Vol. 18(5), pp. 41-47, August 2024
DOI: 10.5897/AJPS2024.2349
Article Number: 1D1E7AB72420
ISSN 1996-0824

http://www.academicjournals.org/AJPS

ACADEMIC JOURNALS
expand your knowledge

African Journal of Plant Science

Full Length Research Paper

Evaluation of different fungicides against wheat rusts in West and Southwest Shewa zones, Ethiopia

Tesfaye Abdissa*, Kitessa Gutu, Tekalign Zeleke and Berhanu Bekele

Ethiopian Institute of Agricultural Research (EIAR), Ambo Agricultural Research Center (AmARC), P. O. Box 37, Ambo, Ethiopia.

Received 22 January, 2024; Accepted 21 June, 2024.

Wheat stem and yellow rusts which are respectively, caused by *Puccinia graminis* f.sp *tritici* and *Puccinia striiformis* f.sp. *tritici*, are among the most devastating diseases of wheat in Ethiopia. The use of fungicides is among the most important wheat rusts management strategy in wheat production and rust hot spot areas. The field experiment was conducted to evaluate the efficacy of some selected fungicides (Azoxystrobin + Cyproconazole, Pyraclostrobin + epoxiconazole, Fenpicoxamid + Pyraclostrobin, Fenpicoxamid + Hexaconazole, and Propiconazole) against wheat rusts in six major wheat growing locations and rust hot-spot areas of the West and Southwest Shewa zones of Ethiopia during the 2020/21 main growing season. The two most susceptible bread wheat varieties, Hidase and Kubsa, were used as test crop respectively, for stem and yellow rusts. The result revealed that significantly ($P \leq 0.05$) the lowest yellow and stem rusts incidences were recorded from plots treated with propiconazole on Kubsa (3.8 and 1.3%) and Hidase (0 and 1.7%) varieties, respectively. Similarly, significantly ($P \leq 0.05$) the lowest yellow (3.8 and 0.0%) and stem (1.3 and 1.7) rusts severity were also noted from plots treated with propiconazole, respectively, on Kubsa and Hidase varieties. Significantly, the highest yields of 5.7 t ha^{-1} from Hidase and 4.6 t ha^{-1} from Kubsa varieties were also observed from plots sprayed with propiconazole as compared to other treatments. Three fungicides used in this study namely propiconazole, fenpicoxamid + hexaconazole, and fenpicoxamid + pyraclostrobin, efficiently controlled the two rusts. From this study, it is concluded that twice spraying of propiconazole or either of these fungicides at a seven-day interval is recommended under high disease pressure conditions for both diseases.

Key words: Bread wheat, incidence, severity, stem rust, yellow rust.

INTRODUCTION

Wheat (*Triticum* species) is one of the most extensively produced cereal crops globally and is used as a staple food crop for more than 40% of the global population (Giraldo et al., 2019; FAOSTAT, 2022). Globally, the crop is grown on more than 220 million hectares of land, yielding about 760 million tonnes of grain annually (FAOSTAT, 2022). It is the world's second-most important industrial and food crop after rice and is also

*Corresponding author. E-mail: tesfayeabdisa08@gmail.com.

traded globally (Falola et al., 2017). Wheat provides around 20% of daily calories and proteins for over 4.5 billion people (Shiferaw et al., 2013; FAOSTAT, 2022). The world's major wheat producers are China, India, Russia, and the United States; however, Ethiopia is the largest wheat producer among Sub-Saharan African countries (USDA, 2019; Hodson et al., 2020; FAOSTAT, 2022). Wheat is estimated to be produced annually on around 1.7 million hectares (M ha) of land in Ethiopia, and it is followed by South Africa grown on 0.5 M ha (Tadesse et al., 2018).

In Ethiopia, wheat is the third-most important cereal crop in terms of area coverage, accounting for around 18.4% of total cereal crop production (CSA, 2022). Both bread (*Triticum aestivum*) and durum (*Triticum turgidum* L. var. *durum*) wheat types are widely cultivated in the country, although other wheat species are cultivated in lesser amounts (Chilot et al., 2013; Hodson et al*.,* 2020). It is a widely adopted crop in various altitude ranges in Ethiopia (Tadesse et al., 2018). Although wheat is previously produced in the Central, Southeastern, and Northwestern highlands and midlands of Ethiopia using rain-fed conditions, currently the government is expanding irrigated wheat production in an unprecedented manner to accommodate local consumption and refuses to import the crop from abroad (Tesemma and Belay, 1991; Demeke et al*.,* 2013; Hodson et al., 2020). Nowadays, it has expanded to all parts of the country, including lowland and moisture stress-prone areas such as Somalia, Gambella, and Afar national regional states, using rainfall and/or irrigation (CSA, 2022). The West and Southwest Shewa zones are among the most potential areas for wheat production in the country, and farmers in these areas are highly engaged in the production of the crop. The crop is produced for food and sometimes as an income-generating commodity for growers. Different cultural food types such as bread, porridge, *kolo, kita, areke, tela*, etc. are prepared from the crop (Tadesse et al., 2020) and its straw is also used for roof hatching and as animal feed (Anteneh and Asrat, 2020).

