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Research Article
Assessment of Sources of Adult Plant Resistance Genes to Stem Rust in Ethiopian Durum Wheat Genotypes

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Abstract

Background and Objective: Stem rust is a devastating disease of bread wheat and durum wheat in the major wheat-growing regions of the world. Particularly, the stem rust race identified as Ug99 and its mutants initially emerged in Uganda in 1999 had crossed borders of neighboring countries in Africa, Middle East and Asia has become a major threat to the world wheat industry. Therefore, the present study was conducted in the greenhouse and field to assess sources of durable resistance to stem rust. **Materials and Methods:** Fifteen durum wheat genotypes and a susceptible cultivar 'Morocco' were evaluated in the greenhouse and field at Debre Zeit Agricultural Research Center, Ethiopia, in order to detect the presence of effective stem rust resistance genes. A mixture of three dominant races of *Puccinia graminis* f. sp. *tritici* (TKTTF, TTKSK and JRCQC) was used for inoculation. The field experiment was conducted using Random Complete Block (RCB) design with three replications at two different locations. **Results:** Phenotyping of the genotypes at seedling stage in the greenhouse showed four genotypes (Ginchi, Quami, DW-#3 and DW-#11) that carried effective All Stage Resistance (ASR) genes; however, the rest 11 genotypes showed susceptible reaction. On the other hand, the field assessment of the genotypes for stem rust resistance showed presence of varied levels of field resistance. The combined results from both seedling reaction test and field experiments indicated that the 11 genotypes might possess one or more Adult Plant Resistance (APR) genes to stem rust of wheat. **Conclusion:** The 11 genotypes that possessed APR genes can be good sources of durable stem rust resistance genes to be incorporated in the Ethiopian durum wheat improvement program.

Key words: Adult plant resistance, seedling resistance, durum wheat, stem rust, physiological races

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Wheat (*Triticum* spp.) is considered as the earliest domesticated cereal crop and currently the most important agricultural product of the world. It is one of the most important cereal crops in the world in terms of cultivation area and amount of produce. According to FAOSTAT[1], 729 million Mt of wheat produced in the world. The major producing countries in the world were European Union, China, India, USA and France in that order. In 2015/16 cropping season during main and minor cropping seasons the average yield of wheat in Ethiopia[2] was 2608 kg ha^{-1}.

There are many known wild and cultivated species of wheat in the genus *Triticum*. However, the principal wheats of commercial importance are *T. aestivum* L. and *T. durum* Desf.[3]. Durum wheat (*T. durum* Desf.) is the predominant tetraploid species that constitutes nearly 10% of wheat production in the world and approximately 30% in Ethiopia[3-5].

In Ethiopia, the most suitable altitudes for wheat production are between 1900-2700 m above sea level[6]. Despite the large area of cultivation under wheat, average yield in Ethiopia is below the world average[7]. The low yield of wheat in Ethiopia is attributed to a number of factors which encompass soil fertility, weeds, moisture stress and pests of which disease is rapidly spreading fungal diseases causing epidemics that require urgent actions[8]. Stem rust is a potentially devastating fungal disease that can kill wheat plants and small grain cereals but more typically reduces foliage, root growth and grain yields[9]. Epidemics of stem rust could cause a loss[10,11] of up to 100%. Temesgen *et al.*[12] reported that an outbreak of stem rust epidemics which occurred in Arsi and Bale regions caused 67-100% loss on commercial durum wheat cultivars. The main reason for such a disaster was the continuous release of cultivars with major gene (race-specific) resistance[13]. Since race-specific resistance usually overcome through emergence of new races of virulence in the pathogen population, durable resistance is of great interest to wheat breeders[14,15].

