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Research Article

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Characterization of Slow Rusting Resistance Against Stem Rust (*Puccinia graminis f. sp. tritici*) in Selected Bread Wheat Cultivars of Ethiopia

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Abstract

Lack of durable resistance in bread wheat cultivars is the main reason for stem rust epidemic which could limit yields in Ethiopia. The present study was conducted to evaluate slow rusting resistance to stem rust among bread wheat cultivars. Twenty-four bread wheat cultivars along with the susceptible check were tested for their seedling and adult plant reactions to stem rust both in greenhouse and field experiments. The seedlings of the wheat cultivars were tested against stem rust race TTKSK (Ug99). The field experiment was conducted during 2016 main cropping season and was planted in randomized complete block design with three replications. Parameters used as criteria to identify slow rusting in the field included terminal rust severity (TRS), coefficient of infection (CI), relative area under disease progress curve (rAUDPC) and infection rate (Inf-rate). Among these parameters, TRS, CI and rAUDPC were found to be reliable to assess slow rusting in the cultivars. The results indicated that wheat cultivars Dinkinesh and Shina had low disease severities (<30%) with compatible field responses (MR) and susceptible seedling reactions, lower rAUDPC values (30%) and CI (<20%) and were identified to have good level of slow rusting resistance. Cultivars Pavon 76, Kakaba, Danda'a, Madawalabu, Kingbird, Bonny, Africa Mayo and Alidoro had moderate values for slow rusting parameters with compatible seedling infection types and were identified as possessing moderate level of slow rusting. The slow rusting cultivars identified from the current study can be used for further manipulation in wheat improvement programs.

Keywords: Durable resistance; Race non-specific; Stem rust

Introduction

Wheat (*Triticum aestivum*) is one of the major food crops in the world. It is produced across a wide range of agro-ecological and crop management regime. Ethiopia is the largest wheat producer in sub-Saharan Africa in 2016 [1,2]. About 5 million Ethiopian farmers produce 4.3 million tons of wheat across 1.7 million hectares of land under rain-fed conditions [3]. Its popularity comes from the versatility of its use in the production of a wide range of food products, such as injera, breads, cakes, pastas, etc. Wheat ranks third in area coverage and total production a ter teff and maize. Although the productivity of wheat has increased in the last few years in Ethiopia; it is still very low as compared to other wheat producing countries. The national average productivity is estimated to be 2.54 t ha^{-1} [3]; which is by far below experimental yields of over 5 tons ha^{-1} [4-6].

The low productivity is attributed to a number of factors including biotic (diseases, insects, weeds and etc.) and abiotic (low and high rainfall, temperature, low adoption of new agricultural technologies and etc.). Among the biotic factors, wheat stem rust, also known as black rust, caused by the fungus *Puccinia graminis* f. sp. *tritici* (Pgt) has been the most devastating disease in Ethiopia causing upto 100% yield losses on susceptible cultivars during epidemic years [7,8]. This biotroph reduces the total photosynthetic area, utilizes plants assimilates and interrupts the normal growth of the host leading to reduction of yield. According to Singh et al. [9] Ethiopia is considered as a hot spot for the development of stem rust races diversity. Studies carried out in Ethiopia showed that most previously identified races such as TTKSK, TKTTF, TTTTF, TRTTF, RRTTF and others were virulent on most varieties grown in the country.

Breeding of wheat cultivars with durable resistance to rust diseases is the best control strategy [10-12]. Generally, two types of resistance have been described in wheat. The first type of resistance is race specific, which is controlled by genes that act in a gene-for-gene manner with the rust fungus. These genes generally confer high level of resistance to specific rust biotypes, both at the seedling and adult plant stages. The second type is race non-specific which is controlled by minor genes and is usually most discernable in adult plants as partial and slow rusting resistance [11,13,14]. Race non-specific resistance is controlled by multiple genes [15] and remains effective against all races of the pathogen. This type of resistance confers durable resistance [12]. So far, few race non-specific genes have been characterized and catalogued in wheat [16-19].

