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Effect of Varieties, Fungicides and Application Frequencies to Wheat Yellow Rust Disease (*Puccinia striiformis* f. sp. *tritici*) Management in Arsi Highlands of Ethiopia

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Abstract: Wheat is one of Ethiopia's foremost important cereal crops in terms of area coverage and volume produced. However, the production and productivity of wheat is constrained by various biotic and a biotic stresses, among which wheat yellow rust disease caused by *Puccinia striiformis* f.sp.*tritici* is the one. Field experiments were conducted to develop integrated wheat yellow rust management strategy based on optimal frequency of fungicide application and wheat varieties combination at hotspot environments of Meraro and Bekoji, Arsi zone, in 2017 main cropping season. Treatments included two different fungicides, Epoxiconazole + Thiophanate-methyl and Propiconazole applied in two frequencies; and four bread wheat cultivars (Kubsa, Danda'a, Lemu and Wane), known for their differential reaction to the disease. Unsprayed controls were also included for comparison purposes. The experiment was laid out in randomized complete block design in factorial arrangement with three replications. Terminal severity levels up to 13%, 37%, 53% and 90% at Bekoji, and 11.67%, 53.3%, 58.33%, 92% at Meraro were recorded on the unsprayed varieties of Wane, Lemu, Danda'a and Kubsa, respectively. Twice application frequency of Epoxiconazole + Thiophanate-methyl resulted in a significant ($P<0.01$) grain yield increment of up to 95.3%, 76.4%, and 1086.8% at Bekoji and 129.7%, 135.5%, 2883.2% at Meraro on unsprayed plots of Lemu, Danda'a, and Kubsa, respectively. But yield increments as a result of fungicide applications were relatively lower (29.8% and 65.9% at Bekoji and Meraro, respectively) on the resistant variety Wane. Twice application of Epoxiconazole + Thiophanate-methyl at 15 days interval starting from the appearance of disease has proved the most effective in terms of reducing the level of stripe rust, and increasing grain and crop biomass yield. The current findings demonstrate the role fungicides and host resistance may play in effectively managing stripe rust of wheat. However, further research is needed to come up with other management options to sustainable and cost effective manage the disease under different agro-ecological settings.

Keywords: AUDPC, Bread Wheat, Fungicide, Incidence, Infection Rate, Severity, Yield, Yellow Rust

1. Introduction

Wheat (*Triticum aestivum*) is one of the major food crops used by more than one-third of world's population as a staple food [1]. The current total area devoted to wheat production in Ethiopia is estimated to be over 1.6 million hectare (13% of national cereal acreage); fourth in area coverage and third in amount of grain production (3.9 million tons) following maize and tef [2]. Despite the large area under wheat production, average yield in Ethiopia is estimated around 2.54 t ha^{-1}, which is far less than potential yields of 8 to 10 t ha^{-1} [2]. This low productivity is partially attributed to the prevalence of various wheat diseases including rusts as well as insect pests, weeds and lack of high yielding varieties.

Wheat stripe rust, caused by *Puccinia striiformis* is one of the most widespread and destructive diseases of wheat worldwide [3], especially in cool climates, present in almost all the wheat growing areas of the world and a formidable threat to global wheat production [4-6]. It is also one of the most important fungal diseases of wheat and the major production bottleneck in the major wheat producing regions of Ethiopia [7]. Arsi and Bale regions are the known hotspots for the epidemics of stripe rust of wheat [8]. The main reasons for periodic outbreaks of yellow rust in Ethiopia are the scarce information on the genetic variation of host-pathogen interactions and unreliability of current sources of resistance to the prevailing race population [9].

Utilization of genetic resistance or disease resistant variety is likely to be the most economical and environmental friendly control measure [5, 10]. However, varieties with a specific resistance gene usually remain effective only for a few years because the extreme selection pressure on the pathogen population with mutants results in a gain in virulence in the pathogen population for that particular gene. The frequent failure of resistant wheat varieties due to changes in pathogen virulence has increased the interest in chemical control of stripe rust for the global food security [11].

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 stripe rust which prevented multimillion dollar losses and significantly reducing crop loss [12]. The timely and proper use of fungicides gives benefits in the effort to increase crop productivity [13, 14] 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 plant 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% [15]. In Australia, foliar fungicide spraying has increased due to the breakdown of resistance to stripe rust in wheat varieties [16]. In China, epidemics of stripe rust in 1950, 1964, 1990, and 2002 resulted in losses of 6.0, 3.2, 1.8 and 1.3 million metric tons, respectively [17].

Yellow rust development on wheat is reduced by fungicide application immediately after the disease symptom appeared. Fungicidal control of yellow rust increased yield of a susceptible variety grown in a high yielding environment, compared with an untreated control. This improved grain yield is especially significant since the high-yielding environment is also conducive to yellow rust development. Wheat grown in a higher-yield potential (highland) environment may be more likely to produce a yield response. Fungicide tests in Kenya showed 50% higher yield in the treated versus the untreated plots [18]. Timely application of fungicides effectively prevented yield losses and further spread of the disease to the wheat production regions, and potentially huge nationwide yield loss was avoided through use of fungicides [17]. The use of chemicals had helped in significantly reducing crop loss during the 2010 yellow rust epidemic [8].

