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Losses Caused by Stem Rust (*Puccinia graminis* f.sp. *tritici*) on Durum Wheat in Ethiopia

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Abstract: Stem rust caused by *Puccinia graminis* f.sp. *tritici* is one of the major biotic constraints of wheat production. The disease may cause substantial quantitative and qualitative yield losses but much of the work in Ethiopia on this pathosystem focuses on quantitative yield loss of durum wheat. This work was carried out at Debre Zeit Agriculture Research Centre during 2015/16 and 2016/17 main and off seasons. Hence the current study was conducted with the objectives to quantify the amount of loss in grain yield due to stem rust and assess the relationship between disease parameters, grain yield and physical quality parameters of improved durum wheat varieties grown in Ethiopia. Artificial inoculation was performed using a mixture of different dominant stem rust races. There were treated and untreated plots by fungicide that serves as protected and unprotected plots, respectively. Disease severity was recorded each 10 days interval and area under disease progress curve (AUDPC), terminal severity and coefficient of infection were calculated. The tested cultivars exhibited different disease severity level, having the mean value of 6.7-76%. High values of area under disease progress curve (AUDPC) were detected on Hitossa, Utuba (1225.7, 585.9). Whereas the lowest values of yield loss were recorded on cvs. Mangudo and Utuba having the mean value of yield loss 40.2 and 44.8%, respectively. The highest yield loss was observed on susceptible variety Hitosa showing the mean value of 70%. Correlation coefficients were tested between yield losses and values of AUDPC, final stem rust severity, coefficient of infection and rate of infection of the tested cultivars. There was strong correlation coefficients among disease parameters (r=0.72-0.99). There was also moderate strong negative correlation coefficient among disease parameters and yield, hectoliter weight and 1000-kernel weight of the test cultivars (r=-0.53 to -0.81). The current study indicated that application of Rex Duo can be used in minimizing yield losses caused by stem rust disease of durum wheat. Therefore, supporting the released durum wheat cultivars with fungicide application is the most pertinent issue in Ethiopia as most of the durum wheat cultivars in farmers hand were moderately susceptible to susceptible cultivars Pgt races.

Keywords: Stem Rust, Losses, Yield, Rex Duo, Durum Wheat

1. Introduction

Stem rust or black rust caused by *puccinia graminis* f.sp. *tritici*, is the most destructive disease of wheat. Stem rust can occur in all wheat production areas where the environment is favorable for disease development [15]. Under favorable conditions, stem rust cause yield loss up to 100% to the susceptible varieties [12, 7].

The new stem rust race which was designated as Ug99 in Uganda in 1999 has threatened wheat production globally [10]. [17] Designated this strain as race TTKS using the letter code stem rust nomenclature system [13]. A fifth set of differential lines was added, thus Pgt-Ug99 is race TTKSK and variants with added virulence to Sr 24 and Sr 36 is TTKST and TTTSK, respectively [3, 4]. Four other variants of the Ug99 race lineage (TTKSF, TTKSP, PTKSK, and PTKST) are present in different parts of Africa [10]. Race TTKSK and its variants are virulent to about 90% of the world's wheat cultivars [15]. Race Ug99 is virulent to a number of stem rust resistance genes, most notably Sr 31 for which Ug99 was the first reported virulent race. Also, Ug99 is highly damaging which was reported to cause yield losses of more than 71% in experimental fields [1]. Host resistance is the effective control method for stem rust and has been used worldwide for over 50 years, but TTKSK is virulent to most Sr genes [5]. Among 60 designated and a few undesignated stem rust resistance genes in wheat, only eight designated genes in the primary gene pool (Sr 13, Sr 14, Sr 22, Sr 28, Sr 33, Sr 35, Sr 42, and Sr 45) confer resistance to TTKSK [11, 5, 2]. Although host resistance to stem rust has generally provided adequate protection without the need for chemicals [9, 16], it is important to evaluate popular commercial cultivars and other improved wheat varieties that may have the potential to replace current susceptible varieties. Recent study by [19] indicated that the races are highly virulent and affect most Sr genes except Sr31 and Sr24. From the race analysis result, TTTTF, and TKKTF have the broadest virulence spectrum race, which affects 90% of the Sr genes. During the past six decades > 160 bread or durum wheat varieties have been released in Ethiopia with the aim of increasing yields and improving disease resistance.