Despite these facts, the crop national average yield is approximately 3.1 t ha^{-1} (CSA, 2022), which is significantly lower than the global average yield (5.2 t ha^{-1}) (FAO*,* 2018; Zegeye et al., 2020). Various abiotic, biotic, and socioeconomic factors contribute to the crop's low productivity (Shiferaw et al., 2013; Abro et al., 2017; Tadesse et al., 2018). Wheat rusts (*Puccinia* species) are among the greatest wheat production constraints, causing significant yield losses in major wheat-producing areas of the country (Zegeye et al., 2001; Ayele et al., 2008; Degefie et al., 2020; Hodson et al., 2020). Recently, fusarium head blight (*Fusarium* species) has also become an increasingly important production limiting factor (Abdissa and Bekele, 2020; Bayoush, 2021), although wheat rusts remain the most economic fungal diseases and have the potential to destroy the entire field in a few weeks (Badebo et al., 2008; Teklay et al., 2013).

Particularly, stem (*Puccinia graminis* f.sp. *tritici*) and yellow (*Puccinia striiformis* f.sp. *tritici*) rusts are the most destructive diseases, respectively, in mid-altitude and highland areas of the country, and they cause significant yield losses unless they controlled at earlier stages (Badebo et al., 2008; Yami et al., 2013; Abebele et al., 2020). According to Eshete (2018) as well as Badebo and Hunde (2016), total grain yield loss due to stem rust was recorded, respectively, on Enkoy and Digelu wheat varieties in 1994 and 2014 in Ethiopia's low and midland areas. Similarly, yellow rust can also result in significant yield loss, reaching up to 100% in midland and highland areas of Ethiopia when susceptible varieties are used for production (Teklay et al., 2013; Wubishet et al., 2015).

The use of fungicides is among the most important wheat rust management strategies in wheat production and hot spots. These rusts are common problems in the West and Southwest Shewa zones, and farmers apply the fungicides they get without understanding the specific chemical needed for the particular disease. This is due to the lack of recommended alternative fungicides for a specific disease in the area. Although the majority of wheat growers in Ethiopia, particularly farmers, understand the benefits of fungicides for controlling rusts, only a few farmers have applied them due to their high cost and low accessibility (Nigus et al., 2022). When wheat cultivars characterized by having high grain yield potential and a susceptible reaction to rusts are preferred by the growers for production, supplementary fungicide application is crucial to avoid crop losses.

In Ethiopia, the majority of the wheat varieties currently under production are susceptible to moderate resistance reactions to rusts (Wan et al., 2017), and the earlier recommended fungicides are not providing effective control to rusts. This could be due to the formation of new rust races every time, a shortage of alternative fungicides, or improper use of fungicides with the recommended rate, time, and high disease intensity level during the application. Therefore, the objective of this study was to evaluate effective fungicides against wheat stem and yellow rusts in the West and Southwest Shewa zones of Ethiopia.

MATERIALS AND METHODS

Description of the study areas

The field experiments were conducted at six locations in the West Shewa and Southwest Shewa zones of Ethiopia. The locations were purposely selected based on their wheat production status as well as hot spot areas for stem and yellow rusts during the 2020/21 main growing season. West Shewa zone is located between 8°17'–8°57' N latitude and 37°08'–38°07' E longitude, with an elevation of 1050 to 3500 m above sea level (m.a.s.l); while Southwest Shewa zone is located at 8º16'-9º56´N latitude and 37º05´–38º46´E longitude and an altitude ranging from 1600 to 3576 m.a.s.l. The mean maximum and minimum temperatures of the study areas were 25.4 and 11.7°C for West Shewa and 25.4 and 11.7°C for Southwest Shewa zones, respectively. West Shewa receives annual rainfall ranging from 600 to 1900 mm, while Southwest

Table 1. Description of fungicides evaluated against yellow and stem rusts of wheat in West and Southwest Shewa zones.

Trade name	Active ingredient	Formulation	Mode of action	Rate Lha^{-1}
Tilt 250	Propiconazole	EC	Systemic	0.5
Amistar Xtra 280	Azoxystrobin + Cyproconazole	SC	Systemic	0.75
Liveshow 173	Pyraclostrobin + epoxiconazole	SE	Systemic	0.6
Quake™ 112.5	Fenpicoxamid + Pyraclostrobin	EC	Systemic	1.0
Union one 400	Fenpicoxamid + Hexaconazole	SE	Systemic	0.4

EC: Emulsifiable concentrates; SC: aqueous suspension concentrates; SE: aqueous suspo-emulsions.