Resistance breeding for wheat rusts in Ethiopia has been based on major genes for a long time. However, durable resistance to stem rust has been re-emphasized with the occurrence and spread of new races of Pgt. Hence, this study was designed to assess the levels of slow rusting resistance in some bread wheat cultivars to stem rust under greenhouse and ield conditions and the information provided here will be important for developing potentially durable combinations of stem rust resistance genes in cultivars.

Materials and Methods

Greenhouse evaluation of bread wheat cultivars for their seedling resistance to stem rust

Greenhouse evaluations were done at Ambo Plant Protection Research Center (APPRC), Ethiopia by using 24 bread wheat varieties and one susceptible check (McNair). Seven seeds of each wheat variety and a susceptible check were planted in 3 cm diameter plastic pots separately in three replications. Seven-days-old seedlings (the irst leaves were fully expanded, and the second leaves were just emerged to grow) were inoculated with spores of virulent race, TTKSK (Ug99). Inoculated plants were then moistened with ine droplets of distilled water by using atomizer and placed in dew chamber for 18 hours in a dark at 18-22°C. Upon removal from chamber, seedlings were exposed to 3 hours of luorescent light to dry dew on the leaves. Following this, the seedlings were transferred to the greenhouse where conditions were regulated at 12 hours photoperiod, at temperature range of 18-25°C and RH of 60-70%. Data on infection types (IT) were recorded 14 days a ter inoculation using 0-4 scale [20].

The IT readings of 3 (medium-size uredia with/without chlorosis) and 4 (large uredia without chlorosis or necrosis) were regarded as compatible reactions. Other readings, that are 0 (immune or fleck), 1 (small uredia with necrosis) and 2 (small to medium uredia with chlorosis or necrosis) were considered as incompatible. The infection types were defined by modifying characters as follows: (-) uredinia somewhat smaller than normal; (+) uredinia somewhat larger than normal for the infection type.

Field evaluation of bread wheat cultivars for their slow rusting resistance to stem rust at adult plant growth stage

The field experiment was conducted at Adet Agricultural Research Center. The center is located 11°17' N latitude and 37°43' E longitude at an altitude of 2240 m.a.s.l. The center receives moderate and pleasant climate with temperature ranging from 8-25°C and annual rainfall of 1270.5 mm.

Experimental materials

The twenty-four bread wheat varieties tested in the greenhouse were also tested against stem rust disease under field condition (Table 1). In the field the susceptible variety Morocco was used as a comparative control. All varieties except Morocco were under production. Morocco was planted perpendicular to the experimental blocks one week before the experimental plots to serve as spreader row. The spreader rows were then inoculated artificially with TTKSK race when most plants were at the stem elongation.

S No	Cultivar	Year of Release	Source Center
1	Pavon-76	1982	KARC/EIAR
2	Kakaba	2010	KARC/EIAR
3	Danda'a	2010	KARC/EIAR
4	Shorima	2011	KARC/EIAR
5	Huluka	2012	KARC/EIAR
6	Hoggana	2011	KARC/EIAR
7	Bonny	1995	KARC/EIAR
8	Africa Mayo	2005	KARC/EIAR
9	Medawalabu	1999	SARC/OARI
10	Galil	2010	Hazera Genetics Ltd
11	Tuse	1997	KARC/EIAR
12	Senkegna	2005	ADARC/ARARI
13	Kingbird	2015	EIAR
14	Hidase	2012	KARC/EIAR
15	Tay	2005	ADARC/ARARI
16	Dinkinesh	2007	SRARC/ARARI
17	Gassay	2007	ADARC/EIAR
18	Abolla	1997	KARC/EIAR
19	Millenium	2007	KARC/EIAR
20	Alidoro	2007	HARC/EIAR
21	Ogolcho	2012	KARC/EIAR
22	Densa	2010	ADARC/ARARI
23	Guna	2001	ADARC/ARARI
24	Shina	1999	ADARC/ARARI
25	Morocco (Sucpt.ck)		

Table 1: List of wheat cultivar used for evaluation of slow rusting resistance to stem rust under field and greenhouse conditions. Source: Crop variety register. Issue No. 16, 2013.

