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New Verification of Fungicide Against Yellow Rust (*Puccinia Striiformis f. sp tritici*) and Stem Rust (*Puccinia Graminis f. sp. tritici*) on Bread Wheat in Highlands of Guji, Ethiopia

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Abstract

Background and Objective: Wheat is one of the major cereal crops in Ethiopia in terms of volume produced and its production. However, the production and productivity of wheat is reduced by various biotic and abiotic stresses. Among the biotic stresses, wheat yellow rust and stem rust is the most feared wheat production bottlenecks. Field experiment was conducted to verify and evaluate the efficacy of fungicides against wheat rust disease and recommend for registration.

Materials and Methods: The trials were carried out at yellow rust and stem rust hotspot location Bore (on-station), Abbay (on-farm) and Anna Sorra on farm during 2022/23 cropping season. Experimental design was non randomized consisting of six fungicides with three-time applications. mTreatments were: Top-ozole and Propiconazole, Tilt 250%, Top Acanazole, Take off, Star and a control treatment without fungicide application. The partial budget analysis was carried out to assess financial profitability of fungicide application for the management of rusts. There was significant difference ($p < 5\%$) in grain yield, biomass yield, thousand seed weight, plant height, spike length and rust (yellow and stem) between fungicide treatments and control/nil application. Fungicide spray treatments significantly reduced yellow and stem rust disease of Area Under Disease Progress Curve (AUDPC), Relative Area under disease progress curve (rAUDPC), Coefficients of Infections (CI) and Finally Rust Severity (FRS) to the lowest level possible over the no application.

Results: There is highly significant difference ($p \leq 5$) in Area Under Disease Progress Curve (AUDPC), Relative Area Under Disease Progress Curve (rAUDPC), Coefficients of Infections (CI) and Finally Rust Severity (FRS) between fungicide treatments and nil application of fungicide. The highest grain yield was obtained from Top-ozole and Propiconazole, Tilt 250%, Top Acanazole, take off, Star sprayed plots while the lowest from no application. The new fungicide (Top-ozole, Propiconazole, Top Acanazole and Star) revealed that there was significant yield advantage than untreated plots.

Conclusion: Therefore, based on partial budget analysis, yield and rust disease control, using of Top-ozole, Propiconazole, Top Acanazole and Star fungicide which leads to the optimum yield of bread wheat by decreasing rusts and can be recommended for the registration and other areas with similar agro-ecologies.

Keyword: Fungicides; Efficacy; Significant; Wheat; Stem rust: Yellow rust

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Introduction

Wheat (*Triticum spp*.) is one of the most important and major cereal crops in the world in terms of volume production and nutritional value. Globally, wheat is the leading cereal crop that is used by more than one-third of the populations in the world as a staple food (FAO, 2018). In fact, the global demand for wheat continuously increased at an annual rate of 1.6% and some estimates indicate that 60% more wheat will be needed by 2050 (Shiferaw *et al*., 2013). It is a major source of starch, protein, energy and provides substantial amounts several components that are essential or beneficial for human health (Shewry and Hey, 2015).

Ethiopia is the second-largest wheat producer in sub-Saharan African countries with 1.89 million ha covered by wheat cultivation and more than 4.57 million households depended on wheat producers [7]. It is ranked 3rd in area next to *teff* and *maize* 2nd production (57,801,306 quintals) and productivity (3.04 t/ha) next to maize [7]. Wheat productivity is more than 7 t /ha and 4 t /ha under demonstration and farmers conditions, respectively (MoANR and ATA, 2018). Despite the favorable environments to the crop production in the country, the national average yield (3.04t/ha) is lower than the world's average (3.5 t /ha) (FAO, 2019) [9].