Currently most of them are susceptible to either stem rust or yellow rust or for both rusts. Recurrent epidemics have occurred during the last decades; including a major wheat stripe rust epidemic in 2010 [9] and a large wheat stem rust outbreak caused by race TKTTF in 2013 with yield losses up to 100% and average losses of approximately 50% (Sanders R, 2011). So for many studies have been conducted on both bread and durum wheat but yield losses caused by stem rust on durum wheat cultivar (s) was or were not studied.

Therefore the current study was conducted with the objectives to quantify the amount of losses in grain yield, hectoliter weight and 1000-kernel weight due to stem rust and assess the relationship between disease parameters and grain yield, hectoliter weight and 1000-kernel weight losses of improved durum wheat varieties grown in Ethiopia

2. Materials and Methods

The experiment was performed in 2016/17 main and off-seasons at Debre Zeit Agricultural Research Center, using three durum wheat varieties. The experimental site was located at latitude of 8°44' N, longitude of 39°2' E. Debre Zeit is mid-highland with altitude of 1900m.a.s.l. and characterized by moderate rainfall (851mm total annual rainfall), average minimum temperature of 8.9°C and mean maximum temperature of 28.3°C. Durum wheat cultivars having different responses to stem rust were evaluated (Table 1).

***Table 1.** Description of durum wheat varieties used in the experiment.*

Cultivars	Year of Release	Pedigree/ Selection History	Source/Origin	(altitude, m.a.s.l)	Response of the cultivars
Mangudo	2012	MRF_ 1STJ2/3/1718BT24//KARIM	CIMMYT/EIAR	1800-2700	MS
Utuba	2015	IDON-MD-2009_off/53/2009	ICARDA/EIAR	1800-2750	MSS
Hitosa (S)	2008	CHEN/ALTAR-84	CIMMYT/OARI	1800-2650	S

Note:- MS: Moderately susceptible; MSS: Moderately Susceptible to Susceptible; S: Susceptible

Eighteen plots (2.5m x 1.2 m=3m^2.) each plot contained six rows with 2.5m and 20 cm between rows. Randomized Complete Block design with three replicates was used.

Stem rust epidemic was initiated by inoculating spreader rows with the mixture of virulent stem rust races at equal proportions. The spreader rows included Malefia, Local red, Arendato, Digalu and PBW343 and they were planted in a mixture of 25% each. Spreaders were planted along the border of experimental plots [6] seven days before the test varieties were planted. Each spreader row was inoculated using the mixtures of each race following the method proposed by [17].

A total of three inoculations were carried out to ensure enough disease pressure and inoculums source to the experimental field. The first two inoculations were done through injection at stem elongation growth stage (Zadoks *et al.,* 1974). Injection of the spreader rows was done at 0.5m intervals using 10ml syringe and randomly plants were inoculated for each single row spreader. The third inoculation was carried at booting growth stage through a battery-powered ultra-low-volume sprayer (Bromyard Industrial Estate, HR7 4HS, United Kingdom).

The stem rust severity scoring started when the infector rows attained about 30% susceptible responses based on modified Cobbs' scale; where 0%=immune and 100%=completely susceptible [22]. From each plot about twenty plants were selected and disease scored for each selected plants. Disease scoring started a week before Rex Duo application was done when 50% of the spreader rows were infected.

The coefficient of infection (COI) for each variety was computed as follows.

COI=Final stem rust severity x the constant value for each response

COI=Coefficient of infection

Yield loss was estimated using simple equation as follows:

Loss%=1-yd/yh*100 [20]

Where: Yd=yield of diseased plants

Yh=yield of healthy plants

The AUDPC is calculated using the midpoint rule method [21] as follows:

$$AUDPC = \sum_{i=1}^{n-1} (y_i + y_{i+1}) / 2 \times (t_{i+1} - t_i)$$

Where "y" is the percentage of affected tissue at each reading, "t" is time in days of each reading and "n" is the number of readings.