Experimental design and field plots

The experiment was laid out using randomized complete block design (RCBD) with three replications. The test materials were sown during the main cropping season of 2016 under rain fed conditions. There were a total of 75 plots comprising 24 bread wheat varieties and one susceptible check (Morocco). Each plot consisted of four rows with a size of 0.8 m × 1.5 m and with a spacing of 1.5 m between blocks and 0.4 m between plots. The inter row spacing was 0.2 m. The recommended fertilizer rate (92/46 N/P_2O_5 ha^{-1}) and seed rate of 100 kg ha^{-1} were used. Urea was applied in split. Weeds were controlled three times by hand weeding.

Disease assessment

Disease severity: Stem rust severity, estimated as a proportion of the stem of the plant affected by the disease, were recorded using the modified Cobb's scale where 0%=immune and 100%=completely susceptible [21]. Disease severity was assessed three times at 20 days interval from 10 randomly pre-tagged plants in the central two rows of each plot. It was recorded from the time of disease appearance until the crop attains its physiological maturity and the mean of the ten plants were calculated. Host plant response to infection was scored using the description of Roelfs et al. [22], where, immune=0.0, R=0.2, MR=0.4, MR-MS=0.6, MS=0.8, MS-S=0.9 and S=1.0.

Average coefficient of infection (ACI)

Average coefficient of infection was calculated by multiplying the percentage severity by a constant for host response [23]. The ACI for each variety was computed from three severity observations and ACI was used for calculating AUDPC for each variety.

Area under disease progress curve (AUDPC)

The data collected were entered in excel worksheets and AUDPC values were generated using the formula below [24].

$$AUDPC = \sum_{i=1}^{n-i} [0.5(X_{i+1} + X_i)(t_{i+1} - t_i)]$$

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

Disease progress rate (Inf-rate)

The three disease severity observations records at 20 days interval were regressed over time and the apparent infection rates as the coefficient of the regression line, ln [X/(100-X)], where X is average coefficient infection plotted against time in days [25] were calculated for each variety.

Grain yield and thousand kernel weight

Thousand kernel weights and grain yield were recorded from the middle two rows of each experimental unit as follows;

- **Grain yield (GY):** The central two rows of each entry were harvested, and their grains weighted for conversion to tones per hectare.
- **Thousand kernel weight (TKW):** One thousand grains select at random were weighted in grams.

Data analysis

Relative forms of the epidemiological parameters were generated by comparing the respective values of each entry with the susceptible variety Morocco. Coefficient of correlation was done using SPSS software version 15 [26] to determine the relationship between disease parameters and the relationship between disease and yield parameters. Seedling evaluation results were analyzed by using the descriptive statistics. Analysis of variance (ANOVA) was used for yield parameters of the field experiment as randomized block design (RCBD) for one factor for yield parameters, following the procedure described by Gomez et al. [27] using SAS computer software. When the variable was significant, mean separations were conducted based on LSD at 5% probability level.

Results and Discussion

Seedling reaction test

Results from the greenhouse test showed that the bread wheat cultivars differed in their reaction to the TTKSK stem rust race. Out of 25 wheat cultivars tested in a greenhouse 11 (Shorima, Hoggana, Galil, Hidase, Tay, Gassay, Abolla, Millenium, Ogolcho, Densa and Guna) showed resistance reactions (1+ to 2+), 7 cultivars (Kakaba, Danda'a, Hulluka, Bonny, Africa Mayo, Alidoro and Shina) had susceptible reactions (3-) and 6 varieties (Pavon-76, Madawalabu, Tuse, Senkegna, Kingbird and Dinkinesh) had mixed reactions (2+ and 3-) at the seedling stage. The susceptible check, Morocco was susceptible to the race, displaying infection type 3+ at the seedling stage (Table 2). The wheat cultivars which showed resistance reaction at seedling stage implied the presence of major gene resistance towards the race.

