Seedling and Adult Plant Resistance in the Ethiopian Bread Wheat Landraces to Stripe Rust Disease

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Abstract

High yielding farmers' bread wheat cultivars are threatened by emerging race(s) of stripe (yellow) rust caused by *Puccinia striiformis* f.sp. *tritici* (*Pst*) in the highlands of Ethiopia. In depletion of rust resistance in commercial cultivars, researchers often look for new sources from close relatives and landraces. The objective of this study was to determine stripe rust resistance in selected Ethiopian bread wheat landraces obtained from the Ethiopian Institute of Biodiversity (IBCE). In 2017, a total of 152 accessions were exposed to the prevailing stripe rust races in hot spot areas (Kulumsa and Meraro) in Arsi zone of Oromia region. In the second year (2018), only promising landraces (57) were evaluated both at seedling and adult plant growth stages. The seedling test was conducted in the greenhouse at Kulumsa research center using three (*PstS2* (v32), (*PstS11*) and (*PstS11 v25*) *Pst* races. In field evaluations, terminal severity (TRS), coefficient of infection (CI), area under disease progress curve (AUDPC), disease progress rate (DPR) and head infection (HI) were considred. High disease pressure was noted with 100% severity on susceptible entries at both locations and seasons. Highly significant (P<0.001) differences were noted among the landraces for all disease parameters indicated above. Of the 152 landraces, 57(38%) exhibited lower or equal disease reaction compared to the resistant check(Enkoy) across locations. Overall, 18 accessions showed resistance to the prevailing *Pst* races both at seedling stage and field conditions whereas14 exhibited susceptible /intermediate reaction at seedling stage, but had lower disease reaction under field conditions. This study has identified potential sources of overall and adult plant resistance in the Ethiopian bread wheat landraces to the prevailing *Pst* races. The authors recommend further studies to determine the diversity and/or novelty of resistance genes in selected accessions. Future wheat improvement should focus on utilization of these genetic resources to minimize the re-current outbreak of rust diseases.

Keywords: bread wheat, landrace, *Pst, race,* resistance, stripe rust

1. Introduction

Wheat is a traditional crop cultivated by small scale farmers under rainfed conditions in Ethiopia. The country is the largest wheat producers in Sub-Saharan Africa (SSA). The crop ranks fourth in area coverage next to tef, maize and sorghum, respectively (CSA, 2018). The area under wheat production is estimated to be about 1.7 million hectares of land with average productivity of 2.7 tons/ha. Wheat production is constrained by several biotic, abiotic and socio-economic factors in the country. The Ethiopian highlands are suitable for the wheat plant as well as for perpetuations wheat rust diseases (Hulluka *et al.,* 1991). Stripe (yellow) rust caused by *P. striiformis* f. sp. *tritici*. Westend *(Pst)* is the most threatening wheat disease in the highlands of Ethiopia (Badebo *et al*., 2008). The disease was first reported in the early 1940's, but it gained importance with the commercialization of wheat in the early 1980s (Gebremariam, 1991). Recurrent stripe rust epidemics has occurred since then; however, the 2010 epidemics was the most damaging. Most of the commercial bread wheat cultivars, including *Kubsa* and *Galama* scummbed to the new *Yr27+* virulent race and caused 70 to 100% yield loss in major wheat producing areas of the country (Abeyo*et al*., 2013).

In the depeletion of rust resistance in commercial cultivars, new sources often sought from landraces and close relatives of wheat. Landraces are grown by farm communities in remote villages using centuries'- old technologies,

including hand planting and harvesting (Feuillet *et al*., 2008). The main reasons for farmers to maintain these historic wheat landraces could be due to their specific adaptability and preferred quality for home use. Wheat landraces contribute important traits including disease resistance (Cavanagh *et al*., 2013; Lopes *et al*., 2015), tolerance to abiotic stresses (Olmstead and Rhode, 2002), and protein content and gluten quality (Zhang*et al*., 2012). Wheat landraces have been successfully used by wheat breeders to improve agronomic traits, particularly disease and pest resistance (Nevo and Payne, 1987).

In Ethiopia, Vavilov identified six wheat "species" in his early expedition to Ethiopia in the late 1920s, but mainly bread wheat (*Triticum aestivum*) and durum wheat (*T.turgidum var. durum*) are cultivated nowadays. Durum wheat is an indigenious crop while bread wheat is considred to be of recent introductions to the country (Gebre Mariam, 1991). However, the recent archaeo-botanical studies identified bread wheat at Aksum, northern Ethiopia dating to the mid-sixth to early seventh centuries (Boardman, 1999). This suggest that bread wheat might have a longer history in Ethiopia than was previously thought. Most of the wheat landraces have been replaced by high yielding semi dwarf bread wheat varieties, but still grown by farmers mainly in the northern part of Ethiopia. A large number of bread wheat collections are preserved in the IBCE (Demissie and Habtemariam, 1991). However, bread wheat landraces have not been well exploited in modern wheat breeding in Ethiopia (Broers and De Haan, 1994). So far, only limited bread wheat landraces have been characterized for their resistance to rust diseases (Badebo and Tessema, 2012; Muleta *et al*., 2017).

In this study a set of Ethiopian bread wheat landraces from IBCE have been characterized for their resistance to the prevailing *Pst* races under field and greenhouse conditions.

2. Materials and Methods

2.1 Description of the Study Areas

The field study was conducted at Kulumsa and Meraro research stations in Arsi Zone of Oromia Region, Ethiopia. The greenhouse experiment was conducted at Kulumsa Agricultural Research Center. Meraro and Kulumsa are known to be hot spot areas for wheat stripe rust, although the disease pressure increases with altitude. Kulumsa represents mid highlands (2200 m.a.s.l.) and located at $39^{o}09'11''$E l and $08^{o}01'10''$N. It has average maximum 22.8 ^{o}C and minimum 10.5 ^{o}C temperatures and receives 832 mm rainfall annually. Meraro represents extreme highlands (2960 m.a.s.l.) and located at $39^{o}14'56''$E and $07^{o}24'27''$N. Meraro receives 1196 mm annual rainfall with maximum and minimum temperatures of 18.1 ^{o}C and 5.7 ^{o}C, respectively.