The Area Under Disease Progress Curve (AUDPC) and terminal severity data was used to compare treatments.

3. Result and Discussions

3.1. Disease Assessment

This study aimed to assess loss in grain yield, hectoliter weight and 1000-kernel weight due to stem rust disease on released durum wheat cultivars. Disease severity of three durum wheat varieties having different response to this disease were evaluated against stem rust during main and off-seasons (irrigated) in 2016/17 under field conditions by studying the relationship between stem rust severity, coefficient of infection, area under disease progress curve (AUDPC) and yield components. The present study obviously showed that the durum wheat cultivars showed high stem rust severity exhibited maximum values of AUDPC and yield losses. While the durum wheat cultivars showed low disease severity displayed minimum values of AUDPC and yield losses. It was also manifest that susceptible wheat cultivars suffered more yield losses than those moderately susceptible (MS) to moderately susceptible-susceptible (MSS) cultivar. The moderately susceptible variety showed less yield, hectoliter and 1000-kernel weight as compared to moderately susceptible to susceptible (MSS) and susceptible cultivars.

3.2. Final Stem Rust Severity

The highest final stem rust severity on unsprayed plots of susceptible cultivar Hitosa accounting about 76%. On the other hand, the final stem rust severity on sprayed plots of the same cultivar (Hitosa) showed 25% (Table 2). The lowest final stem rust severity was recorded on the cultivar Mangudo having the mean value of 6.7% for sprayed plots and 25% for unsprayed one. On susceptible cultivar Hitosa a total sum of 130 and 30% final rust severity was recorded for unsprayed and sprayed plots, respectively (Figure 1).

Table 2. *The effect Rex Duo application on Area under disease progress curve (AUDPC), Final rust severity, Coefficient of infection and Rate of infection.*

Cultivar	Final rust severity		AUDPC		COI		R.I	
	Sprayed	Unsprayed	Sprayed	Unsprayed	Sprayed	Unsprayed	Sprayed	Unsprayed
Mangudo (MS)	6.7	25	97	468.7	3.3	20.3	0.02	0.17
Utuba (MSS)	10.7	40	112.1	585.9	4	36.7	0.03	0.21
Hitosa (S)	15	76	150.5	1225.7	12	59.3	0.12	0.32

Note:- AUDPC: Area under disease progress curve; COI: Coefficient of infection; R.I: Rate of infection

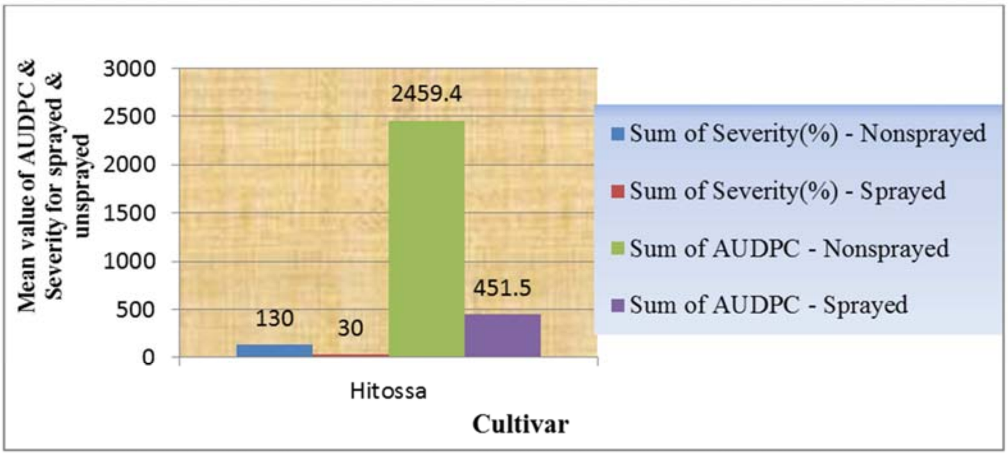
These suggest that a significant reduction in stem rust disease level as the result of fungicide spray. Stephen *et al.* (2009) also reported that application of Tilts effectively reduced disease severity.