Table 2. Description of wheat varieties used for evaluation of chemical fungicides against stem and yellow rusts.

Variety name	Pedigree	Year of release	Releasing center	Altitude (m)	Suitable agroecology	Maturity dates	Yield potential (tha^{-1})
Hidase	ETBW5795	2012	KARC	2200-2600	Mid to highland	121	4.5 to 7.0
Kubsa	HARC1685	1995	HARC	2000-2600	Low to midland	105	3.0 to 5.0

KARC=Kulumsa Agricultural Research Center; HARC=Holeta Agricultural Research Center.
Source: Ministry of Agriculture (MoA, 2012) and Tadesse et al. (2022).

Shewa receives from 900 to 1900 mm. The average minimum and maximum air temperatures in the West Shewa zone are 10 and 35°C, respectively (Source: West and Southwest Shewa zones Agricultural offices).

Treatments and experimental design

Five selected fungicides (Azoxystrobin + Cyproconazole, Pyraclostrobin + epoxiconazole, Fenpicoxamid + Pyraclostrobin, Fenpicoxamid + Hexaconazole, and Propiconazole) with different active ingredients (Table 1) were used for the study, along with two most susceptible bread wheat varieties for stem rust (Hidase) and yellow rust (Kubsa) (Table 2). The selected wheat variety seeds were obtained from the Kulumsa Agricultural Research Center (KARC) of the Ethiopia Institute of Agricultural Research (EIAR). The seeds of the crop were sown in mid-June, at a rate of 125 kg ha^{-1} in all locations. Full NPS at a rate of 100 kg ha^{-1} and 1/3 of nitrogen at 150 kg ha^{-1} were mixed up and used during the sowing date. However, the unused, remaining 2/3 recommended N fertilizer was top-dressed during the mid-tillering growth stage. The treatments were arranged using a Randomized Complete Block Design (RCBD) with six replications, and the locations were taken as blocks. The size of each experimental plot was 4 x 5m = 20 m^2, consisting of 20 total and 18 harvestable rows. The fungicides were obtained from local suppliers and chemical companies prior to the planting date. Fungicide application was commenced manually using a knapsack sprayer when the disease severity reached an economic threshold level (at 5% severity level for both rusts) during and after the flowering growth stage. The first fungicide spray was made at 35 to 40 days after planting for yellow rust and 50 to 60 days for stem rust. Each fungicide was applied twice at a seven-day interval as per the supplier's recommendation rate. The plots were guarded with polyethylene sheets in order to avoid the effect of chemical drift to neighboring plots.

Data collection and analysis

A modified Cobb scale was used to assess disease severity and incidence from 20 pre-tagged plants for each disease (Peterson et al., 1948). Yield and yield-related parameters such as plant height (cm), spike length (cm), plant above ground biomass (t ha^{-1}), thousand kernel weights (g), and yield (t ha^{-1}) data were noted from five harvestable most middle rows per plot (1 × 5 m = 5 m^2). The results of plant biomass and grain yield in this area were converted into tonnes per hectare. All the collected disease and agronomic data were subjected to analysis of variance (ANOVA) using a Statistical Analysis System (SAS), version 9.4 software (SAS Institute Inc.., Cary, USA). The ANOVA was computed based on the PROC GLM procedure, and the mean separations for significantly distinct parameters were made using Least Significant Differences (LSD) values at the α = 5% level of significance.

RESULTS AND DISCUSSION

The result indicates that during 2020/21 cropping season, the rust diseases pressure was very high in all the locations, enabled to determine the potential efficacy of the tested fungicides. The yellow rust appeared earlier during booting to the beginning of anthesis growth stage (GS 35 to 45) on Kubsa variety, while stem rust occurred later at early anthesis (after GS 60 to 69) growth stages (Zadoks et al., 1974) (at early to mid-September) in all the locations. However, at Wanchi, Liban Jawi, and Ambo experimental locations, both yellow and stem rusts occurred simultaneously, and the disease data was noted separately to identify the effect of the fungicides against both rusts.

Given the terminal disease intensity record results presented in Table 3, all the tested fungicides significantly reduced the yellow rust intensity on variety Kubsa as compared with untreated (control) plots. However, their efficacy on both yellow and stem rusts incidence and severity were varied. Propiconazole, Fenpicoxamid + Hexaconazole, Azoxystrobin + Cyproconazole, Pyraclostrobin + epoxiconazole, and Fenpicoxamid +

Table 3. Efficacy of selected fungicides on yellow rust and their effect on yield and yield components of bread wheat in West and southwest Shewa zones, 2021/2022 main season.