All the current commercial wheat cultivars in East Africa are susceptible to the new race and it is not possible to grow a profitable crop of wheat without the application of fungicides [18]. Due to variable environmental conditions and new race formation, different fungicide-variety combinations should be tested across locations. Hence, the present investigations were carried out to develop integrated wheat yellow rust management strategy for hotspot areas of Ethiopia.

2. Materials and Methods

The study was undertaken at Kulumsa Agricultural Research Center, sub-stations Bekoji and Meraro, in Arsi highlands of South Eastern Ethiopia during 2017 main cropping season**.** Bekoji substation is located at 07°32'37"N, 39°15'21"E and at 2780 meters above sea level (m.a.sl). It receives mean annual rainfall of 1020 mm representing highland & high rainfall agro ecology. The monthly mean minimum and maximum temperature is 7.9 and 18.6°C, respectively. The dominant soil type is Clay soil (Nitosols) which is slightly acidic (pH=5.0). Meraro substation is located at 07°24'27"N, 39°14'56"E and 2990 masl. Its average annual rainfall is 1196 mm representing extreme highland and frost prone agro ecology. The minimum and maximum temperature is 5.7 and 18.1°C, respectively. The dominant soil type is Clay soil (Nitosols) which is similar with Bekoji's soil type [19]. Both locations represent major wheat-growing and yellow rust prone areas in the highlands of Arsi. They are also characterized by bimodal rainfall, the short rainy season extending from March to May and the main rainy season from June to September.

Treatments and Experimental design

The experiment was laid out in randomized complete block design (RCBD) in factorial arrangement with three replications.

Wheat varieties and growing conditions

Four bread wheat varieties namely Kubsa, Wane, Danda'a and Lemmu that were released from Kulumsa Agricultural Research Center KARC were used for the experiment (Table 1). These varieties were selected based on their response to stripe rust with Kubsa being susceptible, Danda'a moderately susceptible, Lemu moderately resistant and Wane resistant. All varieties were sown at the recommended rate of 100 kg seed ha^{-1} to six row plots of 2.5m length and 1.2m width with 20 cm inter-row spacing. The gaps between plots and replications were 1m and 1.5m, respectively. Spreader rows consisting of a mixture of highly susceptible bread wheat varieties of Morocco, Kubsa and PBW 343 were planted in each border row in order to ensure uniform spread of inocula and sufficient disease development. A seed rate of 100kg/ha was used. Experimental plots were fertilized with Diamonium phosphate (DAP) and Urea (41kgN/46kg $P_2O_5ha^{-1}$) just at planting and weeds were controlled three times by hand weeding.

Fungicide and application frequency

Wheat plots were sprayed with recently registered and widely used fungicides viz. Rex® Duo (Epoxiconazole + Thiophanate-methyl) and Tilt 250EC*(propiconazole) at 0.5lt product ha-^{1}in 250lha^{-1} water using Manual Knapsack Sprayer. The fungicides were applied once and twice, depending on the particular treatment, with an interval of 15 days starting when spreader varieties reached 20% disease severity. During fungicide sprays, plastic sheets were used to protect the adjacent plots from fungicide drifts. Plots with no fungicide treatment were included as checks.

Data collected

Data were recorded on plot and single plant basis in which plot basis data were taken from the central four rows (2 m^2 net areas) of the plot. On the other hand, individual plant based data were also taken from 10 plants in each plot selected randomly from the central four rows of each plot, and means of the 10 plants were used for data analyses.

Disease data

$$\text{Disease incidence} = \frac{\text{No.of diseased plants}}{\text{Total No.of plants examined}} \times 100 \quad (1)$$

$$\text{Disease Severity} = \left(\frac{\text{Area of plant tissue infected}}{\text{Total area of the plant part examined}}\right)\times 100 \quad (2)$$

The percent rust severity control was calculated by the following formula:

$$\text{Percent Disease Control} = \left(\frac{\text{Percent Severity intreated plot}-\text{percent severity in untreated plot}}{\text{percent severity in untreated check}}\right) \times 100 \quad (3)$$

The final disease severity data for the stripe rust was converted into a coefficient of infection (CI) by multiplying severity with a constant value for field response [20].

Area under disease progress curve: calculated using the CI values from the original rust severity data by using the following formula as suggested by [21].

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5\ (xi + 1 + xi)(ti + 1 - ti) \quad (4)$$

where, xi=the average coefficient of infection of ith record, Xi+1=the average coefficient of infection of i+1th record and t i+1-ti=Number of days between the ith record and i+1th record, and n=number of observations.

Infection rate: calculated from the four disease severity observations as a severity of yellow rust infection at the time of rust pustules appearance and every 15 days thereafter. It was estimated using the following formula adopted by [22].

$$\text{Infection rate}=1/t\ (\ln x/1-x) \quad (5)$$

Where x=the percent of severity divided by 100; t=time measured in days.

Agronomic data

All agronomic, yield and yield related components were recorded on the middle four rows of each experimental unit. The parameters from which data was collected along with their details are mentioned below:

Plant height (PH): Average heights of 10 plants, tagged in each experimental plot were measured in centimeters from ground level to the tip of the spike, excluding awns.