3.3. Area Under Disease Progress Curve (AUDPC)

The area under disease progress curve values on unsprayed plots varied from 468.7 to 1225.5 on moderately susceptible to susceptible cultivars. On moderately susceptible cultivars (Mangudo) 97 and followed by Utuba having the mean value of 112.5 for sprayed plots (Table 2). This study also aligned with the finding of Mr. Taddese *et al. (*2010) which reported higher AUDPC values in untreated plots as compared to treated plots. On susceptible cultivar Hitosa a total sum of 2459.4 and 251.5 area under disease progress curve (AUDPC) was recorded for unsprayed and sprayed plots, respectively (Figure 1). The total sum of area under disease progress curve (AUDPC) on unsprayed plots range 1406 and 2057.9 for cultivar Mangudo and Utuba, respectively.

3.4. Coefficient of Infection

Coefficient of infection on unsprayed plots during the main season ranged from 20.3 to 59.3. Whereas on sprayed plots it ranges from 3.3 to 12. The lowest rate of infection also recorded under sprayed plots moderately susceptible Mangudo having the mean value of 0.02 and followed by Utuba cultivar. The unsprayed plots showed higher rate of infection as compared to the sprayed plots (0.17-0.32) (Table 2).



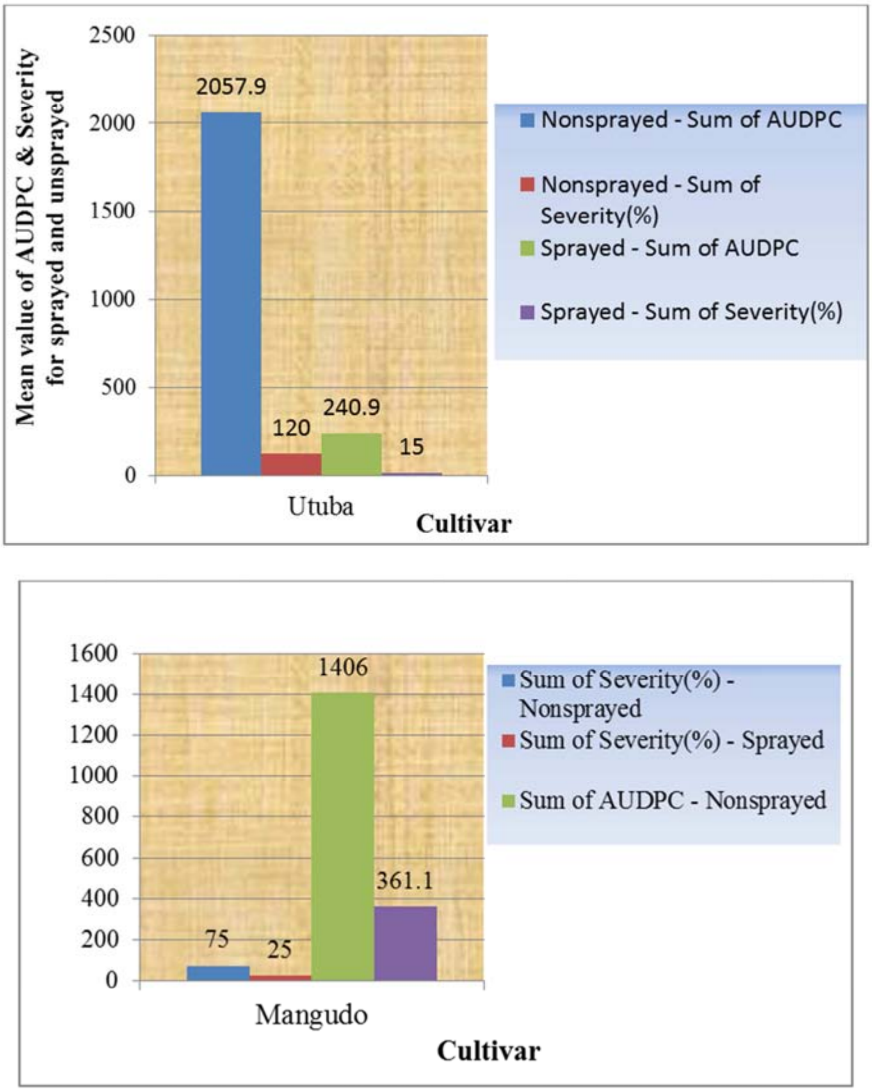


Figure 1. *Final rust severity (%) and area under disease progress curve (AUDPC) for puccinia graminis f.sp. tritici on three durum wheat cultivars evaluated under field conditions at Debre Zeit during 2016/17 main and off seasons*