Treatments	YRI	YRS	SRI	SRS	PH	SL	BM	TKW	GY
Kubsa + (Azoxystrobin + Cyproconazole)	15.0^{bc}	15.0^{bc}	17.5^{b}	18.8^{b}	82.7^{a}	7.0^{a}	10.5^{b}	45.4^{a}	4.1^{a}
Kubsa + (Pyraclostrobin + epoxiconazole)	17.5^{bc}	6.3^{d}	17.5^{b}	15.0^{b}	83.0^{a}	7.1^{a}	10.7^{b}	47.9^{a}	4.2^{a}
Kubsa + (Fenpicoxamid + Pyraclostrobin)	25.0^{b}	21.2^{b}	13.8^{b}	11.3^{b}	86.4^{a}	7.0^{a}	10.7^{b}	47.8^{a}	4.5^{a}
Kubsa + (Fenpicoxamid + Hexaconazole)	7.5^{cd}	8.8^{cd}	1.3^{c}	1.3^{c}	86.0^{a}	7.1^{a}	11.3^{ab}	46.4^{a}	4.2^{a}
Kubsa + Propiconazole	3.8^{d}	3.8^{d}	1.3^{c}	1.3^{c}	87.3^{a}	7.6^{a}	12.1^{a}	46.6^{a}	4.6^{a}
Kubsa + Water (Control)	78.7^{a}	71.3^{a}	85.0^{a}	72.5^{a}	82.1^{a}	6.8^{a}	8.6^{c}	36.6^{b}	3.0^{b}
CV (%)	27.4	21.2	25.1	33.1	4.6	8.0	7.7	8.5	11.0
LSD ($P \leq 0.5$)	10.1	6.7	8.6	9.9	5.9	0.9	1.2	5.8	0.7

BM = Biomass, CV = coefficient of variation, GY = grain yield per hectare (tones/ha), LSD = least significant difference, PH = plant height (cm), SL= spike length (cm), SRI = stem rust incidence, SRS = stem rust severity, TKW = thousand kernel weight (g), YRaI = yellow rust incidence, YRS = yellow rust severity.

Table 4. Efficacy of selected fungicides on stem rust and their effect on yield and yield components of bread wheat in West and Southwest Shewa Zones, 2021/2022 main season.

Treatments	YRI	YRS	SRI	SRS	PH	SL	BM	TKW	GY
Hidase + (Azoxystrobin + Cyproconazole)	10.0^{b}	10.0^{b}	10.0^{b}	6.7^{bc}	90.4^{ab}	7.7^{ab}	9.9^{ab}	57.3^{a}	5.5^{a}
Hidase + (Pyraclostrobin + epoxiconazole)	5.0^{c}	8.3^{b}	6.7^{bc}	11.7^{b}	89.7^{ab}	$8{,}0^{ab}$	10.0^{ab}	54.0^{a}	5.1^{ab}
Hidase + (Fenpicoxamid + Pyraclostrobin)	1.7^{d}	1.7^{cd}	8.3^{bc}	6.7^{bc}	90.3^{ab}	8.1^{ab}	10.3^{ab}	54.0^{a}	4.4^{bc}
Hidase + (Fenpicoxamid + Hexaconazole)	5.0^{c}	6.7^{bc}	1.7^{c}	1.7^{c}	92.4^{a}	8.2^{a}	9.7^{ab}	55.3^{a}	5.4^{a}
Hidase + Propiconazole	0.0^{d}	0.0^{d}	1.7^{c}	1.7^{c}	91.7^{a}	8.3^{a}	11.4^{a}	57.2^{a}	5.7^{a}
Hidase + Water (Control)	23.3^{a}	20.0^{a}	83.3^{a}	78.3^{a}	85.1^{b}	7.5^{b}	8.2^{b}	43.0^{b}	3.6^{c}
CV (%)	21.1	36.5	20.6	15.9	4.0	4.4	13.0	6.1	10.9
LSD ($P \leq 0.5$)	2.8	5.1	6.9	5.1	6.6	0.6	2.4	6.0	1.0

Pyraclostrobin fungicides reduced the yellow rust incidence by 95.2, 90.5, 80.9, 77.8, and 68.2%, respectively. They also reduced yellow rust severity by 94.7, 87.7, 78.9, 91.2, and 70.3%, respectively. Propiconazole and Fenpicoxamid + Hexaconazole fungicides significantly reduced the stem rust incidence and severity as compared with other fungicides and control plots on variety Kubsa (Table 3).