The low productivity of wheat is attributed to biotic, abiotic, socioeconomic, and technical constraints. Diseases are among the biotic factors which cause not only yield reduction, but they also affect the quality of seed or grain. In Ethiopia, over 40 wheat diseases have been reported as constraints to wheat production (Bekele, 1985) [3]. Of these, fungal diseases like rusts (stem, yellow, and leaf rusts), Fusarium head blight (*Fusarium graminearum*), Septoria blotch (*Septoria tritici*), Smut (*Ustilago tritici*), *Helminthosporium* spp., and tan spot (*Pyrenophora tritici repentis)* were reported to be the most dominant. Among those fungal disease, yellow rust (*Puccinia striiformis* f. sp *tritici*), stem rust (*Puccinia graminis* f.sp. *tritici*), leaf rust (*Puccinia triticina* and Septoria diseases are the major one that severely limit wheat production in the country (Endale and Getaneh, 2015; Mengistu *et al*., 2018) [3].

Guji zone is one of the wheat producers in Ethiopia. However, Highlands of Guji zone (Bore, Anna sorra, and Dama) are a hot spot of wheat rusts specially for yellow and stem rust (Tolasa *et al.*,2014). The frequent failure of resistant wheat varieties due to changes in pathogen virulence has increased the interest in chemical control of wheat yellow rust for the global food security [17]. Chemical fungicides get first preferences, when failures of resistant wheat varieties are evident, as they provide a practical and rapid control of the disease. Foliar fungicides have been widely used to control yellow rust which prevented multimillion dollar losses and significantly reducing crop loss [14]. The timely and proper use of fungicides gives benefits in the effort to increase crop productivity [6,8] reported a relatively better yield for sprayed plots as compared to unsprayed plots under experimental condition and the spray interval is reported to be a significant factor in reducing the disease severity and rate of epidemic development. Large scale commercial and government-run wheat farms have generally chosen to rust-susceptible wheat varieties because they have a greater yield potential of 20%- 25% than rust-resistant varieties. The yield increase on susceptible varieties as a result of fungicide treatments is about 13% [10]. To manage yield loss due to these diseases, farmers use different fungicides released for either wheat rusts or other crop diseases alone or in combination of fungicide with each other due to disease aggressiveness under field conditions. Thus, the objective of this study is to verify the efficacy of fungicides against wheat rust diseases and recommend for registration.

Material and Method

The fungicide test was conducted by Bore Agricultural Research Center under Oromia Agricultural Research Institute by the agreement signed between the institute and the chemical company. The study was conducted at three locations namely Bore (on-station), Abbay(on-farm) and Anna Sorra on farm during 2022/23 main cropping season. The experiments were conducted at three locations by plot size of 10mx10m for Bore on station and for both on farms. The new test fungicides Star (Tebuconazole 25 EW), Top acanazole, Propiconazole, Top-ozole along with the standard check of Take off 293% SC, Tilt 250%and unsprayed plot(control) evaluated for their efficiency of manage the disease. The spacing between block to block and plots to plots were 2m and 1.5m, respectively. The experimental design was laid out in non-replicated plots, where locations considered as a replica. Kubsa variety was used as highly susceptible reference for both yellow rust and stem rust. The fungicides applied during booting crop growth stage at appearance of the first yellow rust symptoms and 2% severity level of stem rust. Un-treated plot (un-sprayed) was used as for comparison and all other management practices were applied as per their agronomic recommendations uniformly.

Disease Parameters

Disease incidence: Ten randomly selected pre-tagged plants were chosen from each plot, and the number of plants exhibiting yellow rust disease signs was reported as a percentage (%) infection using the following formula. [16].

$$Disease\ incidence = \frac{\text{Nmber of diseased plants}}{\text{Total plants observed}} \times 100 \quad [16]$$

Disease severity: The modified Cobb scale (Peterson et al., 1948) was used to estimate the approximate percentage of leaf area affected by yellow rust on ten randomly selected plants in the central rows of each plot. The assessment was conducted ten days apart from the date the illness first appeared.