3.5. Yield, Hectolitre Weight and 1000-kernel Weight Losses

The Rex Duo sprays created significantly different levels of terminal stem rust severity across the durum wheat cultivars that enabled to assess the effects of stem rust disease on durum wheat grain yield, hectoliter weight and 1000-kernel weight losses.

In general, the analysis of variance revealed significant ($P < 0.05$) differences among Rex Duo sprayed and control in hectoliter weight (HLW), thousand kernels weight (TKW), and yield. Rex Duo spray interacted highly significantly ($P < 0.001$) with durum wheat varieties in influencing thousand kernel weights.

Estimating yield loss by a disease is a prerequisite to develop strategies for disease control particularity through breeding objectives for disease resistance [23]. Results in table 3 indicated that, loss in grain yield ranged between 40.8-70.4% kg/ha of durum wheat cultivars. And also the loss of 1000-kernel weight ranging from 17.7 to 24.4%. The loss of hectoliter weight due to stem rust disease was ranged from 21.8 to 39.4% (Table 3). These results showed that Hitosa was the most affected cultivars with infection by the stem rust fungus *Puccinia graminis* meanwhile Mangudo was a little beat tolerant to stem rust under field conditions. Similarly [5] reported that stem rust reduced yield irrespective of the type and level of resistance possessed by the varieties. The results also suggest that the effect of fungicides may have in improving yield performance of susceptible wheat varieties. There was significant ($P< 0.05$) increase in grain yield due to Rex Duo application during both seasons (Table 3). The sprayed plots showed significantly increased grain yield, hectoliter weight and 1000-kernel weight of durum wheat cultivars (Table 3). [24] also reported that the Tilt-protected plots remained almost free from stem rust.

Generally, the results indicated that the durum wheat cultivars in this study need the support of fungicides application to minimize the yield losses caused by stem rust of wheat disease. Specially, focusing on the varietal response or reaction may help the farmers to decide how many times the planted cultivar need fungicide application and this needs further study to develop the fungicide applications as packaged since most of the durum wheat cultivars are susceptible to stem rust.

Table 3. *The effect of variety and Rex Duo application on final rust severity, yield, 1000-kernel weight and hectoliter weight of durum wheat cultivars during main and off season seasons at Debre Zeit in 2016/17.*

Cultivar	Frs		1000-KW			HLW			kg/ha		
	Unsprayed	Sprayed	unsprayed	Unsprayed	Loss%	Unsprayed	Sprayed	Loss%	Unsprayed	Sprayed	Loss%
Mangudo (MS)	25.0	6.7	40.1	48.7	17.7	64.5	82.5	21.8	3758.5	6352.7	40.8
Utuba (MSS)	40.0	6.7	39.9	51.7	22.8	52.3	84.5	38.1	3655.7	6555.6	44.2
Hitosa (S)	76	15	30.3	40.1	24.4	50.2	82.9	39.4	1655.6	5594.7	70.4

Note:- Frs: Final rust severity; 1000-KW: thousand kernel weight; HLW: Hectolitre weight; kg/ha: kilogram per hectare

Correlation analysis among disease on yield, hectoliter weight and 1000-kernel weight revealed the negative impact stem rust may have on durum wheat. In general, there was a highly positive correlation between final stem rust severity, coefficient of infection, rate of infection and AUDPC suggesting the possibility of using any of these parameters for evaluation purpose (Figure 2).

Grain yield, hectoliter weight and 1000-kernel weight were negatively correlated with all of the three disease parameters (final rust severity, coefficient of infection and AUDPC) and the correlation coefficient range from moderate negative association to very strong association (r=0.43 to -0.81) (Figure 2). Ochoa and Parlevliet (2007) reported that yield was correlated moderately with area under disease progress curve. This might be due to unfavorable environmental conditions for the development of stem rust during the off-season. El-Shamy *et al*. (2011) also found a significant correlation between mean disease severity and percentage loss in thousand kernel and grain yield/plant.