Spike Length (SL): the main spikes from the five sampled plants were measured and average to represent the spike length in centimeters.

Number of grains per spike (NG): The number of grains of the main tillers of each of the ten randomly taken plants for each experimental unit were recorded and the average of the ten plants was used for analysis.

Thousand Seed weight (TSW): The weights of thousand seeds were determined by carefully using a seed counter, adjusting to 12.5% moisture content and weighing them using sensitive balance.

Hectoliter weight (HLW):-Grain weight of one-litter volume (random sample) was estimated for each experimental unit by following standard procedure [23] and the result was converted to ghl^{-1}.

Grain yield (GY): Grain yield in g/plot at 12.5% moisture content was recorded and converted to kg/hectare.

The percent yield increments (%YI), thousand-kernel and hectoliter weight of each variety were determined as percentage of that of protected plots of the respective variety. Percent increases in yield and yield components by various treatments were calculated by using the formula:

$$\%\text{YI} = \frac{\text{Y1}-\text{Y2}}{\text{Y2}} \times 100 \quad (6)$$

Where, %YI=Percent yield increment (increment of the parameters grain yield, TKW, and HLW), Y1=mean of the respective parameter on protected plots (plots with maximum protection) and Y2=mean of the respective parameter in unprotected plots (i.e. unsprayed plots or sprayed plots with varying level of disease).

Data analysis

Data from each of the two locations were subjected to analysis of variance (ANOVA) according to [24] using SAS computer software package version 9.0 [25]. Least Significant Difference (LSD 0.01 and 0.05) values were used for mean separation. Data on yellow rust disease parameters, yield and yield components were correlated using the Proc-Corr Pearson's correlation Procedures of SAS computer software package version 9.0 [25].

3. Results

Terminal yellow rust severity

Under natural epidemics (no spray) at Bekoji, terminal yellow rust severities of about 90%, 53.3%, 37% and 13% were recorded on unsprayed plots of susceptible variety (Kubsa), moderately susceptible variety (Danda), moderately resistant variety (Lemu) and resistant variety (Wane), respectively, (Table 1).

Average coefficient of infection

Average coefficient of infection was significantly ($P < 0.01$) affected by treatments and their combinations at both Bekoji and Meraro (Table 1).

Table 1. *Effect of fungicides, fungicide application frequencies and bread wheat varieties on terminal yellow rust severity, percent disease control and average coefficient of infection.*

Treatments		**Bekoji**			**Meraro**		
Variety	**Fungicide**	**TRS%**	**PDC %**	**ACI**	**TRS %**	**PDC %**	**ACI**
	Untreated	13^{i}	0	6^{ij}	11.67^{i}	0	4.7^{h}
	Tilt1	10^{ij}	23.1	2.3^{jkl}	8.33^{ij}	28.6	3.3^{h}
Wane (R)	Tilt2	5^{jk}	61.5	1^{kl}	4.67^{ij}	60	1.9^{h}
	Rex1	10^{ij}	23.1	4^{jkl}	6.67ij	42.84	2.7^{h}
	Rex2	1^{jk}	92.3	0.2^{l}	1.33^{j}	88.9	0.3^{h}
	Untreated	37^{f}	0	33^{e}	53.3^{de}	0	43^{c}
	Tilt1	29^{gh}	21.6	24^{fg}	40^{f}	25	24^{e}
Lemu (MR)	Tilt2	12^{i}	67.6	4.7^{ijk}	30^{gh}	43.7	12^{g}
	Rex1	13^{i}	64.9	8^{i}	30^{gh}	43.7	18^{efg}
	Rex2	5^{jk}	86.5	1^{kl}	5^{ij}	90.6	2^{h}
	Untreated	53^{d}	0	48^{c}	58.33^{cd}	0	53^{b}
	Tilt1	43^{e}	18.9	34^{e}	45^{ef}	22.9	36^{d}
Danda'a (MS)	Tilt2	30^{gh}	43.4	18^{h}	28.3^{gh}	51.5	17^{fg}
	Rex1	25^{h}	52.8	23^{g}	25^{h}	57.1	20^{ef}
	Rex2	13^{i}	75.5	2.7^{jkl}	11.7^{i}	79.9	4.7^{h}
	Untreated	90^{a}	0	81^{a}	92^{a}	0	83^{a}
	Tilt1	70^{b}	22.2	56^{b}	70^{b}	23.9	56^{b}
Kubsa (S)	Tilt2	55^{cd}	38.9	44^{d}	36.7^{fg}	60.1	22^{ef}
	Rex1	60^{c}	33.3	48^{c}	63.3^{bc}	31.2	51^{b}
	Rex2	33^{fg}	63.3	27^{f}	26.7^{h}	71	16^{fg}
CV (%)		10.4		9.33	16.1		15.8
LSD$_{(0.05)}$		5.2		3.86	8.6		6.11

LSD$_{0.05}$=List significant difference at 5%, CV (%) = Coefficient of variation, Means with the same letters with the same columns are not significantly difference. T1=Once application of Tilt 250 EC*, T2=Twice application of Tilt 250 EC*, R1=Once application of Rex® Duo, R2=Twice application of Rex® Duo, TRS=terminal rust severity, PDC=percent disease control, ACI=average coefficient of infection.