2.2 Planting Materials

A total of 152 bread wheat landrace accessions plus 3 checks were used in this study. The accessions and checks were obtained from the institute of biodiversity of Ethiopia (IBCE) and the wheat breeding program at Kulumsa research center, respectively. In 2017, all of the accessions were tested under field conditions whereas only selected entries were exposed to the prevailing races of *Pst* in the field and greenhouse during 2018.

2.3 Field Experimental Design and Testing Procedures

The experiment was laid out in augmented design where the three check varieties; *Digelu* (susceptible), *Pavon-76* (moderately resistant) and *Enkoy* (resistant)were replicated in each block. Each plot consisted of *2* rows of *1* m length with 20 cm between rows. To ensure uniform spread of inoculum and sufficient disease development, infector plants consisted of mixtures of different susceptible bread wheat varieties (*Morocco*, *Digelu* and *Kubsa*) bordered the plots in all direction. Fertilizer application and other agronomic practices were applied according to the recommendations for each location.

2.4 Field Disease Assessments

Different epidemiological parameters which include terminal rust severity (TRS), coefficient of infection (CI), area under disease progress curve (AUDPC) and disease progress rate (DPR) were used to determine stripe rust resistance in the wheat landarces.

2.4.1 Disease Severity

Disease severity notes were taken five times on plot bases starting from the onset of rust within 10 days intervals. Stripe rust severity was estimated visually as a proportion leaf area affected by stripe rust using the modified Cobb'sscale (Roelfs *et al*., 1992) and the host plant response (infection type) was noted according to Peterson *et al*. (1948). The CI was calculated by multiplying the level of disease severity and the constant value of infection type. The constant values for infection types were used based on; R = 0.2, MR = 0.4, M= 0.6, MS = 0.8, S = 1 (Stubbs *et al*., 1986). Head infection was noted using 0-5 scale and then converted to percentages for analysis:0 = no infection, 1 = 20%, 3 = 60%, 4 = 80% and 5 = 100% severity.

2.4.2 Area under Disease Progress Curve (AUDPC)

AUDPC is an indicator of disease expression over time (Van der plank 1963), and it was calculated for each experimental unit based on the formula by Wilcoxson *et al*. (1975):

$$AUDPC = \sum_{i=1}^{n}[0.5\,(x_i + x_{i+1})[t_{i+1} - t_i]$$, Where, x_i = the average coefficient of infection of ith record, x_{i+1} = the average coefficient of infection of $i+1^{th}$ record and t_{i+1} - t_i = Number of days between the ith record and $i+1^{th}$ record, and n = number of observations.

2.4.3 Disease Progress Rate

Disease progress rate was estimated from the logistic model ln (Y/(1-Y)) (Van der Plank, 1963) and gompertz model: -ln [-ln(Y)] (Berger, 1981). Where y = the percent of severity divided by 100; t = time measured in days. The model with higher coefficients of determination (R^2) was considered.In this study, Gompertz model was used for all assessment dates because of the higher values of coefficient of determination (R^2) compared to the logistic model.

2.5 Field Data Analysis

Data on different epidemiological parameters were generated for each test material. The data have been transformed using $\sqrt{x + 0.5}$ before analysis. A standard analysis of variance was conducted to identify significance differences among the wheat landarces for each disease parameter. Correlation analysis was done among disease parameters and TKW using Minitab Software (2017). The data were analyzed using SPAD and SPSS software (SPAD 2002; SPSS 2005).

2.6 Seedling Test Procedures

A total of 57 accessions were selected for seedling resistance tests based on their field performances in 2017. The experiment was conducted according to standard procedures (Badebo *et al.,* 2008; Hovmøller *et al*., 2017) in the greenhouse at Kulumsa research center in 2018. Five to six seeds of each entry plus three checks were grown in 7x7x6 cm plastic pots filled with compost, soil and sand at a ratio of 1:2:1 (v/v/v) under spore-free greenhouse compartment under supplemental light. The first l of seven to eight days old seedlings were inoculated with spores of three (*PstS2* (v32), (*PstS11*) and (*PstS11 v25*) individual *Pst* isolates suspended in light weight mineral oil (Soltrol 170) using atomizer. Inoculation was carried in an enclosed cage that was rinsed with water subsequently to avoid spore contamination. Inoculated seedlings were allowed to dry for 20 minutes and then incubated in a dew chamber for about 24 hrs at 9-10 °C and 100% relative humidity. Seedlings were kept in semi open plastic cubicles in a greenhouse compartment at 18-22 °C and 70 to 80% relative humidity. The seedlings were supplemented with 12 hrs light using florescent lamps. The experiment was repeated based on the infection type on susceptable variety (Morocco). Seedlings were evaluated 16-20 days after inoculation using a 0-9 scale (McNeal *et al.,* 1971). Entries with ITs 0-6 were considred as resistant and 7-9 susceptible.

3. Results and Discussion

3.1 Field Reaction of Landraces to Stripe Rust

Stripe rust disease pressure was high in the study areas during 2017 and 2018. The disease severity went up to 100% on susceptible entries accross locations and seasons. There were significant (p<0.001) differences among the test entries for terminal severity (TS), coeffcient of infection (CI), area under disease progress curve (AUDPC), infection rate (DPR) and head infection (HI) as shown in Table 1. The landraces exhibited various reaction to stripe rust on wheat leaves and heads (spikes). The disease pressure was more at Meraro (2900 masl) than at Kulumsa (2200 masl).