Coefficient of infection: The final disease severity data for the yellow rust converted into a Coefficient of Infection (CI) by multiplying severity with a constant value for field response [16].

The Area under Disease Progress Curve (AUDPC): AUDPC value was calculated for each treatment by using the following formula and the value expressed in %-days (Wilcox son *et al*., 1975). $AUDPC = \sum_{i-1}^{n-1} 0.5(xi + 1 + xi)(ti + 1 - ti)$

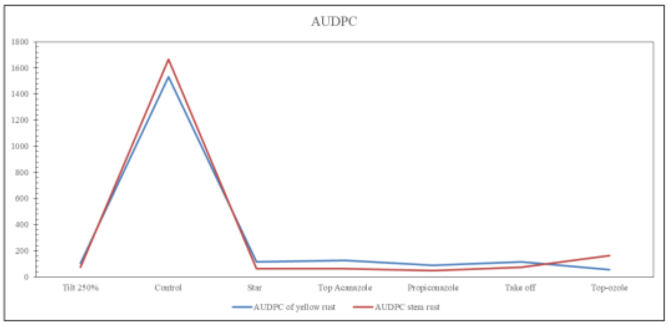

Figure 1: Effect of Fungicides against Bread Wheat Rusts, AUDPC of Bread Wheat at Highlands of Guji Zone.

Where, X_i is the cumulative disease severity expressed as a proportion at the i^{th} observation; t_i is the time (days after planting) at the i^{th} observation and n is total number of observations.

Yield and Yield Related Parameters

Days to 50% heading: It was recorded by counting number of days from the date of sowing until when 50% of the plants in a plot produced spikes above the sheath of the flag leaf that was determined by visual observation.

Days to 90% maturity: It was recorded by counting the number of days from date of sowing until when 90% of the plants changed green color to yellowish, loose its water content and attain to physiological maturity in each plot.

Plant height: Average height of main plant from ten plants (tagged before commencement of tillering) from each plots was measured in centimeter from ground level to the tip of the spike excluding awns.

Spike length: The length of spike in centimeter from 10 randomly wheat plants per plot was measured in centimeter and average height was used for analysis.

Number of grains per spike: the average number of kernels of the main tiller of the ten pre- tagged plants from each plot was recorded.

Thousand-kernel weight: The weight of thousand kernels in gram was sampled at random from the total grins harvested from each experimental plot and measured using sensitive balance.

Above ground biomass yield (t ha^{-1}): Total above ground biomass yield in Kg were measured by weighing the sun dried total above ground plant biomass (straw + grain) of the net plot and converted to ton per hectare

Grain yield: grain yield in kg per plot at 12.5% moisture content from central rows of each experimental unit was recorded and translated in to ton / ha.

Economic Analysis

Economic data were collected to compare the economic advantage of treatment combinations. These included variable input costs and cost for the fungicide and labor during the execution of the experiment. The economic data analysis was done according to CIMMYT (1988) to calculate the incomes and expense of each treatment used in the experiment. The different cost of this experiment includes cost of seed; cost of the fungicide and labor cost to fungicide applications among different treatments were considered. Cost of fungicide was obtained from pesticide companies and local distributing agencies. Purchasing cost for seeds to varieties was taken as Birr 35 kg-1 to Kubsa. Cost to daily labor was 150 Birr per day. The selling price of straw and grain yield during harvesting season of the local market was taken as Birr 4 and 20 kg-1 respectively. For all treatments, total cost and net benefit were calculated. To calculate gross income, yield obtained from each treatment were adjusted by 10%. The following formulas were used to compute partial budget and Marginal Rate of Return (MRR) analysis, respectively. Net field benefits (NBs) = Gross field Benefits (GB) - Total Variable Costs (TVC) and MRR = DNI/DIC, where: MRR = the marginal rate of return; DNI = difference in net income compared with control; and DIC = difference in input cost compared with control.