Area under disease progress curve

Analysis of variance revealed that fungicide application frequencies and bread wheat varieties showed significantly ($P < 0.05$) difference in area under disease progress curve (AUDPC) of yellow rust at both Bekoji and Meraro (Table 2).

Table 2. *Effect of fungicides, fungicide application frequencies and bread wheat varieties on area under disease progress curve, infection rate and disease incidence.*

Treatments		**Bekoji**			**Meraro**		
Variety	**Fungicide**	**AUDPC**	**IR**	**Incid %**	**AUDPC**	**IR**	**Incid %**
	Untreated	147.7^{ijk}	0.13^{j}	30^{g}	164.3^{r}	0.15^{e-g}	36.7^{fgh}
	Tilt1	118^{kl}	0.13^{j}	21.67^{h}	73.83^{r}	0.02^{fg}	26.7^{gh}
Wane (R)	Tilt2	33^{m}	0.01^{k}	16.67^{hi}	84^{q}	0.09^{e-g}	16.7^{gh}
	Rex1	30^{m}	0.02^{k}	18.33^{h}	64^{s}	0.02^{fg}	10^{h}
	Rex2	21^{m}	-0.02^{k}	11.67^{i}	26.67^{t}	0^{g}	8.3^{h}
	Untreated	472^{f}	0.6^{f}	100^{a}	835^{f}	0.08^{a}	96.7^{ab}
	Tilt1	188.7^{hij}	0.23^{i}	65^{c}	741.7^{h}	0.39^{cd}	90^{abc}
Lemu (MR)	Tilt2	336.7^{g}	0.1^{i}	36.67^{f}	320^{m}	0.09^{e-g}	43.3^{efg}
	Rex1	108.3^{kl}	0.23^{i}	61.67^{cd}	235^{o}	0.24^{de}	66.7^{cde}
	Rex2	65^{lm}	0.0^{1k}	21.67^{h}	270.8^{n}	0^{g}	66.7^{cde}
	Untreated	536.3^{e}	1.02^{c}	100^{a}	678.3^{i}	0.91^{a}	100^{a}
	Tilt1	208^{hi}	0.55^{f}	71.67^{b}	778.3^{g}	0.38^{cd}	80^{a-d}
Danda'a (MS)	Tilt2	196.6^{hij}	0.24^{i}	56.67^{de}	538.3^{i}	0.047^{e-g}	70^{b-e}
	Rex1	208^{hi}	0.36^{h}	53.33^{e}	333.3^{l}	0.23^{d-f}	96.7^{ab}
	Rex2	134.7^{jk}	0.01^{k}	20^{h}	405^{k}	0^{g}	60^{def}
	Untreated	1783.3^{a}	1.16^{a}	100^{a}	1750^{a}	1.11^{a}	100^{a}
	Tilt1	808.3^{d}	1.08^{b}	100^{a}	1566.7^{b}	0.63^{b}	100^{a}
Kubsa (S)	Tilt2	1090^{b}	0.43^{g}	100^{a}	1010^{e}	0.41^{bc}	100^{a}
	Rex1	886.7^{c}	0.88^{d}	100^{a}	1345^{c}	0.46^{bc}	100^{a}
	Rex2	528.3^{ef}	0.0^{k}	100^{a}	1085^{d}	0.01^{fg}	100^{a}
CV (%)		9.7	7.09	6.35	4.5	42.6	25.9
LSD$_{(0.05)}$		63.4	0.05	6.21	6.7	0.22	29.3

LSD$_{0.05}$=List significant difference at 5%, CV (%) = Coefficient of variation, Means with the same letters with the same columns are not significantly difference. T1=Once application of Tilt 250 EC*, T2=Twice application of Tilt 250 EC*, R1=Once application of Rex® Duo, R2=Twice application of Rex® Duo, AUDPC=area under disease progress curve, IR=infection rate, Incid (%) = incidence in percent.

Spike infection

The 15 days interval fungicide sprays significantly reduced spike infection of yellow rust on the varieties (Figure 1).