Table 1. Mean square variance of coefficient of infection, terminal rust severity, area under disease progress curve, infection rate and head infection of stripe rust on different bread wheat genotypes at Kulumsa and Meraro, 2017

Location		Source					
	Disease parameter	Block (Adj)	Entry (Adj)	Check	Landrace	Landrace x check	Error
Kulumsa	DF	3	155	2	152	1	6
	CI	0.028^{NS}	3.066***	40.23***	2.65***	26.5***	0.07
	TRS	1.7^{NS}	246.9***	4,747.5***	197.5***	2834.5***	1.4
	AUDPC	3.2^{NS}	73.6***	876***	64.63***	567.3***	1.71
	DPR	0.0001^{NS}	0.0002***	0.003***	0.0001***	0.0034***	0.0017
Meraro	CI	0.097^{NS}	4.5***	38.1***	4.17***	57.6***	0.26
	TRS	15.2^{NS}	498.2***	5443.8***	4511.7***	1657.3***	2.8
	AUDPC	6.13^{NS}	135.7***	1109.7***	125.6***	563.2***	1.4
	DPR	0.00002^{NS}	0.0002***	0.0009***	0.0002***	0.0006***	0.002
	HI	86.59^{NS}	392.05***	4210.01***	398***	1605.2***	5.9

Key: DF= digree of freedom, CI= coefficient of infection, TRS=terminal severity, AUDPC=area under disease progress curve, DPR= disease progress rate, HI= head (spike) infection

3.1.1 Terminal Rust Severity on Wheat Leaves (TRS)

In 2017, the mean severity scores on leaves of resistant, moderately resistant and susceptible checks were, 9.6, 40 and 78% at Kulumsa and 20%, 59% and 94% at Meraro, respectively whereas the mean severity on spikes for the respective checks were 18%, 82% and 62% at Meraro (Table 3). The frequency distribution of bread wheat landrace accession under different disease severity (TRS) classes at Kulumsa and Meraro during 2017 is depicted in Figure 1.The frequency of susceptible entries were more at Meraro than at Kulumsa. A total of 62 (40.8 %) landraces at kulumsa and 54 (35.5 %) and 62 (40 .8%) at Meraro exhibited low (0-20%) severity on leaves and heads, respectively whereas 33 (21.7 %) landraces at Kulumsa and 12 (7.9 %) and 13 (8.6 %) at Meraro, respectively had moderate TRS (21-40%. A total of 29(19.1%) and 28 (18.4 %) exhibited immune reaction to stripe rust on leaves and heads respectively across locations (data not shown).
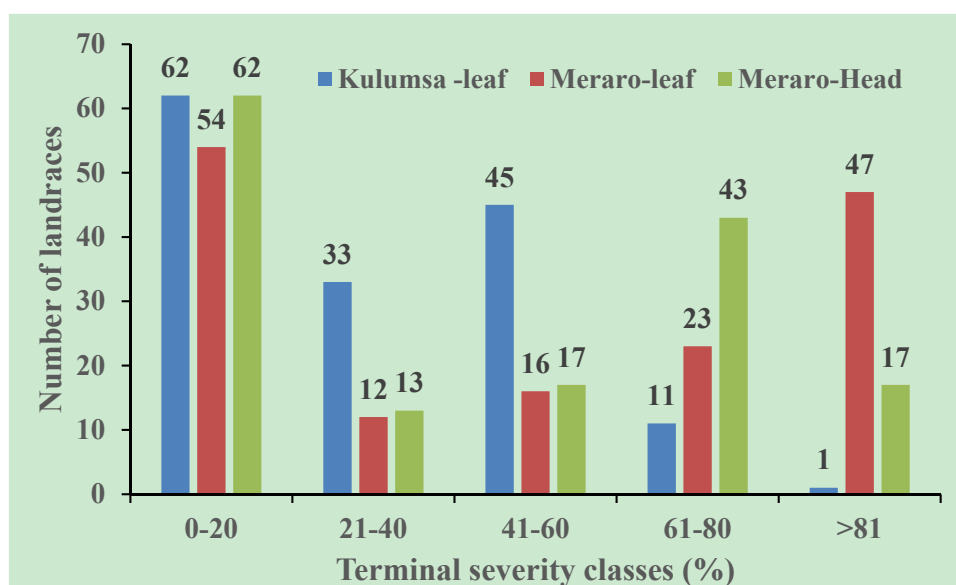

Figure 1. Frequency distribution of bread wheat landraces under different terminal rust severity classes at Kulumsa and Meraro in 2017

The frequency of bread wheat landraces under different stripe rust severity classes at Kulumsa and Meraro during 2018 is shown in Figure 2. Of the total 57 bread wheat lanraces, 55 (96.5%) landraces at Kulumsa and 31 (54.4 %)

and 44 (77.2%) at Meraro exhibited low (0-20) TRS on leaves and spikes, respectively.

Spike infection on moderately resistance check (*Pavon-76*) was higher than on the susceptible and late maturing check (*Digelu*). This could be due to spike morphology and some agronomic traits such as days to heading and maturity. Early headed spikes are more infected by stripe rust than the late ones (data not shown). There is no susbstantial information if resistance on leaves and spikes are controlled by the same or different genes; however, some morphological and agronomic traits were identified to be associated with spike infection (Allan and Pritchett, 1972) On highly infected wheat genotypes, the grains were shriveled and resulted in losses in yield, quality and TKW (data not shown). This result is consistent with the findings of Purdy and Allan (1966) who reported the negative effect of spike infection on yield and yield components. Trace to low levels of spike infection on the moderately resistant and resistant varieties did not affect TKW, yield and yield components. Spike infection of wheat by stripe rust at higher altitudes result in 100% losses (Badebo *et al*., 2008).
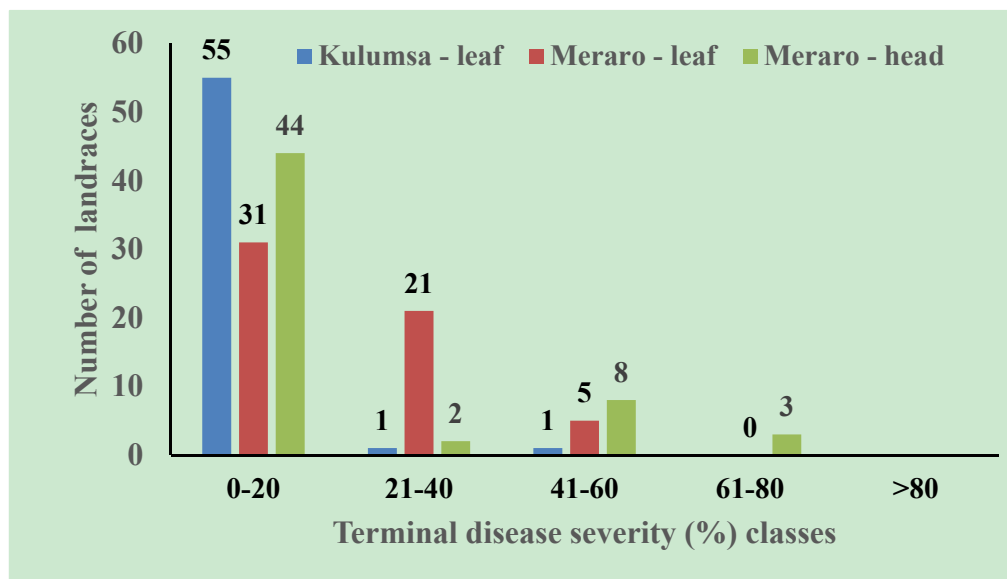