Data Analysis

Data on disease parameters and yield were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) version 9.0 software. Fisher's protected Least Significant Difference (LSD) values was used to separate differences among treatment means (P<0.05) for the field evaluation efficacy.

Results and Discussion

Yield and Yield Related Parameters

Plant height: The analysis of variance revealed that there was a significant ($p < 0.05$) effect on plant height. The tallest plants (86.86cm) were recorded in fungicide (Tubucanazole) followed others and the shortest plants (71.7 cm) were observed in un sprayed (Table 1). The difference in plant height of the varieties should be attributed to the difference in their genetic makeup and the effect of different fungicide [12]. Similarly, Shahzad *et al*. (2007) who reported that height of the crop is mainly controlled by genetic makeup of a genotype, the effect of different fungicide and it can also be affected by the environmental factors.

Spike length: The statistical analysis results revealed that spike length was significantly ($p <0.05$) affected by new fungi-

Table 1: Rate of fungicide and rate of water were used.

Trade name	Comman name	Rate of water	Rate of chemical
Top- ooze	Pyraclostrobin 11g/l + Tebuconazole 230g/l EC	250L/ha	0.5 L/ha
Tra –zole	propiconazole 25%EC	250L/ha	1L/ha
Tilt 250%	Propiconazole	200l/ha	1 l/ha
Top Acanazole	Propiconazole 250g/ lEC	250L/ha	0.75 L/ha
Take off	Tebuconazole	250l/ha	1 l/ha
Star	Tebuconazole 25 EW	300l/ha	1.5 l/ha

Table 2: Effect of Fungicides against Bread Wheat Rusts, disease parameter of Bread Wheat at Highlands of Guji Zone.

	Wheat yellow rust				Wheat stem rust			
TRT	AUDPS	RAUDPS	CI	FRS	AUDPS	RAUDPS	CI	FRS
Tilt 250%	103.33^b	6.33^a	4.667^b	5.00^{cb}	73.3^b	4^b	2.667^a	3.33^b
Control	1533.33^a	90^a	85^a	85^a	1666.67^a	92.66^a	83.3^a	83.33^a
Star	116.67^b	7.00^b	4.667^b	30^b	65^b	3.667^{bc}	2.67^b	5^b
Top Acanazole	125.00^b	7.33^b	7.33^b	8.33^{bc}	61.67^b	4^b	6.67^b	6.63^b
Trail zole	90^b	5.66^b	0^b	0^c	50^b	4.33^b	6^b	5.67^b
Take off	115^b	7.33^b	3.33^b	2.00^c	75^b	6.667^b	10^b	7.33^b
Top-ozole	56.67^b	3.667^b	1.67^b	0.67^c	163.33^b	8.667^b	8.3^b	6^b
Mean	305.71	18.2	15.2	18.7	307.85	17.7	17.09	16.7
CV	30.9	29.76	14.09	8.21	24.41	23.57	13.54	30.37
Lsd 5%	168.26		27.039	43.4	214.4	7.4	9	14.5

Key; LSD: Least Significant Difference among treatment means CV= Coefficient of Variation, Means with the same letter within the same column are not significantly different from each other Area under disease progress curve (AUDPC), Relative Area under disease progress curve (rAUDPC), CI: Coefficients of Infections; FRS: Finally Rust Severity

Table 3: Partial budget analysis for the management of yellow and stem rust disease of bread wheat at highlands Guji zone.

Treatment	Grain yield	Adjusted	Total benefit cost	Total variable cost	Net benefit cost	MRR%	Rank
Tilt 250%	36.26	32.63	114219	24600	89619	244.20	5
Control	12.05	10.84	37957.5	22500	15457.5	0	7
Star	33.76	30.38	106344	25000	81344	253.02	4
Top Acanazole	36.4	32.76	114660	25500	89160	274.08	2
Trial zole	33	29.7	103950	24700	79250	264.96	3
Take off	30.75	27.67	96862.5	25000	71862.5	225.62	6
Top-ozole	38.48	34.63	121212	25000	96212	310.5	1

cide. The longest spike length of (7.86cm) was recorded from fungicide (Topocanazole). The shortest spike length was observed from un treated (6.23 cm) (Table1).