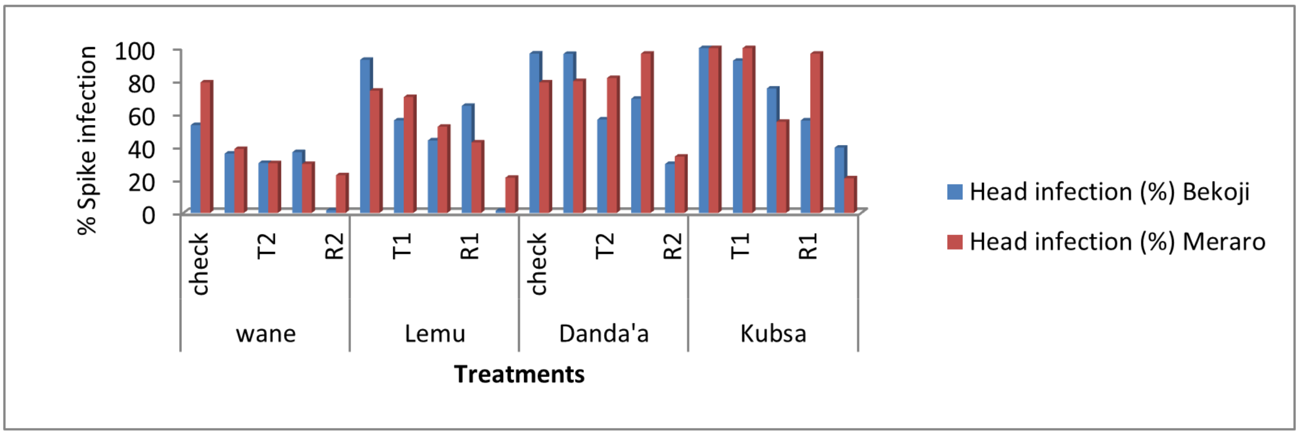

Figure 1. *Effect of fungicide and fungicide frequency on Spike infection of bread wheat varieties at %, T1=Once application of Tilt 250 EC*, T2=Twice application of Tilt 250 EC*, R1=Once application of Rex® Duo, R2=Twice application of Rex® Duo, check=nil application.*

Grain yield

Analysis of variance revealed that the interaction effect of fungicides application frequency and wheat varieties significantly ($P < 0.01$) affected on grain yield at both locations (Table 3).

Table 3. *Effect of fungicides, fungicide application frequencies and bread wheat varieties on grain yield.*

Treatment		**Bekoji**		**Meraro**	
		Grain yield	**Incr**	**Grain yield**	**Incr**
Variety	**Fungicide**	**kgha^{-1}**	**%**	**kgha^{-1}**	**%**
Wane (R)	Untreated	4688.0^{d}	0	2965.0^{f}	0
	Tilt1	4805.0^{cd}	2.5	2978.3^{f}	0.45
	Tilt2	5921.7^{ab}	26.32	4651.7^{b}	56.89
	Rex1	5108.3^{c}	8.96	3335.0^{d}	12.48
	Rex2	6085.0^{a}	29.8	4920.0^{a}	65.94
Lemu (MR)	Untreated	2938.3^{f-}	0	2151.7^{ij}	0
	Tilt1	3048.3^{fg}	3.74	2498.3^{h}	16.11
	Tilt2	4545.0^{d}	54.7	3665.0^{c}	70.33
	Rex1	4151.7^{e}	41.32	3180.0^{e}	47.79
	Rex2	5738.3^{b}	95.3	4943.3^{a}	129.7
Danda'a (MS)	Untreated	2638.3^{hi}	0	1565.0^{l}	0
	Tilt1	2753.3^{g-i}	4.36	1860.0^{k}	18.85
	Tilt2	3955.0^{e}	49.92	2658.3^{g}	69.84
	Rex1	2831.7^{gh}	7.35	2160.0^{i}	38.02
	Rex2	4653.3^{d}	76.38	3685.0^{c}	135.5
Kubsa (S)	Untreated	273.3^{l}	0	106.7^{o}	0
	Tilt1	948.3^{k}	247.25	406.0^{n}	279.4
	Tilt2	2521.7^{i}	823.81	2100.0^{j}	1863
	Rex1	2126.7^{j}	679.12	601.0^{m}	461.7
	Rex2	3240.0^{f}	1086.81	3191.7^{e}	2883
CV%		5.11		1.33	
LSD$_{(0.05)}$		307.73		58.85	

LSD$_{0.05}$=List significant difference at 5%, CV (%) = Coefficient of variation, Means with the same letters with the same columns are not significantly different. T1=Once application of Tilt 250 EC*, T2=Twice application of Tilt 250 EC*, R1=Once application of Rex® Duo, R2=Twice application of Rex® Duo, Incr=increment, %=Percent, R=resistant, MR=moderately resistant, MS=moderately susceptible, S=susceptible.

Thousand Seed weight

Analysis of variance revealed that the interaction effect of fungicides application frequency and wheat varieties showed significantly ($P < 0.01$) difference on thousand seed weight at both locations (Table 4).

Table 4. *Effect of fungicides, fungicide application frequencies and bread wheat varieties on thousand seed weight.*