Figure 2. Frequency distribution of bread wheat landraces under different terminal stripe rust severity classes at Kulumsa and Meraro in 2018

The present study identified considerable variations among the Ethiopian bread wheat landraces in TRS at both locations and seasons. The higher disease severity level was observed at Meraro compared to Kulumsa. This may be attributed mainly due to more favourable environmental conditions such as cool temperature and high humidity at Meraro than at Kulumsa. In this study, 55(96.5%) and 31(54%) accessions exhibited high level of slow rusting resistance at Kulumsa and Meraro, respectively.

Wheat lines with a low terminal disease severity under high disease pressure might have more additive genes that render adult plant resistance (Singh *et al*., 2005). This kind of resistance is possibly polygenic controlled by more than one gene (Dehghani and Moghaddam, 2004). Ali *et al*. (2007) proposed that lines with CI values of 0-20, 21-40, and 41-60 were regarded as possessing high, moderate, and low levels of slow rusting resistance, respectively. According to thier classification, a total of 55 (94.5%) and 3 (5.3%) accessions at Kulumsa and 32 (56%) and 22 (38.6%) at Meraro could be categorized as high and moderate level of slow rusting resistance, respectively (data no shown). Resistance in these accessions might be controlled by several minor genes which give longlasting resistance.

3.1.3 Area under Disease Progress Curve

The distribution of bread wheat landraces under AUDPC values across locations in 2017 and 2018 seasons is shown in Figure 3. In 2017, of the total number of bread wheat landraces, 51 (33.6%) and 22(14.5%) showed lower AUDPC values than the resistant (*Enkoy*) and moderately resistant (*Pavon-76*) checks at Kulumsa and 50(32.9%) and 26(17.1%) at Meraro, respectively.
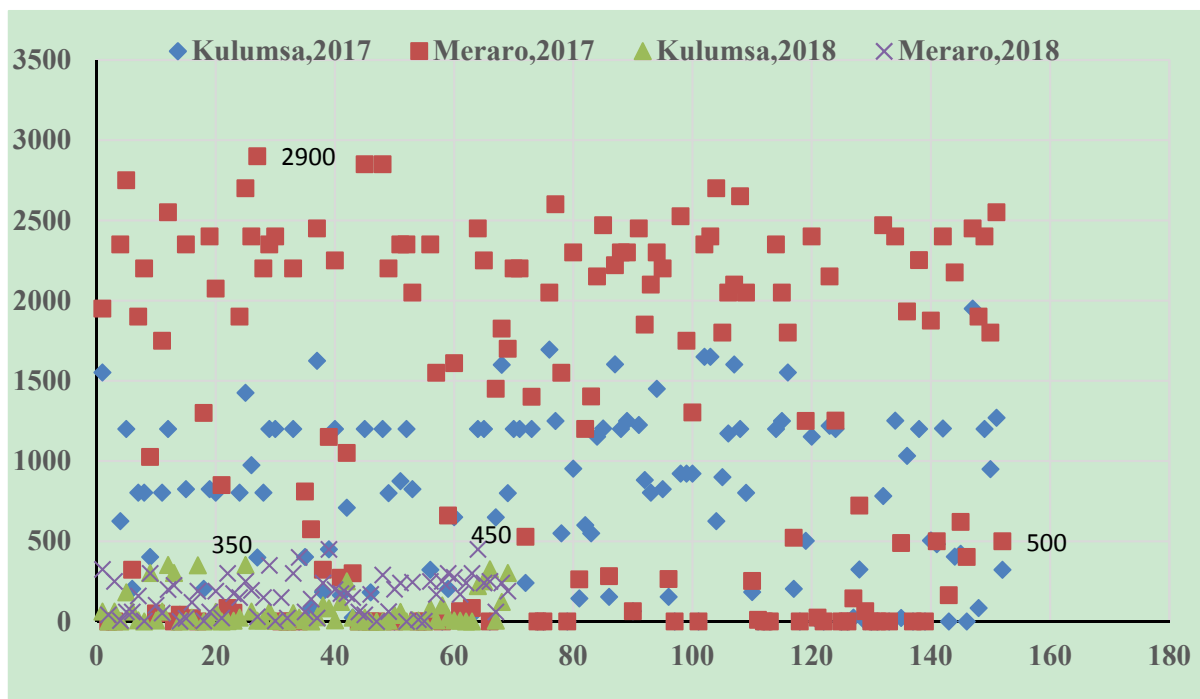
Figure 3. The distribution of AUDPC values of bread wheat landraces across locations in 2017 and 2018

The landrace accession with lower AUDPC values than the resistant check (*Enkoy*) are considred to posess slow rusting resistance. AUDPC is a good indicator of adult plant resistance under field condition (Wang *et al*., 2005). It is directly related with grain yield loss (Jeger, 2004; SubbaRao*et al*., 2008) and provides critical information for designing effective disease management practices for lines with different types and levels of resistance.