Field experiment

Slow rusting cultivars were identified on the bases of their terminal rust severity (TRS), coefficient of infection (CI), area under disease progress curve (AUDPC) and rate of rust progress (Inf-rate value).

Terminal severity of stem rust

There was wide variation in the stem rust severities ranging from 30% to 85% during the 2016 main cropping season at the Adet Research Center. Different field reactions ranging from moderately resistance (MR) to susceptible (S) responses were also observed at the trial. The observed stem rust severities of the cultivars and their infection types are presented in Table 2. Terminal rust severity represents the cumulative result of all resistance factors during the progress of epidemics [28]. Based on terminal rust severity, the tested wheat cultivars were grouped into three groups of slow rusting resistance, i.e., high, moderate and low levels of partial resistance having 1-30%, 31-50% and >50% TRS, respectively.

During the 2016 cropping season four wheat cultivars (Galil, Dinkinesh, Millenium and Shina) displayed disease severities of 30% with moderately resistant (MR) field responses. Of these, Dinkinesh and Shina had susceptible infection types at seedling stage. Similar trends were previously observed with Ethiopian wheat lines showing susceptible infection types at the seedling stage and maintaining low severity to stem rust in the field [29], confirming that these cultivars have race non-specific resistance to the disease. On the other hand, twenty cultivars were included in the second group with final rust severities ranging from 35-50% and were regarded as possessing moderate levels of slow rusting resistance. Of these, eight cultivars (Pavon-76, Kakaba, Danda'a, Madawalabu, Kingbird, Bonny, Africa Mayo and Alidoro) had compatible field (MR-S to MS-S) and seedling (2+3- to 3-) reactions and are of great importance to achieving effective breeding for durable resistance to stem rust [30,31].

According to Nzuve et al. [30], the available resistance genes in these materials overcame the stem rust virulence in the field and led to statistically low disease severities despite the compatible host-pathogen reactions. Previously, Ali et al., Li et al., Safavi, Tabassum [32-35] also used final rust severity to assess slow rusting behavior of wheat lines. On the other hand, cultivars Tuse and Abolla had disease severities more than 50% with MR-MS field responses and were regarded as susceptible to the disease. The susceptible check, Morocco, displayed the highest disease severity of 85% with completely susceptible (S) responses indicating that an acceptable epidemic pressure was established over the season for field experiment. There was no complete resistance (zero infection type) observed in all tested wheat cultivars at adult plant stage in the season.

Coefficient of infection

The data on disease severity and host reaction were combined to calculate CI (Table 2). According to Ali et al. [36], varieties with CI values of 0-20, 21-40, 41-60 were regarded as possessing high, moderate and low levels of slow rusting resistance, respectively. In the present study 13 cultivars (Shorima, Hulluka, Hoggana, Galil, Senkegna, Hidase, Tay, Dinkinesh, Gassay, Millenium, Densa, Guna and Shina) showed CI values between 0 and 20 and were designated as having high level of slow rusting. Cultivars Pavon-76, Kakaba, Danda'a, Madawalabu, Tuse, Kingbird, Abolla, Alidoro and Ogolcho had CI values between 21 and 40, designated as having moderate levels of slow rusting resistance.

Cultivars Bonny, Africa Mayo and the susceptible check had a CI value of more than 40 showing low levels of slow rusting resistance. Many earlier researchers such as Draz et al. [10], Pathan et al. [37], Patil et al. [38] also appraised slow rusting resistance to wheat stem rust using coefficient of infection and reported the presence of different partial resistance conferring genes in wheat lines.