Treatment		**Bekoji**		**Meraro**	
		TKW	**Incr**	**TKW**	**Incr**
Variety	**Fungicide**	**(g)**	**(%)**	**(g)**	**(%)**
Wane (R)	Untreated	27.6^{d-f}	0	33.7^{i}	0
	Tilt1	30.6^{b-e}	10.87	33.9^{hi}	0.59
	Tilt2	30.2^{b-f}	9.42	37.8^{fg}	12.17
	Rex1	29.2^{c-f}	5.8	36.3^{g}	7.72
	Rex2	33.7^{ab}	22.1	39.3^{ef}	16.62
Lemu (MR)	Untreated	27.9^{d-f}	0	36.2^{gh}	0
	Tilt1	29.6^{c-f}	6.09	38.0^{fg}	4.97
	Tilt2	30.2^{b-f}	8.24	41^{b-e}	11.88
	Rex1	32.5^{a-c}	16.49	36.9^{g}	1.93
	Rex2	34.4^{a}	23.3	42.8^{ab}	18.23
Danda'a (MS)	Untreated	26.4^{fg}	0	42^{a-c}	0
	Tilt1	26.9^{ef}	1.89	42^{a-d}	0
	Tilt2	30.4^{b-e}	13.64	42^{a-d}	0.24
	Rex1	27.9^{d-f}	6.06	43^{a-c}	1.19
	Rex2	32.9^{a-c}	25	43.0^{a}	1.42
Kubsa (S)	Untreated	17.0^{i}	0	36.5^{g}	0
	Tilt1	19.5^{hi}	11.76	39.9^{d-f}	11.11
	Tilt2	31.0^{a-d}	82.35	40^{c-e}	11.94
	Rex1	22.9^{gh}	35.29	40^{def}	10.56
	Rex2	33.4^{ab}	94.12	41^{a-e}	12.5
CV%		8.03		3.61	
$LSD_{(0.05)}$		3.81		2.34	

$LSD_{0.05}$=List significant difference at 5%, CV (%) = Coefficient of variation, Means with the same letters with the same columns are not significantly different. T1=Once application of Tilt 250 EC*, T2=Twice application of Tilt 250 EC*, R1=Once application of Rex® Duo, R2=Twice application of Rex® Duo, TKW=thousand seed weight, Incr=increment, %=Percent, R=resistant, MR=moderately resistant, MS=moderately susceptible, S=susceptible.

Hectoliter weight

Analysis of variance revealed that the interaction effect of fungicides application frequency and wheat varieties showed significantly ($P < 0.01$) difference on hectoliter weight at both locations (Table 5).

Table 5. *Effect of fungicides, fungicide application frequencies and bread wheat varieties on hectoliter weight.*

Treatment		**Bekoji**		**Meraro**	
		HLW	**Incr**	**HLW**	**Incr**
Variety	**Fungicide**	**($kghl^{-1}$)**	**(%)**	**($kghl^{-1}$)**	**(%)**
Wane (R)	Untreated	59.5^{f-i}	0	66.6^{cd}	0
	Tilt1	60.9^{d-h}	2.35	66.8^{cd}	0.3
	Tilt2	61.9^{c-g}	4.03	68.0^{c}	2.1
	Rex1	60.2^{e-i}	1.18	68.7^{bc}	3.15
	Rex2	65.4^{a-c}	9.92	73.4^{a}	10.21
Lemu (MR)	Untreated	56.4^{ij}	0	61.9^{ef}	0
	Tilt1	57.2^{h-j}	1.42	67.4^{cd}	8.89
	Tilt2	62.7^{c-f}	11.17	71^{a-c}	14.86
	Rex1	60.6^{e-h}	7.45	67.8c	9.53
	Rex2	63.9^{b-e}	13.3	71^{a-c}	15.02
Danda'a (MS)	Untreated	43.8^{l}	0	61^{e-g}	0
	Tilt1	50.1^{k}	14.38	66.6^{cd}	10.08
	Tilt2	55.1^{j}	25.57	67.9^{c}	12.23
	Rex1	49.5^{k}	11.87	63.2^{de}	4.46
	Rex2	58.7^{g-j}	34.7	71^{a-c}	16.86
Kubsa (S)	Untreated	23.3^{m}	0	56.7^{g}	0
	Tilt1	23.3^{m}	0	61.7^{ef}	8.82
	Tilt2	64.5^{a-d}	178.3	71^{a-c}	25.04
	Rex1	66.5^{ab}	187	70^{a-c}	23.28
	Rex2	68.0^{a}	195.7	72.9^{ab}	28.57
CV%		4.14		4.13	
$LSD_{(0.05)}$		3.79		4.55	

$LSD_{0.05}$=List significant difference at 5%, CV (%) = Coefficient of variation, Means with the same letters with the same columns are not significantly different. T1=Once application of Tilt 250 EC*, T2=Twice application of Tilt 250 EC*, R1=Once application of Rex® Duo, R2=Twice application of Rex® Duo, HLW=hectoliter weight in $kghl^{-1}$, Incr=increment, %=Percent, R=resistant, MR=moderately resistant, MS=moderately susceptible, S=susceptible.

4. Discussion

The terminal yellow rust severity after once spray of Rex® Duo was reduced by 33%, 13%, 5% and 1% on Kubsa, Danda, Lemu and Wane varieties, respectively. At Meraro, the terminal yellow rust severities 92%, 58.3%, 53.3% and 11.67% were recorded on unsprayed plots of Kubsa, Danda, Lemu and Wane varieties, respectively. After two application of Rex® Duo, it varied from 1.33% on the resistant variety (Wane) to 26.7% on the susceptible variety (Kubsa). The moderately resistant and susceptible varieties had intermediate disease levels. The lowest terminal yellow rust severity (1%) was recorded in twice application frequency of Rex® Duo followed by twice application frequency of Tilt 250 EC with (1.3%) on resistant and (5%) on the moderately resistant varieties at both locations. The highest disease severity (90 and 92%) was recorded in unsprayed plots of the susceptible variety at Bekoji and Meraro, respectively. The application of fungicides reduced stripe rust by 39 to 92% depending on the wheat variety. Among the two fungicides foliar sprays twice application frequency of Rex® Duo was found most effective against rust and it gave the highest disease control (63-92%) followed by twice application frequency of Tilt 250 EC which reduced stripe rust by 39-68% over the untreated control (Table 1).