3.1.4 Disease Progress Rate (DPR)

The frequency of bread wheat landraces under different disease progress rate (DPR) classes at Kulumsa and Meraro during 2017 is shown in Figure 4. The DPR values ranged from 0 to 0.072 per unit time at Kulumsa and 0 to 0.131 at Meraro.Of the tested entries, 32(21%) and 30 (20%) landraces exhibited no disease progress at Kulumsa and Meraro, respectively. However, 55(36.2%) landraces had lower DPR value per unit time than the resistant check and and moderately resistant checks each at Kulumsa and 48(31.6%), 29(19.1%) at Meraro, respectively.
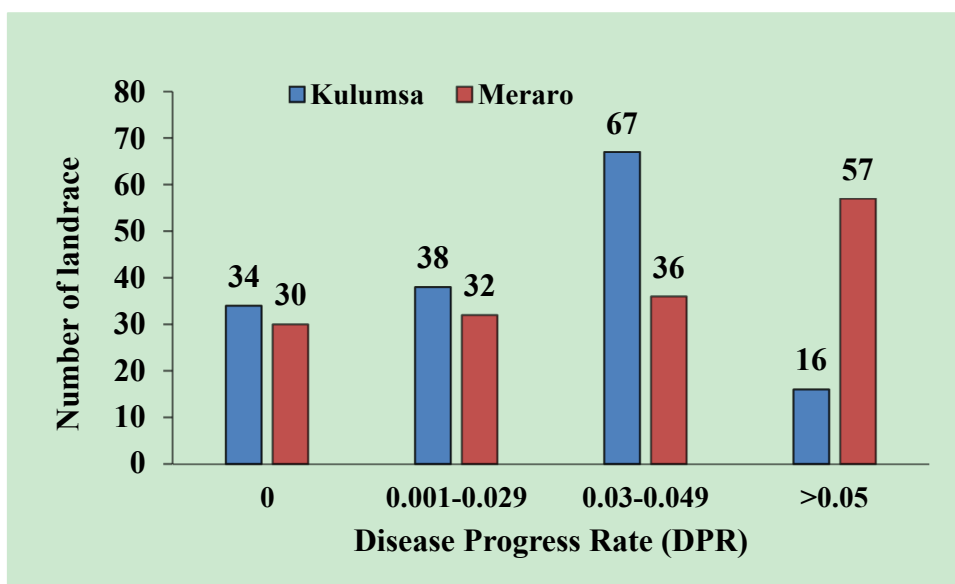

Figure 4. The frequency of bread wheat landraces under different disease progress rate classes at Kulumsa and Meraro, 2017

Of the total 57 bread wheat landraces, 16(28%) and 2(5.3%) showed no progress in disease severity in 2018. However, 40(70.2%) and 12(21.1%) had lower DPR value per unit time than the resistant and moderately resistant checks at Kulumsa and 42(73.7%), 13(22.8%) at Meraro, respectively (data not shown). Disease progress rate in terms of disease spread was lower in resistant varieties compared to the susceptible ones. In general, a low AUDPC value in an accession might not ensure low in DPR, because the later depends on the differences in the initial and final disease severity. Once the pathogen reaches its maximum infection level, the DPR value may decrease or remain constant as disease progresses, because the green leaf area is not available for spread of the pathogen (Ali *et al.,*2009). The Ethiopian bread wheat landrace accessions with low DPR value per unit time could be potential sources to be exploited in breeding program.

3.1.5 Correlation among Disease Parameters and Thousand Kernel Weight (TKW)

Highly significant (P<0.001) and positive correlations observed among the disease parameters across locations and seasons (Table 2). There was high correlations between terminal rust severity with AUDPC and disease progress rate at Kulumsa (r = 0.976 and 0.949) and Meraro (r = 0.980 and 0.945), respectively. Relatively lower correlations were noted between AUDPC and DPR compared to the other slow rusting parameters at Kulumsa (r =0.880) and Meraro (r = 0.896). Despite the severity and AUDPC increase, the rate of infection could be slowed down over time because as the epdemics progresses less plant tissue could be available for further infection of the pathogen (Freedman and Mackenzie, 1992). The TKW has negatively correlated at P<0.001 with all the disease paramters at both locations.

Table 2. Pearson linear correlation coefficients among stripe rust disease parameters and thousand kernel weight in Ethiopian bread wheat landrace at Kulumsa and Meraro, 2017

Location	Paramter	CI	TRS	AUDPC	DPR
Kulumsa	TRS	0.985***			
	AUDPC	0.978***	0.976***		
	DPR	0.939***	0.949***	0.880***	
	TKW	-0.494***	-0.393***	-0.390***	-0.355***
Meraro	TRS	0.995***			
	AUDPC	0.985***	0.980***		
	DPR	0.893***	0.945***	0.896***	
	TKW	-0.603***	-0.631***	-0.642***	-0.570***
	HI	0.609***	0.598***	0.581***	0.526***

CI = Coefficient of infection, TRS = Terminal Rust Severity, AUDPC = Area under Disease Progress Curve, DPR = Disease progress rate, TKW = 1000 kernel weight, HI = Head (spike) infection of wheat by stripe rust,

*** Significant at ***P***<0.001.

Highly significant and positive correlation observed between spike (head) infection and the major disease paramters; however, the correlation of HI with TKW was negative. The positive correlations among the disease parameters observed in this study is in agreement with the results of other researchers in cereal rust pathosystems (Safavi, 2012). All disease parameters were highly correlated in the present study and all affected TKW. Qamar*et al.* (2007) and Safavi*et al*. (2013) reported higher selection gains of slow rusting resistance using low terminal rating, AUDPC and CI under field condition.