Almost similar results were observed when the efficacy of these fungicides was evaluated for stem rust on the Hidase variety (Table 4). Significantly, the lowest stem rust incidence was obtained from plots sprayed with Propiconazole, Fenpicoxamid + Hexaconazole, Pyraclostrobin + epoxiconazole, Fenpicoxamid + Pyraclostrobin, and Azoxystrobin + Cyproconazole on wheat variety Hidase with 1.7, 1.7, 6.7, 8.3, and 10.0%, respectively, stem rust incidences. Propiconazole, and Fenpicoxamid + Pyraclostrobin also significantly reduced the yellow rust incidence and severity on the Hidase variety by 21.7 and 21.0%, respectively. In general, the minimum disease intensity was obtained from plots treated with propiconazole, followed by Fenpicoxamid + Hexaconazole, Fenpicoxamid + Pyraclostrobin, and Pyraclostrobin + epoxiconazole in all experimental areas. Based on this result, it is recommended that either of these chemical fungicides be alternatively used to control wheat rust. In line with this finding, Azmeraw and Admassu (2022) reported that propiconazole fungicide significantly reduced stem rust severity, followed by potassium carbonate in Ethiopia.

This study found that fungicides with different active components had varying levels of efficiency and yield responses against both rusts (Tables 3 and 4). Even though their efficacy levels were varied, almost all the tested fungicides were able to control these rusts. Previously, similar findings were reported that products with propiconazole, epoxiconazole, and thiophanate-methyl active ingredients effectively controlled both stem and yellow rusts (Bekele, 2003; Alemu and Mideksa, 2016). According to Mengesha (2020), the propiconazole product, which has a propiconazole active ingredient, effectively controls both wheat yellow and stem rusts and increases crop yield in Ethiopia. Tesfaye et al. (2018) and Nemomsa (2019) reported that propiconazole fungicides control yellow and stem rusts alone or in combination with moderately resistant wheat varieties.

However, the continuous use of the same fungicide or fungicides with the same active ingredient(s) year after year may facilitate development of the pathogen races fungicide resistance. To overcome pathogen-fungicide-resistant development, alternative fungicides that have a relatively similar efficacy level to propiconazole can be employed for the control of wheat rusts. Propiconazole and difeconazole fungicides have also been reported to be effective against stripe rust when applied at the proper time and rate (Basandrai et al., 2013). Likewise, it is reported that products having Azoxystrobin and Cyproconazole active ingredients also effectively control the wheat rusts and decrease yield loss due to the diseases (Parween et al., 2016; Basandrai et al., 2020). In line with this finding, Wanyera et al. (2009) also reported that foliar application of the Azoxystrobin + Cyproconazole fungicide efficiently reduces stem rust severity and increases yield in Kenya. Likewise, Singh et al. (2016) also reported that Azoxystrobin and Cyproconazole significantly control wheat rusts as compared with difenoconazole. Furthermore, Boualem et al. (2017) found that Azoxystrobin and Propiconazole were effective in the treatment of powdery mildew, yellow rust, and leaf rust diseases.

Effect of fungicides on yield and yield components

As presented in Tables 3 and 4, there was a statistically significant difference in yield, plant biomass, and thousand seed weight between the treated and untreated (control) plots. However, there was no statistically significant difference among the tested fungicides in thousand kernel weight and grain yield. There was also no significant difference among tested fungicides and control plots in plant height and spike length. Significantly maximum plant biomass was obtained from plots sprayed with Propiconazole (12.1 t ha^{-1}) and Fenpicoxamid + Hexaconazole (11.3 t ha^{-1}) on variety Kubsa for yellow rust management (Table 4). Statistically non-significant, but relatively highest, plant biomass was also recorded from plots sown to Hidase and sprayed with Propiconazole for stem rust management (Table 3). Statistically significant yield advantages were obtained from the Hidase variety treated with Azoxystrobin + Cyproconazole, Fenpicoxamid + Hexaconazole, and Propiconazole with, respectively, 5.5, 5.4 and 5.7 t ha^{-1} when compared with the control (3.6 t ha^{-1}).

The results of this study identified the role of different fungicides with different modes of action in controlling wheat rusts. This in turn generated an effective alternative chemical fungicide for rust control and also contributed to managing the outbreak of fungicide-resistant races. In the absence of variety conferring resistance, developing such alternative chemical fungicides is immensely contributing to susceptible wheat production in the West and Southwest Shewa zones and beyond in the country. Therefore, proper application of fungicides at the appropriate time, rate, and frequency, along with their alternate use, is critical for better product results, sustainability, and efficacy. Success stories of proper utilization of particular products based on manufacturer recommendations are available. The differences in efficacy across fungicide products are mostly determined by product type, timing, and rate of treatment. Since the majority of the wheat varieties currently under production in Ethiopia are susceptible to the newly emerging wheat rust races (Wan et al., 2017), it is practically difficult to grow successful wheat production without the use of fungicides. Therefore, it is mandatory to make farmers aware of using alternative chemical fungicides as per manufacturer recommendations in situations where there is an intention of growing high-yielding but susceptible to rust disease varieties in order to attain high production and productivity.