Number Grains per spike: The statistical analysis results revealed that was significantly ($p < 0.01$) in Grains per spike yield. In the case of fungicide application frequency, maximum number of grains per spike (7.6) was obtained from the plot that received three times application of fungicide followed by twice application of fungicide (7.48). Minimum number of grains per spike (4.5) obtained from untreated plot (table 1). This result is in accordance with the work of Dereje Hailu and Chemeda Fininsa (2007) reported relatively better grains per spike for sprayed plots as compared to unsprayed plots under experimental condition. This result also supported by the work done by Yared Tesfaye *et al*. (2018), who reported relatively higher grains per spike over untreated plots.

Above ground biomass yield: The statistical analysis results revealed that there was significantly ($p < 0.05$) different between the fungicide in above ground biomass yield. Maximum above ground biomass yield (8.41 t ha-1) was recorded from Topocanazole treated with six fungicide application frequency, whereas minimum above ground biomass yield was observed from untreated Kubsa (1.37t ha-1)(Table 1). This is because biomass yield mostly related with plant height and yield. Fungicide given a chance of prolonged green leaf area through delayed leaf senescence [4] allowing photosynthetic activity to continue and enables the plant assimilate more carbon and nitrogen for biomass production (Rodrigo *et al*., 2014). On the other hand the pathogen uses nutrients and that can be used for synthesis of dry matter by the plant (Chen *et al*., 2014). As a result more treated plots resulted high above ground biomass yield over less treated plots. This result is in agreement with the work of Wubishet Alemu and Tamene Midikesa (2016), who reported a biomass yield of 6.86 t/ha up to 7.13 t/ha on plots treated with different fungicides and 4.65 t/ha biomass yield from untreated plot at Bale districts.

Thousand kernel weight: The analysis of variance showed that there was a significant ($p<0.05$) effect of fungicide to control wheat yellow rust and stem rust on TKW (Table.1). Maximum TKW (58.13gm) was recorded from Topocanazole as well as Minimum (19.49 gm) TKW was recorded from untreated with kubsa variety (Table 1). If there is no reduction in assimilate production, high assimilate supply per grain, inducing grain weight increase, and by the result grain yield also increased (Zhang *et al.,* 2010). These findings supported by Alemu Ayele *et al.* (2019), who reported 82%, yield increment from treated over untreated plot of S, varieties, respectively.

Grain yield: The analysis of variance showed that Topocanazole had very high significant ($p<0.05$) effect on grain yield (Table.1). Maximum grain yield (36.4 Qut/ ha-1) was recorded from S variety treated with three application of Topocanazole, respectively. Minimum grain yield was obtained from untreated HS variety, Kubsa (12.0 Qut/ ha-1). Different studies from different areas have demonstrated grain yield increases in wheat due to fungicide application. Alemu Ayele et al. (2019), who reported that grain yield increased in high range over untreated plots when wheat was treated with foliar fungicide, Tilt 250 EC. Up to 42% yield loss was prevented by applying foliar fungicides to winter wheat [20]. Kelley (2001) also found that over a period of six years, the fungicide Tilt 250 EC significantly increased winter wheat yield by 77%.

Disease

Finally rust severity: Finally yellow and stem rust severity was significantly ($P<0.05$) affected by treatments fungicides and their combinations under natural epidemics (no spray). The highest terminal yellow rust and stem rust severities of about 85 % were recorded on unsprayed plots of susceptible variety (Kubsa). As well as the smallest final yellow rust and stem rust severities of about 85 % were recorded Propiconazole and Topozole , Top Acanazole, Tilt 250%, Take off, Star (Table 2). Similarly, the lowest finally rust severities in different environments could be the inherent behavior of the host and the supplemented fungicides, having responsible active substances in the formulation, for the management of rusts during the cropping (Milus, 1994, Campbell and Madden, 1990, Willyerd *et al.*, 2015 and Wubishet and Tamene, 2016) [13,22-25].