No	Cultivar	TTKSK	TRS†	Infection Response	CI
1	Pavon-76	2+3-	50.0	MS	40.0
2	Kakaba	3-	45.0	MS	36.0
3	Danda'a	3-	45.0	MS	36.0
4	Shorima	1+	40.0	MR	16.0
5	Hulluka	3-	45.0	MR	18.0
6	Hoggana	1+	35.0	MR	14.0
7	Madawalabu	2+3-	45.0	MR-MS	27.0
8	Galil	1+	30.0	MR	12.0
9	Tuse	2+3-	55.0	MR-MS	33.0
10	Senkegna	2+3-	40.0	MR	16.0
11	Kingbird	2+3-	50.0	MR-MS	30.0
12	Hidase	1+	35.0	MR	14.0
13	Tay	2	35.0	MR	14.0
14	Bonny	3-	50.0	MS-S	45.0
15	Africa Mayo	3-	50.0	MS-S	45.0
16	Dinkinesh	2+3-	30.0	MR	12.0
17	Gassay	2	40.0	MR	16.0
18	Abolla	22+	65.0	MR-MS	39.0
19	Millenium	1+	30.0	MR	12.0
20	Alidoro	3-	45.0	MS	36.0
21	Ogolcho	2-	45.0	MR-MS	27.0
22	Densa	1+	35.0	MR	14.0
23	Guna	1+	35.0	MR	14.0
24	Shina	3-	30.0	MR	12.0
25	Morocco	3+	85.0	S	85.0

Table 2: Summary of wheat seedling reaction tests to stem rust under greenhouse and different disease parameters under field conditions on 25 tested wheat cultivars. †TRS=Terminal rust severity; MR=moderately resistant; MR-MS=moderately resistant to moderately susceptible; MS=moderately susceptible; MS-S=moderately susceptible to susceptible; S=Susceptible, CI=Coefficient of infection.

Area under disease progress curve

According to Wang et al. [39] area under disease progress curve is a good indicator of partial resistance under field condition. It is directly related with yield loss [40] and provides critical information for designing effective disease management practices [41]. Cultivars which had low AUDPC and terminal severity values may have good level of adult plant resistance. Therefore, selection of cultivars having low AUDPC and terminal disease scores is normally accepted for practical purposes where the aim is to utilize slow rusting resistance as one of the disease management strategy [42]. Based on the AUDPC values in this study, the 25 varieties were categorized in to two distinct groups. The first group comprised varieties exhibiting relative AUDPC values up to 30% of the check, while showing relative AUDPC values up to 70% of check were placed in second group. All those cultivars of group 1 were ranked as better slow rusting and that of group 2 were marked as moderately slow rusting because rust develops slowly at this stage exhibiting high infection types [29].

In the present study, varieties Shorima, Hulluka, Hoggana, Madawalabu, Galil, Tuse, Senkegna, Hidase, Tay, Dinkinesh, Gassay, Millenium, Ogolcho, Densa, Guna and Shina were having lowest rAUDPC values of 30% and less. Of these, Huluka, Madawalabu, Tuse, Senkegna, Dinkinesh and Shina had compatible seedling and field reactions, and were regarded as having high level of partial resistance. Group 2 included varieties Pavon-76, Kakaba, Danda'a, Kingbird, Bonny, Africa Mayo, Abolla and Alidoro. Except variety Alidoro, cultivars under group 2 had susceptible infection types at seedling stage (2+3- to 3-) and compatible field responses (MR-MS to MS-S). Wheat cultivars with slow rusting genes are often susceptible at the seedling stage but may be moderately to highly resistant to all races at the adult stage [11,43]. Singh et al. [12], Brown et al. [44], Kaur et al. [45] also stated that cultivars which had MS or MR infection types may carry genes for durable resistance. Despite the MS infection types exhibited on the cultivars, the disease progression remained slower and highly retarded among these cultivars. Such partially resistant varieties could highly delay evolution of new virulent races of the pathogen because multiple point mutations are extremely rare in normal circumstances [46-48].

