note: Values in the same column followed by different superscript letters significantly differ in LSD (least significant difference) test (P < 0.05). TGW = thousand-grain weight, CV (%) = coefficient of variation.

Among the fungicide sprayed plot, a minimum of thousand-grain weight was found from the plot treated with Goldman 80 WP (26.83 g) followed by Rovral 50 WP (27.55 g), and Awal 72 WP (28.40 g). The lowest thousand-grain weight was obtained from the control (21.97 g). The maximum thousand-grain weight increase was found with Folicur 250 EC (45%), and the minimum was from Goldman 80 WP sprayed plot (22%). All the sprayed fungicide increases thousand-grain weight over control ranging from 22 to 45%. Alemu and Mideksa (2016) reported a non-significant difference among different fungicides on the thousand-grain weight of wheat infected by rust diseases, which differs from the present research work. Tesfaye *et al*. (2018) obtained higher thousand-grain weight using Rex®Duo and Tilt 250 EC fungicide to control strip rust of wheat.

Grain Yield

All fungicide increases grain yield per plot over control (Table 4). Three years of experimentation regarding grain yield per plot (3 m^2) showed a similar trend. In 2017–2018, the highest maximum grain yield was obtained from Folicur 250 EC (642 g), followed by Nativo 75 WG (640 g), while the highest maximum grain yield was in 2018–2019 from Awal 72 WP (752 g), and in 2019–2020 it was from Tilt 250 EC (677.66 g) followed by Folicur 250 EC (708 and 674 g, respectively) in both experiment season. The lowest minimum grain yield was obtained from Goldman 80 WP in 2017–2018 and 2019–2020 (403 and 444 g, respectively), but in 2018–2019 it was from Rovral 50 WP (493.66 g).

When average grain yield was considered, the maximum was obtained from Folicur 250 EC (675 g) with a yield increase of 170%, followed by Tilt 250 EC (674 g), Nativo 75 WG (674 g), and Awal 72 WP (629 g) with a yield increase 169, 169, and 151% respectively over unsprayed plot. Among the sprayed plot, the lowest minimum grain yield per plot was obtained from Goldman 80 WP treated plot (479 g) with a 92% yield increase, followed by Rovral 50WP (497 g) with a 99% yield increase and Positive 300 SE (598 g) with 139% yield increase. In 2011, 25% of the Argentine wheat production area was under fungicide application; both Uruguay and Paraguay had an area under fungicide application of 0.5 million hectares. In Brazil, 2.3 million hectares of wheat area were under fungicide application on susceptible varieties, and the increased yield is about 13% (German *et al*., 2011). In the present experiment, all the fungicides increased yield over control. According to Nelson and Meinhardt (2011), fungicides have some effects in improving yield in wheat and corn. The present research points out that two applications of foliar fungicides at heading and 12 days after 1st spray effectively reduce the severity of leaf rust disease with higher grain yield.

Efficacy of Fungicide

The average AUDPC of three consecutive years of experimentation was found to be highest from the control, which was 1,411 with 0% fungicide efficacy (Figure 5). Among the fungicide-treated plot, the lowest AUDPC was obtained from the Folicur 250 EC treated plot (30) followed by Nativo 75 WG (32), Tilt 250 EC (33), Positive 300 SE (41), and Awal 72 WP (42) with 98% fungicidal efficacy (Nativo 75 WG and Tilt 250 EC) and 97% (Positive 300 SE and Awal 72 WP). The highest AUDPC was found with the fungicide Goldman 80 WP treated plot (653), followed by Rovral 50WP (371) treated plot with 54% and 74% fungicidal efficacy, respectively.

Table 4 Effect of different fungicides on the grain yield of wheat

Fungicides	Grain yield/3m² (g)				Yield increase (%)
	2017–2018	2018–2019	2019–2020	Mean	
Tilt 250 EC	638.00 ± 2.52[c]	705.00 ± 1.00[c]	677.66 ± 1.53[a]	674 ± 33.68	169
Folicur 250 EC	642.00 ± 1.00[a]	708.00 ± 1.00[b]	674.00 ± 1.00[c]	675 ± 33.00	170
Positive 300 SE	586.00 ± 1.00[d]	622.00 ± 1.00[d]	587.00 ± 1.00[e]	598 ± 20.50	139
Goldman 80 WP	403.00 ± 1.00[g]	590.00 ± 1.00[e]	444.00 ± 1.00[g]	479 ± 98.29	92
Rovral 50 WP	510.00 ± 1.00[f]	493.66 ± 1.53[f]	486.00 ± 1.00[f]	497 ± 12.25	99
Awal 72 WP	536.00 ± 1.00[e]	752.00 ± 1.00[a]	598.00 ± 1.00[d]	629 ± 111.21	151
Nativo 75 WG	640.00 ± 1.00[b]	705.00 ± 1.00[c]	676.00 ± 1.00[b]	674 ± 32.56	169
Control	150.00 ± 2.00[h]	290.00 ± 1.00[g]	310.00 ± 1.00[h]	250 ± 87.17	0
LSD (0.05)	1.905	1.429	1.429	-	-
CV (%)	0.21	0.13	0.15	-	-
P-value	0.00001	0.00001	0.00001	-	-

Note: Values in the same column followed by different superscript letters significantly differ in LSD (least significant difference) test ($P \leq 0.05$). CV = coefficient of variation.