3.2 Seedling Resistance

A total of 57 bread wheat landrace accessiosn were exposed to the three most virulent stripe rust isolates (*YR28WAB16, YR80NWA17 and YR39AD17*) which were later designated as *PstS2 (v32),* (*PstS11*) and *PstS11 (v25)*, respectively (data not shown). Of these lanraces, 41(71.9%), 41 (71.9%) and 31(54.4%) showed resistance reaction to *PstS2* (v32), (*PstS11*) and (*PstS11 v25*), respectively (Figure 5). Twenty-seven (47.4%) and 9(15.8%) accesions showed resistance and susceptible reaction to all of the three isolates, respectively whereas 21(36.8%) reacted differently.
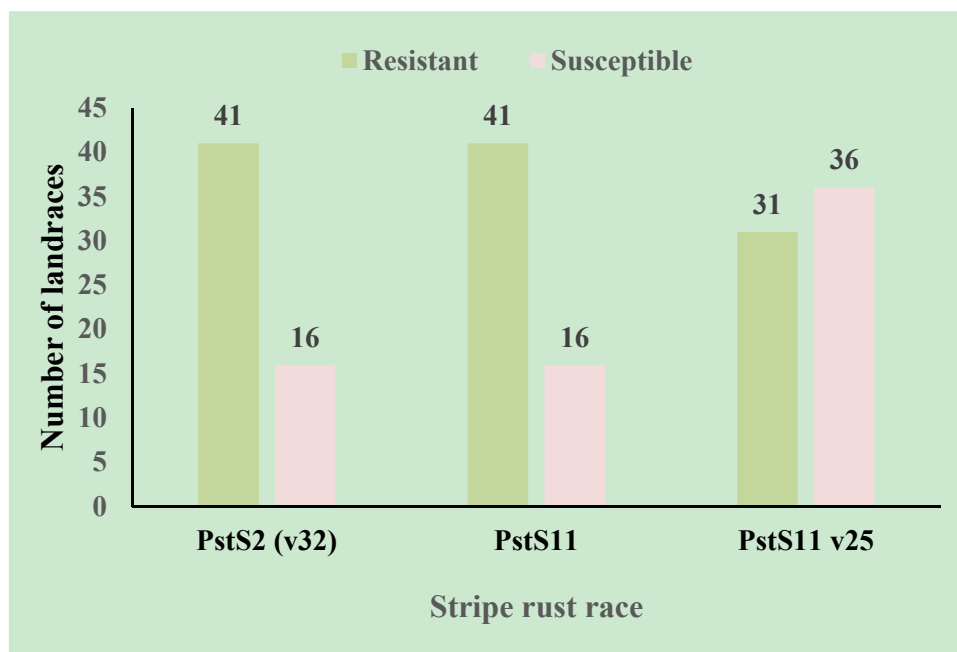
Figure5. Frequency distribution of resistant and susceptible bread wheat landrace accesions to three stripe rust races at seedling stage

3.3 Characterization of Stripe Rust Resistance in Bread Wheat Landraces

A total of 57 bread wheat landraces evaluated both at seedling and adult plant growth stages and of these, 32 (56.1%) exhibited lower values for all disease paramters under field conditions (Table 3). Eighteen (31.6 %) landraces exhibited resistance at seedling (to all isolates) and adult plant growth stage whereas 14 (24.6 %) showed susceptible/intermediate reaction at seedling stage but had low disease level for all paramters under field conditions.

Table 3. The reaction of selected bread wheat landarces to stripe rust at seedling and adult plant growth stages

No	Accession no. / variety	Seedling ITs (0-9)			Severity %				HI%	AUDPC % days			
		Isolate			Kulumsa		Meraro			Kulumsa		Meraro	
		PstS2	PstS11	PstS11+	2017	2018	2017	2018	2017	2017	2018	2017	2018
1	5011	4_5	2	4	1	1	5	20	0	5	6	54	102
2	5435	2_3	3_4	5_6	0	0	0	5	0	0	0	0	22
3	6296	2	2	2	0	1	10	30	20	0	6	164	170
4	6930	2	2	2	0	0	0	0	0	0	0	0	0
5	7145	2	5_6	5_6	0	1	0	1	0	0	4	0	4
6	7178	2_3	6	2	0	1	0	5	0	0	6	0	12
7	7251	2_3	3	3_4	0	0	0	5	0	0	0	0	22
8	7292	2	2	2	0	1	0	10	0	0	24	0	42
9	7407	4	3_4	5_6	1	1	10	15	10	2	5	64	62
10	7451	2	2_3	4_5	0	0	0	10	0	0	0	0	42
11	8470	3_4	1	6_7	0	0	0	1	0	0	0	0	4
12	206657	1_2	4_5	3_4	0	1	0	20	0	0	7	0	150
13	206689	0	5	5_6	0	5	0	10	0	0	62	0	52.5
14	213135	2_3	3_4	2	10	1	10	30	4	84	5	84	170
15	222491	1_2	4_5	5_6	0	1	0	30	0	0	5	0	175
16	222679	2	3_4	2	0	0	0	30	0	0	0	0	170
17	221735	5_6	2_3	3_4	0	30	0	30	0	0	452	0	250
18	222758	5_6	3_4	3	0	1	0	20	0	0	24	0	150
1	5380	9	5_6	8	10	5	20	30	20	144	52	262	300
2	7309	7_8	5_6	6_7	15	1	20	5	10	184	3	322	20
3	7253	5_6	8	7	10	1	10	10	0	64	7	64	60
4	213144	7_8	7	8	10	1	15	20	0	164	24	272	120
5	213147	8	9	7_8	10	5	10	10	20	42	62	42	60
6	214348	7_8	7	6_7	10	1	0	10	60	182	8	0	60
7	219348	7	6	7	0	5	0	30	60	0	60	0	190
8	219350	5_6	8	7	5	5	10	30	10	54	62	64	195
9	222313	7	7_8	7	10	1	10	20	80	40	7	84	150
10	222445	8	8	8	0	0	0	1	0	0	0	0	2
11	222492	7_8	5	7	0	0	0	0	0	0	0	0	0
12	222550	6_7	5_6	6_7	1	1	5	5	30	5	5	24	30
13	222560	7	7_8	8	10	0	5	1	30	24	0	50	6
14	222674	7	5	6	0	1	0	40	0	0	41	0	202
Check													
1	Enkoy	7	7	7	9.6	1.5	20.4	14.2	18	138.1	11.5	292	98.7
2	Pavon -76	5-6	6-7	5-6	40	28	59.2	35	82	490.5	282	1481	271
3	Digelu	8	9	5-6	78	52	94.2	60	62	1655	680	2438	454

Wheat genotypes could be susceptible at seedling tests but exhibit moderate resistance to moderate susceptible reaction at adult plant stage and these lines with show slow rusting resistance parameters at adult plant stage could

have durable resistance (Singh *et al*. 2005). This kind of resistance can be kept for a long time even if pathogen changes its genotype, it is controlled by more than one gene (Dehghani and Moghaddam 2004). Generally, the seedling resistance genes are also active during the adult plant stage and they are classified into race-specific resistance types (Lagudah, 2010).