Even though Kubsa and Hidase varieties are high-yielder varieties, they are currently becoming highly susceptible to the rusts and consequently, they are becoming out of production. This could be attributed to the presence of favorable environmental conditions for disease outbreaks and the emergence of new virulent pathogen races. According to Solh et al. (2012), the association of current climatic changes with virulent stem rust strain (Ug99) has caused rust disease epidemics in Ethiopia. Olivera et al. (2015) reported that heavy infection with stem rust TKTTF race resulted in total crop failures on the Digelu wheat variety in Ethiopia during the 2013/14 cropping season. Similarly, it is also reported that yellow (stripe) rust caused 68.30% yield loss in the Ethiopian highlands on the Kubsa wheat variety in 2018 (Mengesha, 2020). Likewise, Badebo and Hundie (2016) also reported that wheat varieties Enkoy and Degelu were severely affected by stem rust, which caused up to a total yield loss. This disease became a major threat to wheat production in the low- and mid-altitude areas of Ethiopia, which has warmer temperatures. Similarly, Park (2007) found that black rust can cause up to 100% yield loss if vulnerable cultivars are used for production, and epidemics occur in mid-land agro ecologies. In addition to yield quantity losses, it is reported that stem and yellow rusts are also causing yield quality losses by giving light, shriveled, prematurely ripened grains under severe infection. They weaken the plants, particularly stem rust, which weakens the plant stems, and consequently, plants become lodged by heavy winds and rain (Leonard and Szabo, 2005).

CONCLUSIONS AND RECOMMENDATIONS

Yellow and stem rusts are among the most devastating wheat diseases, resulting in severe yield losses in West and Southwest Shewa zones of Ethiopia. The result of this study revealed that high-yielding, but either moderately susceptible or susceptible wheat varieties can be produced using twice the application of either Propiconazole, Fenpicoxamid + Hexaconazole, or Fenpicoxamid + Pyraclostrobin fungicides for yellow rust control, and farmers can also use Propiconazole, Fenpicoxamid + Hexaconazole, Union Oxie 400 SE, Fenpicoxamid + Pyraclostrobin, Pyraclostrobin + Epoxiconazole, or Azoxystrobin + Cyproconazole fungicides alternatively for stem rust at a seven-day interval, starting when disease severity reached 5%. These are evidenced by the maximum yield advantages of 5.7, 5.5, and 5.4 t ha^{-1} attained, respectively, when plots were treated with Propiconazole, Azoxystrobin + Cyproconazole, and Fenpicoxamid + Hexaconazole. Hidase and Kubsa wheat varieties used in this experiment are high-yielders, but they are susceptible to rusts; and therefore, the producers should use either of the recommended fungicides alternatively.

The fungicides used in this study were effective in controlling the diseases; however, when the economic feasibility and accessibility of fungicides are considered, the farmers are advised to use Propiconazole spraying twice at seven days interval when the disease appears. Therefore, farmers in the research areas and elsewhere with similar agro-ecological conditions as in Ethiopia can use these varieties with the fungicides alternatively for effective wheat rust management and increased grain output without sacrificing profit. Awareness should also be given to the farmers on proper major disease identification, the critical time for applying fungicides, and the type of product they need to use before these diseases cause significant yield losses. Furthermore, the evaluation of more fungicides should continue in the future to broaden alternatives for producers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors are grateful to Ethiopian Institute of Agricultural Research and Ambo Agricultural Research Center (EIAR) for funding the work.

REFERENCES

Abdissa T, Bekele B (2020). Assessment of wheat Fusarium head blight and associated *Fusarium* species in West Shewa, Ethiopia. International Journal of Agriculture and Biosciences 9(6):299-304.

Abebele GM, Admasu MA, Agdu BH (2020). Field evaluation of bread wheat (*Triticum aestivum* L.) genotypes for stripe rust (*Puccinia striiformis* W.) resistance in Arsi highlands of Oromia region, South-eastern-Ethiopia. Journal of Plant Pathology and Microbiology 11:521.

Abro ZA, Jaleta M, Qaim M (2017). Yield effects of rust-resistant wheat varieties in Ethiopia. Food Security 9(6):1343-1357.

Alemu W, Mideksa T (2016). Verification and evaluation of fungicides efficacy against wheat rust diseases on bread wheat (*Triticum aestivum* L.) in the Highlands of Bale, Southeastern Ethiopia. International Journal of Research Studies in Agricultural Sciences 2(9):35-40.

Anteneh A, Asrat D (2020). Wheat production and marketing in Ethiopia: Review study. Cogent Food and Agriculture 6(1):1778893.

Azmeraw Y, Admassu B (2022). Integrated management of wheat stem rust (*Puccinia graminis* f. sp. *tritici*) through host resistance and inorganic salts foliar sprays. Archives of Phytopathology and Plant Protection 55(17):2009-2022.