Area under disease progress curve: Analysis of variance revealed that there were a significantly ($P<0.05$) different fungicide in area under disease progress curve (AUDPC) of yellow and stem rust (Table 2). The highest area under disease progress curve (AUDPC) yellow rust (1533.33) and stem rust severities (1666.67) of about were recorded on unsprayed plots of susceptible variety (Kubsa). As well as the lowest final yellow rust and stem rust severities of about were recorded Top-ozole and Propiconazole followed Tilt 250%, Top Acanazole, Take off, Star (Table 2). The present finding was supported by Ransom and McMullen (2008), Tadesse *et al.* (2010) [19], Wubishet and Tamene (2016) [23,25] and Phillip and Nathan (2018) who reported that the highest value of AUDPC for yellow and stem rusts resulted from the highest disease development on plots that had no spray with any combinations of crop varieties and fungicide applications; the lowest AUDPC for yellow and stem rust diseases when supplemented with fungicide application.

Relative Area under disease progress curve (rAUDPC): Relative Area under disease progress curve (rAUDPC) is a better indicator of disease expression over time (Vandr plank, 1963). Therefore, selection of fungicide and lines having lower rAUDPC value is acceptable for practical purposes. Based on the rAUDPC values, the tested wheat lines categorized in to three distinct groups for slow rusting resistance. Lines and fungicide exhibited AUDPC values up to 30% of the check were grouped as having high level of partial resistance [2]. There were a significantly ($P<0.05$) different fungicide in area under disease progress curve (AUDPC) of yellow rust (Table 2). The highest Relative

Area under disease progress curve (rAUDPC) yellow rust (90) and stem rust (92.66) severities were recorded on unsprayed plots (Table 2). As well as The smallest final yellow rust and stem rust severities of about were recorded Top-ozole and Propiconazole followed Tilt 250%, Top Acanazole, Take off, Star (Table 2).

Coefficients of infections: The data acquired from disease severities and host reactions were combined to compute coefficient of infection (CI). According to Ali *et al.* (2007), genotypes with CI values of 0-20, 21-40, 41-100 were regarded as possessing high, moderate and low levels of adult plant resistance, respectively. There were a significantly (P<0.05) different fungicide in Coefficients of infections of yellow rust (Table 2). The highest Coefficients of infections yellow rust (85) and stem rust severities (83.3) were recorded on unsprayed plots. As well as The smallest final yellow rust and stem rust severities of about were recorded Top-ozole and Propiconazole followed Tilt 250%, Top Acanazole, Take off, Star (Table 2). This result in agreement with the work done 42 by Alemu Ayele *et al.* (2019) [8], who reported that the CI on unsprayed plots, varied from 6 % on resistant variety (Wane) to 81% on susceptible (Kubsa) and CI after 2 nd spray fungicide it ranged from 0.2 on the resistant variety (Wane) to 27% on the susceptible variety (Kubsa).

Economic Analysis

As indicated in table 3, the result of economic analysis showed that the maximum net benefit (ETB 96212 ha-1) with an acceptable MRR was obtained on three times of applications of Top-ozole fungicide. This has resulted in the net benefit advantage of Birr 310. The treatment that with three frequency Tilt 250% (89619ETB ha-1), Star with three (81344ETBha-1) and Top Acanazole with three (89160ETBha-1) Trail-zole with three (79250 ETBha-1) Take off with three (71862.5 ETBha-1) fungicide application frequency also have highest net benefit with three application frequency of Top-ozole EC. However other treatments were eliminated by dominance analysis (CIMMYT, 1988) since the net benefit obtained decreased as the cost increased. Therefore, in the study area with three times applications of those fungicides is preferable tentatively within acceptable marginal rate of return and very large net benefit for all tested a fungicide frequency point of view.