Overall, local variations in rust severity occurred and this is perhaps related to differences in weather conditions. Despite variations, the four wheat varieties were attacked by stripe rust in the absence of fungicide application suggesting the lack of immunity or complete resistance among the varieties tested in the current experiment. The fungicide treatments were effective in reducing disease severity. This is in agreement with the work done by [26], who reported that fungicide application increases the control of yellow rust over the untreated control treatments. [27] also reported that sprays of Tilt 250 EC reduced rust severity, increased grain and forage yield of pearl millet. [28] concluded that to get the maximum protection from yellow rust, the fungicide should be sprayed either at flag leaf emergence or when about 20% of leaves showed symptoms.

At Bekoji, average coefficient of infection on unsprayed plots varied from 6% on the resistant variety (Wane) to 81% on the susceptible variety (Kubsa). The average coefficient of infection after 2nd spray fungicide ranged from 0.2 on the resistant variety (Wane) to 27% on the susceptible variety (Kubsa) (Table 1). At Meraro, average coefficient of infection on unsprayed plots ranged from 4.7% on the resistant variety (Wane) to 83% on the susceptible variety (Kubsa). Fungicide sprays resulted in significant decrease in the average coefficient of infection over the unsprayed plots albeit variations between fungicides and their application frequencies.

At Bekoji, AUDPC values on untreated plots varied from 147.7 on the resistant variety (Wane) to 1783.3 on the susceptible variety (Kubsa) (Table 2). On the other hand, the AUDPC values on treated plots varied between 21 on the resistant variety and 528.3 on the susceptible variety. At Meraro, AUDPC values on untreated plots ranged from 164 on the resistant variety (Wane) to 1750 on the susceptible variety (Kubsa). On the other hand, on treated plots, AUDPC values varied from 27 on the resistant variety to 1085 on the susceptible variety (Table 2). The lowest AUDPC value was recorded from the resistant variety (Wane) treated with two applications of Rex® Duo at both locations. (29) also reported higher AUDPC values in untreated plots as compared to treated plots. The twice application frequency of Rex® Duo was significantly different from other spray schedules having a mean value of AUDPC of 187.5 and 446.9 at Meraro and Bekoji, respectively, (Table 2). The mean value for this parameter was lower at Bekoji than Meraro. The highest mean value of AUDPC (734.8 at Bekoji) and (856.9 at Meraro) was recorded on untreated plots.

AUDPC is the result of all factors that influenced disease development such as environments, cultivars and population of the pathogen [30]. As a result it gives a better indication on disease development over time, which is essential to predict yield losses. For yellow rust, it has been reported that fungicides reduced subsequent disease progress on plant parts that were slightly infected at the time of fungicide application, but they were not effective on plant parts that were heavily infected [beard]. Therefore, the yellow rust control strategy through fungicide must consider the time of onset, early detection of the disease and early application of fungicides if economic control of the disease is intended [31-32]. On the other hand, propiconazole has shown only minimal symplastic movement (transport in the living part), which implies poor control of disease at blade leaf part of plants following foliar application [33]. This might have also contributed to the reduced effect of the fungicide on further progress of yellow rust when it was applied less frequently.

In general, the less frequent sprays allowed development of multiple levels of epidemics and were not effective in controlling the disease on Kubsa and Danda'a as stripe rust severity exceeded 20% within two weeks of its appearance. These results reiterate the role of varietal resistance in determining the frequency and effectiveness of chemical sprays once rust is established, [34] reported that the more resistant cultivars had very low AUDPCs and would probably not benefit from an application of fungicide to control stripe rust, unless the pathotype present was highly virulent against these cultivars.

Infection rate

At Bekoji, infection rate of yellow rust on untreated plots varied from 0.13 units' day^{-1} on the resistant variety (Wane) to 1.16 units' day^{-1}on the susceptible variety (Kubsa). On treated plots, however, it ranged from-0.02 units day^{-1} on the resistant variety to 0.02 units day^{-1} on the susceptible variety (Table 2). At Meraro, the infection rate on untreated plots varied from 0.15 units day^{-1} on the resistant variety (Wane) to 1.11 units day^{-1} on the susceptible variety (Kubsa) (Table 2). Rate of infection on treated plots was 0 on the resistant, moderately resistant and moderately susceptible varieties while it was 0.01 units day^{-1} on the susceptible variety. The lowest rate of infection was also obtained from twice application frequency of Rex® Duo regardless of the wheat varieties. As pointed out by Campbell (1998), AUDPC and apparent infection rate are suited to answer specific questions about the epidemics to be compared; AUDPC shows the level of disease that induces stress during the season and can be used as predictor of yield; while infection rate answers the question 'does disease develop more rapidly in plots of treatment A than in plots of treatment B?'. As evidenced in the current experiment, the fungicide treatments were effective in markedly slowing down the progress of the disease.