4. Conclusion

Most of the commercial bread wheat cultivars in Ethiopia scumb to new races of stripe rust in hot spot areas in Ethiopia. In the depletion of resistance in the cultivated wheat, new sources are sought from landraces. In this study, a total of 152 bread wheat landrace accessions from IBCE have been tested to stripe rust during 2017 whereas only selected 57 accessions were exposed to the prevailing *Pst* races both in the field and at seedling stage in the greenhouse 2018. Overall, 32 accesions exhibited resistance in the field across locations and seasons. Of these, 18 and 14 accesions showed resistant and susceptible reaction to the three *PSt* races at seedling stage, respectively. This study has shown that Ethiopian bread wheat landraces are potential sources of overall (seedling) and adult plant resistances (APR) to stripe rust. A large number of bread wheat collections are preserved in the Institute of Biodiversity (IBCE). To cope up with the ever threatening races of the pathogen, future wheat improvement should focus on exploiting these gene pool in the breeding program.

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References

Abeyo, B., Hodson, D., Hundie, B., Woldeab, G., Girma, B., Badebo, A., … Denbel, W. (2014). Cultivating success in Ethiopia: The contrasting stripe rust situations in 2010 and 2013. Poster 65, BGRI 2014 Technical Workshop, Obregon, Mexico.

Ali, S., Shah, S. J. A., Khalil, I. H., Raman, H., Maqbool, K., & Ullah, W. (2009). Partial resistance to yellow rust in introduced winter wheat germplasm at the north of Pakistan. *Australia Journal of Crop Science, 3*, 37-43.

Ali, S., Shah, S.J. A., & Ibrahim, M. (2007). Assessment of wheat breeding lines for slow yellow rusting (*Pucciniastriiformis* west. *tritici*). *Pakistan Journal of Biological Science, 10*, 3440-3444. https://doi.org/10.3923/pjbs.2007.3440.3444

Allan, R. E., & Pritchett, J. A. (1972). Relationships of Stripe Rust Spike Infection to Morphologic and Agronomic Traits of Wheat. *Crop Science, 12*(4), 412-414. https://doi.org/10.2135/cropsci1972.0011183X001200040004x

Badebo, A., Fehrmann, H., & Yahyaoui, A. (2008). Status of wheat stripe rust (*Pucciniastriiformis*) races and their virulence in major wheat growing areas of Ethiopia. *Pest Management Journal of Ethiopia, 12*, 1-7.

Badebo, A., Tessema, B., Abeyo, W., Denbel, B., Girma, F., Eticha, & Fufa, F. (2012). Resistance in the Ethiopian Bread Wheat Landraces to Ug99 (TTKSK) and other Prevalent Races of Stem rust at DebreZeit, Ethiopia. Poster presented on Africa wheat conference 8-12 October, 2012. Addis Ababa, Ethiopia.

Berger, R. D. (1981). Comparison of the Gompertz and logistic equation to describe plant disease progress. *Phytopathology, 71*, 716-919. https://doi.org/10.1094/Phyto-71-716

Boardman, S. (1999). The agricultural foundation of the Aksumite Empire, Ethiopia. In M. van der Veen (Ed.), *The Exploitation of Plant Resources in Ancient Africa* (pp. 137-147). Plenum Publishers, New York. https://doi.org/10.1007/978-1-4757-6730-8_12

Broers, L. H. M., & De Haan, A. A. (1994). Relationship between the origin of European landraces and the level of partial resistance to wheat leaf rust. *Plant Breeding, 113*, 75-78. https://doi.org/10.1111/j.1439-0523.1994.tb00705.x

Cavanagh, C. R., Chao, S., Wang, S., Huang, B. E., Stephen, S., Kiani, S., & Forrest, K. (2013). Genome-wide comparative diversity uncovers multiple targets of selection for improvement in hexaploid wheat landraces and cultivars. *Proccedings of the National Acadamy of Science of the United States of America, 110*, 8057-8062. https://doi.org/10.1073/pnas.1217133110

CSA. (2018). Agricultural sample survey: Report on area and production of major crops, Central Statistical Agency, Addis Ababa, Ethiopia. Pp. 18.

Dehghani, H., & Moghaddam, M. (2004). Genetic analysis of latent period of stripe rust in wheat seedlings. *Journal of Phytopathology, 152*(6), 325-330. https://doi.org/10.1111/j.1439-0434.2004.00848.x

Demissie, A., & Habtemariam, G. (1991). Wheat Genetic Resources in Ethiopia. In Gebremariam, H., Tanner, D. G., & Hulluka, M. (Eds.), *Wheat research in Ethiopia: A historical perspective* (pp. 33-46). Addis Ababa, IAR/CIMMYT.

Feuillet, C., Langridge, P., & Waugh, R. (2008). Cereal breeding takes a walk on the wild side. *Trends Genetics, 24*, 24-32. https://doi.org/10.1016/j.tig.2007.11.001

Freedman, J., & Mackenzie, D. R. (1992). Disease progress curves, their mathematical description and analysis to formulate predictors for loss equations. In Teng P. S. (Ed.), *Crop loss assessment and pest management* (pp. 37-48). International Book Distributing Co., Lucknow, India.

Gebremariam, H. (1991). Bread wheat breeding and genetics research in Ethiopia. In Hailu, G., Tanner, D. G., & Mengistu, H. (Eds.), *Wheat research in Ethiopia: A historical perspective* (pp. 73-93). Addis Ababa, IAR/CIMMYT.