Ayele B, Eshetu B, Betelehem B, Bekele H, Melaku D, Asnakech T, Melkamu A, Amare A, Kiros M, Fekede A (2008). Review of two decades of research on diseases of small cereal crops. Increasing crop production through improved plant protection 1:375-416.

Badebo A, Assefa S, Fehrmann H (2008). "Yellow Rust Resistance in Advanced lines and Commercial Cultivars of bread wheat from Ethiopia." East African Journal of Sciences 2(1):29-34.

Badebo A, Hundie B (2016). Incidence and challenges of rust diseases in wheat production. Containing the Menace of Wheat Rusts: Institutionalized Interventions and Impacts. Ethiopian Institute of Agricultural Research 153 p.

Basandrai AK, Mehta A, Rathee VK, Basandrai D, Sharma BK (2020). Efficacy of fungicides in managing yellow rust of wheat. Journal of Cereal Research 12(2):103-108.

Basandrai AK, Sharma BK, Basandrai D (2013). Efficacy of triazole fungicides for the integrated management of yellow rust, leaf rust and powdery mildew of wheat. Plant Disease Research 28(2):135-139.

Bayoush BY (2021). Distribution and Integrated Management of Fusarium Head Blight of Wheat (*Triticum aestivum* L.) in South Eastern, Ethiopia (Doctoral dissertation, Haramaya University).

Bekana NB (2019). Efficacy evaluation of different foliar fungicides for the management of wheat strip rust (Puccinia striiformis) in West Shoa Zone, Oromia, Ethiopia. Journal of Applied Sciences and Environmental Management 23(11):1977-1983.

Boualem B, Mohamed B, Moulay B (2017). Effect of application timing of artea and amistar xtra on the yield of wheat (*Triticum aestivum* L.) under foliar disease in the East-Algerian. International Journal of Agricultural Research 12:10-18.

Central Statistics Agency (CSA) (2022). Agricultural sample survey of area and production of major crops (Private peasant holdings, Meher Season). https://www.statsethiopia.gov.et/. Vol. 1, Statistical Bulletins 590, Addis Ababa, Ethiopia.

Chilot Y, Moti J, Bekele S, Groote Hd, TM, Ali O (2013). Analysis of Adoption and Diffusion of Improved Wheat Technologies in Ethiopia. Research Report 101. Ethiopian Institute of Agricultural Research (EIAR) and CIMMYT, Addis Ababa, Ethiopia.

Degefie T, Almaz N, Olika D, Abu T (2020). Spatiotemporal hotspot patterns of wheat rust inciden-ce and severity in Ethiopia. African Journal of Agricultural Research 16(9):1289-1297.

Demeke M, Di Marcantonio F, Morales-Opazo C (2013). Understanding the performance of food production in sub-Saharan Africa and its implications for food security. Development and Agricultural Economics 5(11):425-443.

Eshete BB (2018). Status and challenges of wheat stem rust (*Puccinia graminis* f. sp. *tritici*) and threats of new races in Ethiopia. International Journal of Forestry and Horticulture 4(4):22-31.

Food and Agriculture Organization of the United Nations Statistics (FAOSTAT) (2022). Food and agriculture data. Food and Agriculture Organization of the United Nations Statistics Division. 〈https://www.fao.org/faostat/en/#data. Accessed 2022 May 15.

Falola A, Achem BA, Oloyede WO Olawuyi GO (2017). Determinants of commercial production of wheat in Nigeria: a case study of Bakura Local Government Area, Zamfara State. Trakia Journal of Sciences 15(4).

Giraldo P, Benavente E, Manzano-Agugliaro F, Gimenez E (2019). Worldwide research trends on wheat and barley: A bibliometric comparative analysis. Agronomy 9(7):352.

Hodson DP, Jaleta M, Tesfaye K, Yirga C, Beyene H, Kilian A, Carling J, Disasa T, Alemu SK, Daba T, Misganaw A (2020). Ethiopia's transforming wheat landscape: tracking variety use through DNA fingerprinting. Scientific Reports 10(1):18532.

Leonard KJ, Szabo LJ (2005). Stem rust of small grains and grasses caused by *Puccinia graminis*. Molecular Plant Pathology 6(2):99-111.

Mengesha GG (2020). Management of yellow rust (*Puccinia striiformis* f. sp. *tritici*) and stem rust (*Puccinia graminis* f. sp *tritici*) of bread wheat through host resistance and fungicide application in Southern Ethiopia. Cogent Food and Agriculture 6(1):1739493.

Nigus M, Shimelis H, Mathew I, Abady S (2022). Wheat production in the highlands of Eastern Ethiopia: opportunities, challenges and coping strategies of rust diseases. Acta Agriculture Scandinavica, Section B—Soil and Plant Science 72(1):563-575.