In 15 days interval sprayed plots, the spike of infection of wane, Lemu, Danda'a and Kubsa at twice Rex® Duo application frequency had 1.6, 1.4, 29.7 and 39.9% at Bekoji and 22.9, 21.4, 34.2 and 21% at Meraro while at nil fungicide application, it had 53.3, 92.9, 96.7 and 100% spike infection at Bekoji and 79.2, 74.2, 79.2 and 100% spike infection at Meraro on varieties of Wane, Lemu, Danda'a and Kubsa respectively (Figure 1). The maximum spike infection of yellow rust had scored on Kubsa 100% and also had affected by the fungicide treatments. In the unsprayed plots in all varieties at both locations, were significantly different from the 15 days interval sprayed plots of the all treatments.

At Bekoji grain yield on untreated plots were 273.3 kgha^{-1} on susceptible (Kubsa), 2638.3 kgha^{-1}on moderately susceptible (Danda'a), 2938.3 kgha^{-1} on moderately resistant (Lemu) and 4688 kgha^{-1} on resistant varieties (Wane) (Table 3). Grain yield on treated plots varied from 3240.0 kgha^{-1}on the susceptible variety to 6085 kgha^{-1}on the resistant variety. At Meraro, grain yield on untreated plots varied from 106.7 kgha^{-1} on the susceptible to 2965 kgha^{-1} the resistant varieties (Table 3). Grain yield on treated plots at Meraro were ranged from 3191.5 kgha^{-1} on the susceptible (Kubsa) to 4920 kgha^{-1} on resistant varieties (Wane). Twice application of both fungicides, Rex® Duo and Tilt 250 EC, were effective in obtaining higher yields. The result was in accordance with that of [35], who reported that yield increased in range between 34% and 41% over untreated plots when wheat was treated with foliar fungicides. [36] on the other hand reported yield increase in several years of study due to a single fungicide treatment during the period 1983-2007.

At Bekoji thousand seed weight on untreated plots were recorded 17.0 g on susceptible (Kubsa), 26.4 g on moderately susceptible (Danda'a), 27.9 g on moderately resistant (Lemu) and 27.0 g on resistant varieties (Wane) (Table 4). Thousand seed weight on treated plots was 33.4g on susceptible, 32.9g on moderately susceptible, 34.4gon moderately resistant and 33.7g on resistant varieties. Thousand seed weight on untreated plots at Meraro were 36.5g on susceptible (Kubsa), 42g on moderately susceptible (Danda'a), 36.2g on moderately resistant (Lemu) and 33.7 on resistant varieties (Wane). Thousand seed weight on treated plots varied from 72.9g on susceptible variety to 73.4g resistant variety. Treatments with twice fungicide application frequency had significantly higher thousand seed weights ($p<0.05$) than either once and nil fungicide sprayed at both locations. These findings are similar to [37-39], who reported similar effects of fungicide application on increased kernel weight.

At Bekoji hectolitre weight on untreated plots varied from 23.3 kghl^{-1} on susceptible (Kubsa) to 59.5 kghl^{-1}on resistant varieties (Wane) (Table 5). Hectolitre weight on treated plots ranged from 58.7 kghl^{-1} on moderately the susceptible to 68.0 kghl^{-1} on the susceptible varieties. At Meraro, Hectolitre weight on untreated plots was recorded 56.7kghl^{-1} on susceptible (Kubsa), 60.5 kghl^{-1}on moderately susceptible (Danda'a), 61.9kghl^{-1} on moderately resistant (Lemu) and 66.6 kghl^{-1}on resistant varieties (Wane). On treated plots, Hectolitre weight varied from 70.7 kghl^{-1} on the moderately susceptible to 73.4kghl^{-1}the resistant varieties. [40] suggested that shrivelling of wheat kernels reduces flour yield and the work of [41] indicated that stripe rust affected grains resulted in lower dough strength (the physical strength to resist extension), which in turn, could affect baking quality.

5. Conclusion

There is need to quantify the effect of stripe rust on the yield and yield components of bread wheat varieties and evaluate integrated effect of bread wheat varieties in response to reaction and fungicide frequency that can effectively control the disease and increase yield. Therefore, the present study aims to contribute towards integrated management of wheat yellow rust for improved yield and physical qualities of bread wheat in Ethiopia. For this purpose, field experiment was conducted during 2017/18 cropping season at yellow rust hotspot areas of Arsi highlands of Ethiopia.

Yellow rust disease resulted in significant reduction in grain yield, hectolitre weight (HLW), and thousand kernel weight (TKW) during main cropping season. Evaluation of fungicides and fungicides frequencies based on the response of bread wheat varieties confirmed that varieties having susceptible, moderately susceptible and moderately resistant reaction to yellow rust disease performed when treated with twice frequency of Rex® Duo at 15 days interval at both locations. Twice application of Rex® Duo at 15 days interval starting from the appearance of disease was proved to be most effective against stripe rust increased grain yield and crop biomass yield and highest net monetary returns of grain followed by twice application of Tilt 250 EC*, once application of Rex® Duo and Tilt 250 EC*, over control treatment.

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