Conclusions

The result analysis of variance showed that there was highly significant difference between the new test fungicides Star (Tebuconazole 25 EW), Top acanazole, Trial zole, Top-ozole along with the standard check of Take off 293% SC, Tilt 250% and unsprayed plot(control) by reducing both yellow rust and stem rust diseases of Area under disease progressing curve, Relative area under disease progressing curve, coefficient infection, final rust severity. The agronomic result showed that there was a significant difference between the new test fungicides Star (1.5l/ha), Top acanazole(0.75 l/ha), Trail-Zole (0.5l/ha), Top-ozole(0.5 L/ha) along with the standard check of Take off 293% SC(l/ha), Tilt 250%(1l/ha)and unsprayed plot(control) in controlling wheat yellow rust and stem rust diseases by provided better biomass yield, grain yield, and other agronomic parameters. These fungicides reduced both yellow rust and stem rust diseases severity to the lowest level possible and revealed grain yield advantage better than the standard checks and nil fungicide (control) application.

Recommendation

The disease assessment and evaluation result of the newly verified fungicides indicated that there was very effective in controlling both yellow rust and stem rust diseases of wheat. Therefore, based on partial budget analysis, yield and rust disease control, using of Star (1.5l/ha), Top acanazole(0.75 l/ha), Trail-Zole (0.5l/ha), and Top-ozole(0.5 L/ha) fungicide which leads to the optimum yield of bread wheat by decreasing rusts and can be recommended for the registration and other areas with similar agro-ecologies.

Significance Statement

Wheat is the major crop cultivated in the zone. However, there is limited information on the performance and variability of most effective fungicides. The low yield in this area is mainly attributed to recurrent resistance and low adoption of most effective fungicides. Hence, it is paramount to introduce most effective fungicides to the target area for improved wheat production and productivity across the areas. Therefore, this experiment was conducted to recommend the most effective fungicides. Two fungicides are recommended for demonstration and popularization in the study area and similar agro-ecology of the zone.

Author Statements

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References

1. Alemu A, Alemayehu CH, Elfinesh S. Effect of varieties, fungicides and application frequencies to wheat yellow rust disease (Puccinia striiformis f. sp. tritici) management in Arsi Highlands of Ethiopia. American Journal of Bio Science. 2019; 7: 113-122.

2. Ali S, Leconte M, Walker AS, Enjalbert J, de Vallavieille-Pope C. Reduction in the sex ability of worldwide clonal populations of Puccinia striiformis f. sp. tritici. Fungal Genetics and Biology. 2010; 47: 828–838.

3. Ayele B, Fehrmann H, Yahyaoui A. Status of wheat stripe rust (Puccinia striiformis) races and their virulence in major wheat growing areas of Ethiopia. Pest Management Journal of Ethiopia. 2008; 12: 1-7

4. Chen WQ, Kang ZS, Ma ZH, Xu SC, Jin SL, Jiang YY. Integrated managem ent of wheat stripe rust caused by Puccinia striiformis f. sp.tritici in China. Sci Agric Sin. 2013; 46: 4254–4262.

5. CIMMYT. From agronomic data to farmer recommendations: An Economics Work boo k. CIMMYT, ISBN 968-127-19-4, Mexico. 1988; 8-28.

6. Cooper J, Dobson H. The benefits of pesticides to mankind and the environment. Journal of Crop protection. 2007; 26: 1337-1348.

7. CSA (Central Statistical Agency). Agricultural sample survey, 2020/2021 (Report on area and production of crops (Private peasant holdings, main season). Statistical Aut hority, Addis Ababa, Ethiopia. Statistical Bulletin No. 446. 2021; 5: 60.

8. Dereje H, Chemeda F. Relationship between stripe rust (Puccinia striiformis) and grain quality of bread wheat (Triticumaestivum) in the highlands of Bale, South Eastern Ethiopia. International Journal of Food, Agriculture and Environment. 2007; 5: 24-30.