Varieties	AUDPC	rAUDPC	Inf-Rate
Pavon-76	1642.7	49.4	0.017
Kakaba	1360.0	40.9	0.019
Danda'a	1434.7	43.2	0.009
Shorima	620.0	18.7	0.020
Hulluka	1052.0	31.7	0.012
Hoggana	544.0	16.4	0.019
Madawalabu	1002.0	30.2	0.026
Galil	756.0	22.7	0.018
Tuse	844.0	25.4	0.029
Senkegna	656.0	19.7	0.032

Kingbird	1294.0	38.9	0.030
Hidase	600.0	18.1	0.035
Tay	668.0	20.1	0.038
Bonny	1929.0	58	0.023
Africa Mayo	1914.0	57.6	0.013
Dinkinesh	644.0	19.4	0.025
Gassay	688.0	20.7	0.023
Abolla	1446.0	43.5	0.029
Millenium	488.0	14.7	0.007
Alidoro	1440.0	43.3	0.039
Ogolcho	1070.0	32.2	0.022
Densa	548.0	16.5	0.023
Guna	478.7	14.4	0.026
Shina	538.7	16.2	0.028
Morocco	3323.3	100	0.054

Table 3: Area under disease progress curve and infection rates of stem rust on the cultivars tested. AUDPC=Area under disease progress curve; rAUDPC=Relative area under disease progress curve; Inf-Rate=Infection rate.

Infection rate

A high disease progress rate (Inf-rate=0.054) was observed on susceptible check Morocco and the lowest (Inf-rate=0.007) was recorded from Millenium (Table 3). In the present study, infection rate showed more variation among the tested cultivars than the other slow rusting parameters. Some of the cultivars belonging to group 1 in terms of other slow rusting parameters (such as Galil, Dinkinesh and Shina) had higher infection rate values than some cultivars in group 2 (such as Danda'a, Africa Mayo and Pavon-76). Similarly, the results of previous studies conducted by Ali et al. [46], Sandoval-Islas et al. [49], Safavi [50] indicated that infection rate did not mark some cultivars as having moderate and low level of slow rusting and it was an unreliable estimate of slow rusting resistance when compared with TRS, CI, and rAUDPC. Moreover, more variation in infection rate among the tested lines than the disease severity and AUDPC, is partly because apparent infection rate is a regression coefficient with larger error variance. Ali et al. [32], Ali et al. [46] also found similar results for stem rust and leaf rust of wheat.

Correlation between slow rusting parameters

A positive and highly significant correlation of TRS with CI (r=0.872) and AUDPC (r=0.860) was observed during 2016 main cropping season (Table 4). The high correlation coefficient (r=0.990) was also observed between AUDPC and CI in the season. These strong correlations agreed with the results of Ali et al. [46]. Although positive correlations were observed between infection rate and other disease parameters, the relationship between the variables was weak. This indicates that although severity or the area under the disease progress curve was increasing, the rate of infection reduced as epidemic progressed because less healthy plant tissue was available for additional infections [51].

Since TRS, CI and AUDPC had strong positive correlations in the present study, selection of lines having terminal disease score less than or equal to 30%, CI between 0 and 20 and rAUDPC less than 30% with compatible seedling and adult plant responses is normally accepted for practical purposes. Feasibility of measuring slow rusting resistance preferably by low final ratings and CI has been reported previously by Hei et al. [29], Safavi et al. [50], Singh et al. [52]. Singh et al. [52] also reported that field selection of the slow rusting trait preferably by low rAUDPC and terminal ratings along with CI is feasible.