Hovmøller, M. S., Rodriguez-Algaba, J., Thach, T., & Sørensen, C. K. (2017). Race Typing of *P.striiformis* on Wheat. In S. Periyannan (Ed.), Wheat Rust Diseases: Methods and Protocols, *Methods in Molecular Biology* (Vol. 1659, pp. 29-40). https://doi.org/10.1007/978-1-4939-7249-4_3

Hulluka, M., Woldeab, G., Andnew, Y., Desta, R., & Badebo, A. (1991). Wheat pathology research in Ethiopia. In Gebremariam, H., Tanner, D. G., & Hulluka, M. (Eds.), *Wheat research in Ethiopia: A historical perspective* (pp. 173-217). Addis Ababa. IAR/ CIMMYT.

Jeger, M. J. (2004). Analysis of disease progress as a basis of evaluating disease management practices. *Annual review of Phythopathology, 42*, 61-82. https://doi.org/10.1146/annurev.phyto.42.040803.140427

Lagudah, E. S. (2010). Molecular genetics of race non-specific rust resistance in wheat. Borlaug Global Rust Initiative, *Proceeding of Technical Workshop* St. Petersburg, Russia, May 30-31, 2010.Pp 183-196.

Lopes, M. S., Dreisigacker, S., Peña, R. J., Sukumaran, S., & Reynolds, M. P. (2015). Genetic characterization of the wheat association mapping initiative (WAMI). panel for dissection of complex traits in spring wheat. *Theoretical and Applied Genetics, 128*, 453-464. https://doi.org/10.1007/s00122-014-2444-2

McNeal, F. H., Konzak, C. F., Smith, E. P., Tate, W. S., & Russell, T. S. (1971). A uniform system for recording and processing cereal research data. *Agricultural Research Service Bulletin,* USDA, Washington, DC, USA: 34-112.

Muleta, K. T., Rouse, M. N., Rynearson, S., Chen, X., Buta, B. G., & Pumphrey, M. O. (2017). Characterization of molecular diversity and genome-wide mapping of loci associated with resistance to stripe rust and stem rust in Ethiopian bread wheat accessions. *Plant Biology, 17*, 134. https://doi.org/10.1186/s12870-017-1082-7

Nevo, E., & Payne, P. I. (1987). Wheat storage proteins: Diversity of HMW glutenin subunits in wild emmer from Israel. Geographical patterns and ecological predictability. *Theoretical and Applied Genetics, 74*, 827-836. https://doi.org/10.1007/BF00247564

Olmstead, A. L., & Rhode, P. W. (2002). The red queen and the hard reds: productivity growth in wheat, 1800–1940. *Journal of Econmic Hist*ory*, 62*, 929-966. https://doi.org/10.1017/S0022050702001602

Peterson, R. F., Campbell, A. B., & Hannah, A. E. (1948). A diagrammatic scale for estimating rust intensity of leaves and stem of cereals. *Canadian Journal of Research, 26*, 496-500. https://doi.org/10.1139/cjr48c-033

Purdy, L. H., & Allan, R. E. (1966). A stripe rust race pathogenic to 'Suwon 92' wheat. *Plant Diease Report, 50*, 205-207.

Qamar, M., Mujahid, M. Y., Khan, M. A., Ahmad, Z., Kisana, N. S., & Rattu, Atiq-ur-Reman. (2007). Assessment of partial resistance in seven spring bread wheat genotypes to stripe rust *P. striiformis*under field conditions. *Sarhad journal of agriculture, 23*(4), 1003-1008.

Roelfs, A. P., Singh, R. P., & Saari, E. E. (1992). Rust diseases of wheat: Concepts and Methods of Diseases Management. Mexico, DF (Mexico). CIMMYT, 81pp.

Safavi, S. A., & Afshari, F. (2012). Identification of resistance to *P. striiformis*f. sp. *tritici*in some elite wheat lines. *Journal of Crop Protection, 1*(4), 293-302.

Safavi, S. A., Ahari, A. B., Afshari, F., & Arzanlou, M. (2013). Slow rusting resistance in Iranian barley cultivars to *P.striiformis*f. sp. *hordei*. *Journal of Plant Protection Research, 53*, 2-7. https://doi.org/10.2478/jppr-2013-0001

Singh, R. P., Huerta-Espino, J., & William, H. M. (2005). Genetics and breeding for durable resistance to leaf and

stripe rusts in wheat. *Turkish Journal of Agriculture and Forestry, 29*, 121-127.

Stubbs, R. W., Prescott, J. M., Saari, E. E., & Dubin, H. J. (1986). *Cereal Disease Methodology Manual.* CIMMYT: Mexico, D.F. 46p.

SubbaRao, K. V., Snow, J. P., & Berggren, G. T. (2008). Effect of growth stage and Initial inoculum Level on the Leaf Rut Development and Yield loss caused by *P. recondita f. sp.tritici* Article first published online.

Van der Plank, J. E. (1963). *Plant diseases. Epidemic and Control.* Academic Press, New York. Pp. 17-27. https://doi.org/10.1016/B978-0-12-711450-7.50006-8

Wang, Z. L., Li, L. H., He, Z. H., Duan, X., Zhou, Y. L., Chen, X. M., … Xia, X. C. (2005). Seedling and adult plant resistance to powdery mildew in Chinese bread wheat cultivars and lines. *Plant Diseases, 89*, 457-463. https://doi.org/10.1094/PD-89-0457

Wilcoxson, R. D., Skovmand, B., & Atif, A. H. (1975). Evaluation of wheat cultivars ability to retard development of stem rust. *Annual Review of Applied Biology, 80*, 275-281. https://doi.org/10.1111/j.1744-7348.1975.tb01633.x

Zhang, H. C., Wang, C. F., Cheng, Y. L., Chen, X. M., Han, Q. M., Huang, L. L., … Kang, Z. S. (2012). Histological and cytological characterization of adult plant resistance to wheat stripe rust. In the *Proceedings of the 13th International Cereal Rusts and Powdery Mildews Conference.*28 Aug.-1 Sept. 2012, Beijing, China. (Abstr.) pp. 127.

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