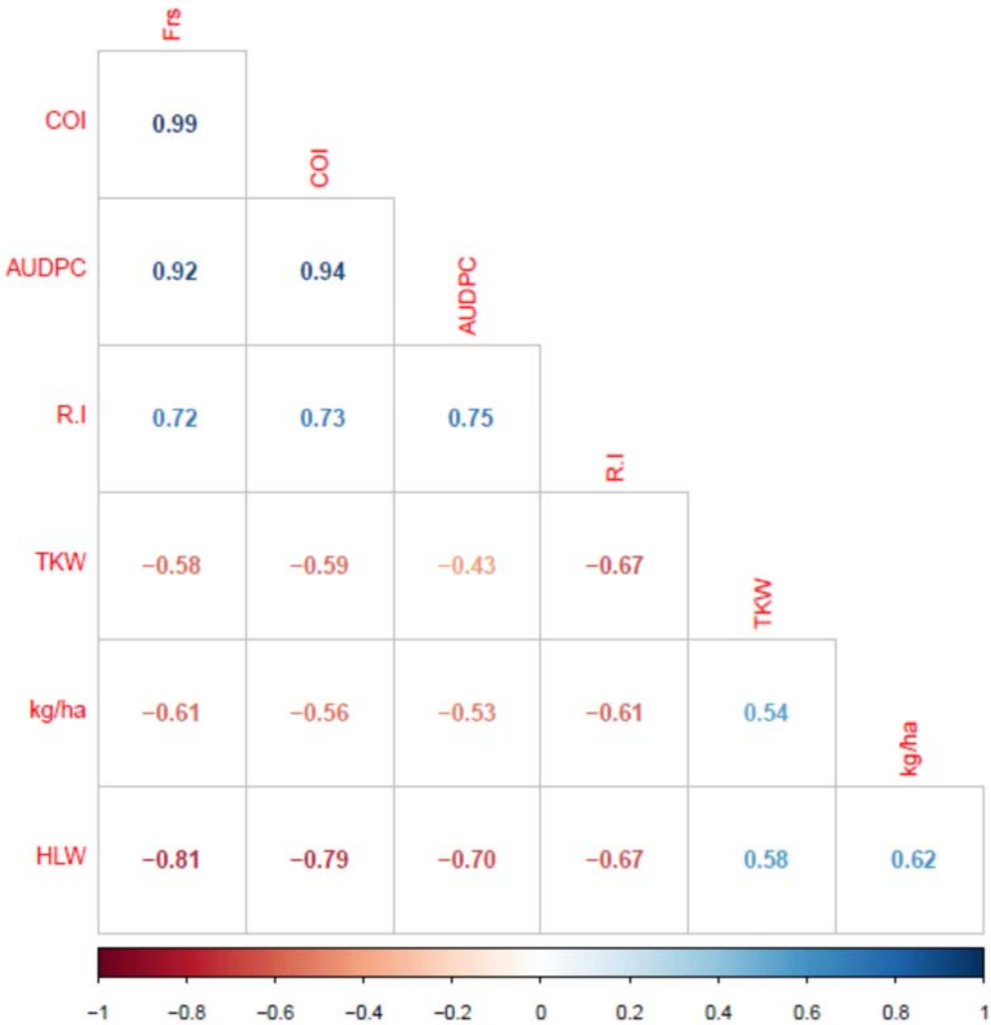


Figure 2. *Correlation coefficients among disease parameters, yield and physical quality parameters.*

4. Conclusion

Stem rust disease resulted in significant reduction durum grain yield, hectoliter weight and 1000-kernel weight. However, application of Rex Duo fungicides significantly reduced disease parameters (final rust severity, Area under disease progress curve, coefficient of infection and infection rate) and increase grain yield, hectoliter weight and 1000-kernel weight. The current result demonstrated that supporting cultivars through the application fungicides are the most pertinent and advisable to durum wheat producers in the country.

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