In the present study varieties Galil, Dinkinesh, Millenium and Shina had TRS of 30% with MR field responses, CI<20 and rAUDPC<30%. However, Millenium and Galil showed resistant infection types (1+) at seedling stage implying the presence of seedling or major gene resistance towards the disease. Varieties Dinkinesh and Shina had susceptible infection types at seedling stages and were identified as having high slow rusting resistance. On the other hand, Pavon 76, Kakaba, Danda'a, Madawalabu, Kingbird, Bonny, Africa Mayo and Alidoro had TRS 31-50% with compatible field responses (MR-MS to MS-S), CI values ranging from 21-45 (Cultivars Bonny and Africa Mayo which had slightly higher CI values of 45) and rAUDPC 31-70%. These varieties also had susceptible infection types at seedling stage and were regarded as moderately slow rusting. The slow rusting wheat cultivars identified in the current research were supposed to be having genes for durable resistance and may be used for further genetic manipulation in wheat improvement programs. Singh et al. [53] also reported that genotypes under group 1 and 2 could have durable resistance controlled by more than one gene which can serve as good parents for breeding.

Parameters	TRS	CI	AUDPC
TRS	1		
CI	0.872**	1	
AUDPC	0.860**	0.990**	1
Inf-rate	0.309	0.292	0.332

Table 4: Pearson's correlation coefficient for the disease parameters among the wheat cultivars at Adet, 2016 main cropping season. **Large positive relationship between the variables at $p \leq 0.05$; TRS=Terminal rust severity; CI=Coefficient of infection; AUDPC=Area under the disease progress curve; Inf-rate=Infection rate.

Grain yield

There was a highly significant difference (P<0.01) between cultivars for grain yield (Table 5). The highest grain yield, 5.51 t ha^{-1}, was obtained from cultivar Hidase whereas the lowest, 2.79 t ha^{-1}, was displayed from cultivar Africa Mayo. Although varieties Hidase, Densa, Shina, and Guna had grain yields more than 5 t ha^{-1}, the yield obtained from Hidase was significantly different from the others. Since the disease severity recorded in this study was high, it might have caused yield differences. However, disease severity difference alone could not cause variation in yield among the cultivars. Cultivars might also differ in their genetic yield potential. For examples, the disease severity recorded on cultivar Hidase was 35% during the season but the yield obtained from the Hidase was higher than some cultivars that had low disease severities, such as Millenium (30%) and Galil (30%). The yield obtained from Africa Mayo was below the yield of the susceptible cultivar Morocco. This would also be due to the lower genetic potential of Africa Mayo for grain yield.

In general, the yields obtained from the majority of the cultivars were more than 3 t ha^{-1}. Among the slow rusting cultivars identified, Shina, Kakaba, Madawalabu, Pavon 76 and Alidoro had the highest yields (>4.0 t ha^{-1}) in the season. Their comparatively better yields make them good candidates as donor parent for the incorporation of durable resistance in the bread wheat improvement programmes. Although there were variations in grain yields among the cultivars, there was no protected check plot established for each genotype to calculate yield loss.

Thousand kernel weight (TKW)

The wheat cultivars also showed variation in TKW (P<0.01). The highest TKW was recorded from variety Hidase (63.33 g). The lowest was obtained from Morocco (17 g). Among the slow rusting genotypes identified, Kakaba and Bonny had high TKW values in the season. Thousand kernel weight is an important component of yield mostly affected by stem rust. The reduction in TKW for Morocco might be due to the effect of the disease on the size and mass of the seed. Infection on wheat stem and leaf sheaths by stem rust affects the transport of assimilates to the developing kernel and results in shriveled kernel [54].