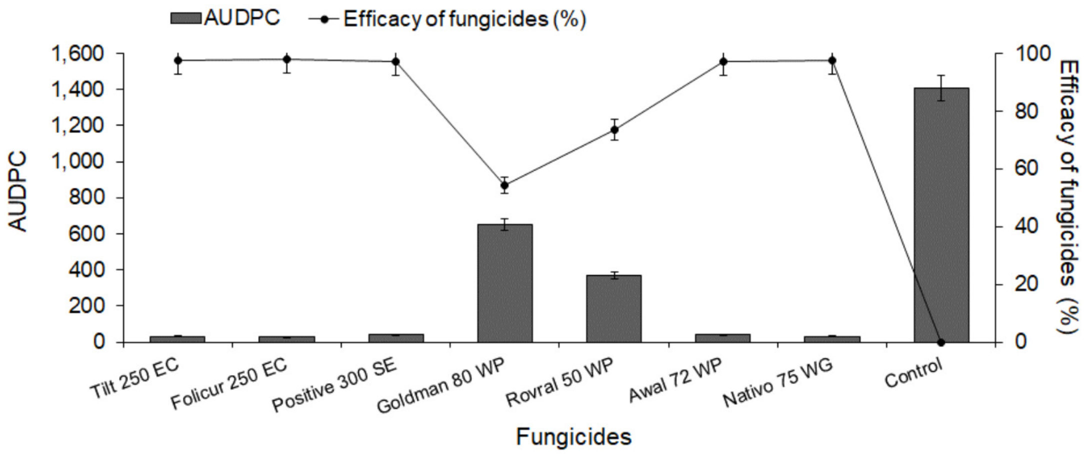

Figure 5 Effect of fungicide on the average area under diseased progress curve (AUDPC) of the three consecutive years 2017–2018, 2018–2019, 2019–2020 and fungicide efficacy

For the management of leaf rust of wheat, Kalappanavar and Patil (1998) found that the fungicide propiconazole, in combination with tridimefon and hexaconazole was found the most effective. Mesta *et al.* (2003) found propiconazole (0.1%) effective against some other diseases, such as the *Alternaria* blight of sunflowers. According to Galano *et al.* (2008), propiconazole application is more pronounced in most susceptible varieties to control net blotch (*Pyrenophorateres*) on malt barley. During the experiment's three consecutive seasons of the experiment propiconazole, tebuconazole, propiconazole, difenoconazole, hexaconazole, and tebuconazole, along with trifloxystrobin found very effective in reducing AUDPC. Ahmad *et al*. (2010) observed that as the area under the disease of leaf rust increased, the yield losses also increased and the present study follows a similar trend.

Economic Assessment of All Treatments

From the economic point of view, the maximum gross return (33,733 BDT) was recorded for the fungicide Folicur 250 EC, followed by Tilt 250 EC (33,717 BDT), Nativo 75 WG (33,683 BDT) and Awal 72 WP (31,433 BDT). In comparison, the minimum gross return (23,950 BDT) was recorded for the fungicide Goldman 80 WP (Table 5). Considering the benefit-cost ratio (BCR), fungicide Tilt 250 EC (8.03) showed the maximum BCR followed by Positive 300 SE and Goldman 80 WP (7.48), while fungicide Rovral 50 WP showed the minimum BCR. However, the disease control (%) and yield increase (%) of Tilt 250 EC and Nativo 75 WG were the same, but the BCR of Nativo 75 WG was lower due to the higher price. The calculation of BCR estimates from the present research reveals that fungicides application to control wheat leaf rust disease was found profitable, although there was some cost.

Table 5 The economic assessment of all fungicides (three years of mean data were used for the assessment

Treatment	Yield (kg/ha)	Total cost (BDT)	Gross return/ha (BDT)	BCR
Tilt 250 EC	2,248	4,200	33,717	8.03
Folicur 250 EC	2,249	4,700	33,733	7.18
Positive 300 SE	1,994	4,000	29,917	7.48
Goldman 80 WP	1,597	3,200	23,950	7.48
Rovral 50 WP	1,657	6,500	24,850	3.82
Awal 72 WP	2,096	5,000	31,433	6.29
Nativo 75 WG	2,246	6,680	33,683	5.04
Control	833		12,500	

Note: 84 BDT = 1 US$. BCR = benefit-cost ratio.

CONCLUSION

The experiment of three consecutive seasons showed that fungicides could successfully manage wheat leaf rust. All the fungicides were found effective compared to the control. Among these fungicides, propiconazole (Tilt 250 EC), tebuconazole (Folicur 250 EC), and a combination of propiconazole + difenoconazole (Positive 300 SE) were found effective for controlling leaf rust in wheat. While the combination of tebuconazole + trifloxystrobin (Nativo 75 WG) was the most effective for controlling wheat leaf rust and increasing grain yield. From an economic point of view, the fungicide Folicur 250 EC showed the maximum gross return, followed by Tilt 250 EC, Nativo 75 WG, and Awal 72 WP, while the gross return was the least in Goldman 80 WP. Considering the BCR, Tilt 250 EC showed the maximum BCR, and Rovral 50 WP showed the minimum BCR. Therefore, Tilt 250 EC could be recommended for controlling leaf rust in susceptible wheat cultivars to get a desirable yield.

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