9. FAO, IFAD, UNICEF, WFP, and WHO. The state of food security and nutrition in the world 2018. (Building climate resilience for food security and nutrition) (pp.202). FAO .License: CC BYNCSA 3.0 IGO.ISBN9789251305713. 2021.

10. German S, Campos P, Chaves M, Madariaga R, Kohli M. Challenges in controlling leaf rust in the Southern Cone region of South America. BGRI Technical Workshop. St. Paul, Minnesota. 2011.

11. CIMMYT (International Maize and Wheat Improvement Center). Farm agronomic data to farmer recommendations: An economics training manual. Completely revised edition. CIMMYT. 968-6127-18-6. 1988.

12. Jemal Abdulkerim, Tamado Tana, Firdissa Eticha. Response of Bread Wheat (Tritic um aestivum L.) Varieties to Seeding Rates at Kulumsa, South Eastern Ethiopia. Asian Journal of Plant Sciences. 2015; 14: 50-58.

13. Kebede Tadesse, Ayalew Amare, Ayele Badebo. Effect of Tilt on the development of wheat stem rust and yield of wheat varieties in highlands of Ethiopia. African Crop Science Journal. 2010; 18: 23-33.

14. Line RF. Stripe rust of wheat and barley in North America: a retrospective historical review. Annual Review of Phytopathology. 2002; 40: 75-118.

15. McIntosh RA, Hart GE, Devos KM, Rogers WJ, Morris CF, Appels R. et al. Catalogue of gene symbols for wheat: 2007 supplement. 2007.

16. Roelfs AP, Singh RP, Saari EE. Rust Diseases of Wheat: Concepts and Metho ds of Disease Management. CIMMYT, Mexico, D. F. P. 1992; 81.

17. Rowell JB. Chemical control of the cereal rusts. Annual Review Phytopathol. 1968; 6: 243-262.

18. Shahzad MA, Wasi-ud-Din, Sahi ST, Khan MM, Ehsanullah, Ahmad M. Effect of sowing dates and seed treatment on grain yield and quality of wheat. Pakistan Journal of Agriculture Science. 2007; 44: 581-583.

19. Tadesse K, Ayalew A, Badebo A. Effect of fungicide on the development of wheat stem rust and yield of wheat varieties in highlands of Ethiopia. African Crop Science Journal. 2010; 18: 23–33.

20. Wegulo SN, Breathnach JA, Baenziger PS. Effect of growth stage on the relationship between tan spot and spot blotch severity and yield in winter wheat. Crop Protection. 2009; 28: 696-702.

21. Worku D, Ayele B, Tameru A. Evaluation of ethiopian commercial wheat cultivars for resistance to stem rust of wheat race ‘UG99’. International Journal of Agronomy and Plant Production. 2013; 4: 15–24.

22. Wubishet A, Chemeda F. Effects of Environment on Wheat Varieties’ Yellow Rust Resistance, Yield and Yield Related Traits in South-Eastern Ethiopia. Science publishing group. Plant. 2016; 4: 14-22.

23. Wubishet Alemu, Tamen Mideksa. Verification and Evaluation of Fungicide 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 (IJRSAS). 2016; 2: 35-40.

24. Wubishet A, Chemeda F. Effects of environment on wheat varieties’ Yellow Rust resistance, yield and yield related traits in South-Eastern Ethiopia. Plant. 2016; 4: 14–22.

25. Wubishet A, Tamene M. 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. 2016; 2: 35–40.

26. Wubishet A, Chemeda F, Bekele H. 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. 2015; 3: 096–107.

27. Zheng W, Huang L, Huang J, Wang X, Chen X, Zhao J, et al. High genome heterozygosity and endemic genetic recombination in the wheat stripe rust fungus. Nature Communications. 2010; 4: 2673.