Varieties	GY	TKW
Hidase	5.50667^{a‡}	63.33^{a}
Densa	5.32000^{b}	53.33^{ab}
Shina	5.24000^{b}	31.00^{de}
Guna	5.16667^{b}	22.67^{efg}
Kakaba	4.95667^{c}	50.33^{abc}
Madawalabu	4.65333^{d}	40.67^{bcd}
Senkegna	4.58333^{ed}	30.00^{def}
Millenium	4.57333^{ed}	48.67^{bc}
Tay	4.56000^{ed}	50.00^{abc}
Tuse	4.48333^{ef}	30.00^{def}
Pavon-76	4.42667^{ef}	31.00^{de}
Alidoro	4.34333^{f}	39.67^{cd}
Shorima	4.16333^{g}	40.33^{bcd}
Galil	4.06667^{g}	50.00^{abc}
Hulluka	3.82667^{h}	30.00^{def}
Bonny	3.79333^{h}	50.33^{abc}
Dinkinesh	3.79333^{h}	49.33^{bc}
Danda'a	3.75333^{h}	38.00^{cd}
Hoggana	3.75000^{h}	40.00^{bcd}
Ogolcho	3.73333^{hi}	21.33^{efg}
Kingbird	3.71333^{hi}	38.00^{cd}
Abolla	3.56667^{ij}	50.00^{abc}
Gassay	3.52333^{j}	51.00^{abc}
Morocco	2.80667^{k}	17.00^{fg}
Africa Mayo	2.79000^{k}	40.00^{bcd}
CV	2.422745	21.2359
LSD	0.1672	13.471

Table 5: Grain yield and thousand kernel weight of the tested cultivars. ‡Means within column followed by the same letter are not significantly different.

Correlation between yield and disease parameters

The correlation coefficients considered between pairs of the respective disease parameters with yield data were highly negatively correlated (Table 6). The negative relationship between disease parameters and yield variables involving thousand kernel weight and grain yield showed harmful effects of stem rust on plant characteristics. Relatively higher negative correlations were observed between yield parameters and terminal stem rust severity. These were -0.64 and -0.66, respectively for grain yield and thousand kernels weight. This indicated that as the stem rust severities increased the negative effects of the disease on the TKW and GY increased.

The large negative correlation between TKW and TRS can be attributed to the fact that the fungus damages the vascular system of the susceptible host plant extensively limiting transportation of water and nutrients from the soil to the developing kernel and other organs as well as interfering with translocation of photosynthesis, which leads to shriveled grains [55]. Similar results have been reported by numerous previous research groups [56-58].

Parameters	GY	TKW
TRS	-0.64**	-0.66**
CI	-0.63**	-0.51**
AUDPC	-0.62**	-0.61**

Table 6: Correlation between yield data and stem rust disease data on wheat cultivars at Adet, 2016 main cropping season. **significant at p=0.01 probability level; TRS=terminal rust severity; AUDPC=area under disease progress curve; CI=coefficients of infection.

Conclusion

The results of the current study showed that most of the tested bread wheat varieties had susceptible infection types for the TTKSK race at seedling stage. All evaluated cultivars exhibited moderately resistant to susceptible field responses under field condition whereby the susceptible check showed the highest disease severity with susceptible reaction. Varieties Galil, Dinkinesh, Millenium and Shina showed moderately resistance reaction to the disease at adult plant stage, with minimum AUDPC and terminal severities. Of these, Galil and Millenium had resistant type of reaction at seedling stage indicating that they possess major gene resistance. Therefore, they can be used as sources of stem rust resistance when the aim of the breeding program is for major gene.

Whereas, Dinkinesh and Shina with the susceptible seedling infection types and low disease parameters in the field were identified as highly slow rusters. On the other hand, cultivar Pavon 76, Kakaba, Danda'a, Madawalabu, Kingbird, Bonny, Africa Mayo and Alidoro had TRS 31-50% with compatible field responses (MR-MS to MS-S), CI values ranging from 21-45 and rAUDPC 31-70% were regarded as moderately slow rusting. The principal effect of slow rusting resistance in the studied cultivars highlighted the value of having them as sources of durable resistance in breeding programmes.

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