Olivera P, Newcomb M, Szabo LJ, Rouse M, Johnson J, Gale S, Luster DG, Hodson D, Cox JA, Burgin L, Hort M (2015). Phenotypic and genotypic characterization of race TKTTF of *Puccinia graminis* f. sp. *tritici* that caused a wheat stem rust epidemic in southern Ethiopia in 2013–2014. Phytopathology 105(7):917-928.

Parween T, Bhandari P, Bajya DR (2016). Evaluation of Amistar Xtra 280 SC (Azoxystrobin 18.2%+ Cyproconazole 7.3%) against Yellow rust (*Puccinia strifformis*), Brown rust (*P. triticina*) and powdery mildew in wheat. Annals of Plant Protection Sciences 24(1):132-135.

Peterson RF, Campbell AB, Hannah AE (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Canadian journal of research 26(5):496-500.

Shiferaw B, Smale M, Braun HJ, Duveiller E, Reynolds M, Muricho G (2013). Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. Food Security 5:291-317.

Singh VK, Mathuria RC, Gogoi RO, Aggarwal RA (2016). Impact of different fungicides and bioagents, and fungicidal spray timing on wheat stripe rust development and grain yield. Indian Phytopath 69(4):357-362.

Solh M, Nazari K, Tadesse W, Wellings CR (2012). The growing threat of stripe rust worldwide. In Borlaug Global Rust Initiative (BGRI) conference, Beijing, China pp.1-4.

Tadesse W, Bishaw Z, Assefa S (2018). Wheat production and breeding in Sub-Saharan Africa: Challenges and opportunities in the face of climate change. International Journal of Climate Change Strategies and Management 11(5):696-715.

Tadesse NS, Beyene GF, Hordofa TB, Hailu AA (2020). Traditional foods and beverages in Eastern Tigray of Ethiopia. Journal of Ethnic Foods 7(1):16.

Tadesse W, Zegeye H, Debele T, Kassa D, Shiferaw W, Solomon T, Negash T, Geleta N, Bishaw Z, Assefa S (2022). Wheat production and breeding in Ethiopia: retrospect and prospects. Crop Breeding, Genetics and Genomics 4(3).

Teklay A, Getaneh W, Woubit D, Adhiena M, Yemane N (2013). Distribution and Seasonal Variation in Occurrence of Wheat Yellow Rust in Tigray, Ethiopia. Direct Research Journal of Agriculture and Food Science 1(2):11-17.

Tesemma T, Belay G (1991). Aspects of Ethiopian tetraploid wheats with emphasis on durum wheat genetics and breeding research.

Tesfaye Y, Teshome G, Asefa K (2018). Evaluation of fungicide efficacy against stripe rusts (*Puccinia striiformis* F. sp) at Guji Zone Southern Ethiopia. The International Journal of Research in Agriculture and Forestry 5(10):6-13.

United States Department of Agriculture (USDA) (2019). Crop production 2018 summary (February 2019). USDA National Agricultural Statistics Service. https://www.nass.usda.gov/Publications/Todays_Reports/reports/cropan19.pdf

Wan A, Muleta KT, Zegeye H, Hundie B, Pumphrey MO, Chen X (2017). Virulence characterization of wheat stripe rust fungus *Puccinia striiformis* f. sp. *tritici* in Ethiopia and evaluation of Ethiopian wheat germplasm for resistance to races of the pathogen from Ethiopia and the United States. Plant Disease 101(1):3-80.

Wanyera R, Macharia JK, Kilonzo SM, Kamundia JW (2009). Foliar fungicides to control wheat stem rust, race TTKS (Ug99), in Kenya. Plant disease 93(9):929-932.

Wubishet A, Chemeda F, Bekele H (2015). Effects of environment on epidemics of yellow rust (*Puccinia striiformis* West.) of bread wheat (*Triticum aestivum* L.) in Bale highlands, South-Eastern Ethiopia. Global Journal of Pests, Diseases and Crop Protection 3(2):096-107.

Yami M, Solomon T, Begna B, Fufa F, Alemu T, Alemu D (2013). Source of technical inefficiency of smallholder wheat farmers in selected waterlogged areas of Ethiopia: A translog production function approach. African Journal of Agricultural Research 8(29):3930-3940.

Zadoks JC, Chang TT, Konzak CF (1974). A decimal code for the growth stages of cereals. Weed Research 14(6):415-421.

Zegeye F, Alamirew B, Tolossa D (2020). Analysis of wheat yield gap and variability in Ethiopia. International Journal of Agricultural Economics 5(4):89-98.

Zegeye T, Taye G, Tanner D, Verkuijl H, Agidie A, Mwangi W (2001). Adoption of improved bread wheat varieties and inorganic fertilizer by small-scale farmers in Yelmana Densa and Farta districts of Northwestern Ethiopia. EARO and CIMMYT. Mexico City, Mexico.