Stem rust of wheat caused by the pathogen *Puccinia graminis* f. sp. tritici (Pgt) has become an important disease of wheat in the major wheat producing regions of Ethiopia. Hence, use of resistant cultivars particularly of Adult Plant Resistance (APR) genes is the most effective, sustainable and environment friendly way of managing rust diseases of wheat due to its durable nature of resistance[16]. Presence of a single or couple of APR genes in a cultivar may not provide sufficient resistance levels in a high disease pressure area. However, cultivars with high levels of resistance were developed by pyramiding 3-5 APR genes[17-21]. In Ethiopia wheat varieties are becoming vulnerable to stem rust epidemics largely due to the use of varieties with race specific major gene resistance developed materials. A case in point could be the emergence of the new race Ug99 in Uganda in 1999[22] which later appeared in Kenya and Ethiopia in 2005 that broke the resistance of the most widely deployed seedling resistance gene *Sr31* after decades of control of the pathogen[20]. The Ug99 has brought a major anxiety in the world wheat production as majority (>90%) of the world's commercial wheat varieties became susceptible to it[23]. Hence, this necessitates the need to identify sources of race non-specific adult plant resistance germplasm to be incorporated in the wheat breeding scheme. Thus, this study was initiated to assess sources of resistance to stem rust in the durum wheat genotypes.

MATERIALS AND METHODS

Description of experimental site: Field experiments were conducted during July-December, 2017 main cropping season at Debre Zeit Agricultural Research Center, Ethiopia in two different testing sites. The sites are located within the range of approximate geographical coordinates of 8° 44"N latitude and 38°57"E longitude with altitude range of 1900-1950 m above sea level. The average annual rainfall of the area is 851 mm and the soil type of the site is eutric vertisol (87.74%) and haplic andosols and vectric andosols constituting 5.94% each, respectively. The average minimum and maximum annual temperatures of the study sites are 11.23 and 25.19°C, respectively[24].

Plant materials: Fifteen durum wheat genotypes and four bread wheat genotypes including 'Morocco' were used as sources of plant materials in this study. The four bread wheat genotypes were used as spreaders or susceptible cultivars to facilitate infections and also as standard for susceptibility in scoring at greenhouse and field studies. Details of the plant materials are described in Table 1.

Pathogen materials: An equal proportion of the mixture of currently dominant stem rust races in the field (TKTTF, TTKSK and JRCQC) was used as source of inoculums to evaluate the durum wheat genotypes both in the greenhouse and field.

Greenhouse seedling evaluation for stem rust resistance: Phenotyping of the 15 durum wheat genotypes and one susceptible check (Morocco) was conducted to detect the

Table 1: Description of durum wheat genotypes used in the study

Genotypes	Altitude	Pedigree	Year of release	Sources
Alemtena	1500-1800	Icasyr-1/3/Gen//Sti/Mrb3	2016	DZARC
Tesfaye	1800-2800	ARMENT//SRN-3/NIGRIS-4/3/CANELD-9.1/4/TOSKA-26/RASCON-37//SNITSN/5/PLAYERO	2016	DZARC
Mangudo	1800-2600	MRF_ 1STJ2/3/1718BT24//KARIM	2012	DZARC
Utuba	188-2600	Durum ICARDA/Ethiopia IDON-MD 53	2015	DZARC
Denbi	1800-2650	(AJAIA/ BUASHEN)	2009	DZARC
Ude	1800-2400	CHEN/ALTAR 84//JO 69	2002	DZARC
Boohai	-	-COO "S"/CANDEAL II CD 3062- BS OGR	-	DZARC
Mekuye	1800-2600	STJ3//BCR/LK54/3/TER-3	2012	DZARC
Asasa	1680-2400	(DZ 2085)	1997	DZARC
Quamy	1600-2200	CD-75533-A	1996	DZARC
Ginchi	2000-2300	DZ-1050	2000	DZARC
Yerer	2000-2200	chen/Tez/3/Guil//cII CD 94026-4y-040m-030y-pAp-0y	2002	DZARC
DW-NVT-OHMA-16/17-set-I-#3	-	-	-	DZARC
Hitosa	1800-2650	CHEN/ALTAR-84	2009	DZARC
DW-NVT-OHMA-16/17-set-I #11	-	-	-	DZARC
PBW 343	-	-	-	DZARC
Digelu	-	SHA 7/ KAUZ or HAR 3116	-	DZARC
Arendato	-	-	-	DZARC

Source: Debre Zeit Agricultural Research Center (DZARC), Ethiopia

presence of effective seedling resistance genes to stem rust. Ten seeds of each wheat variety and a susceptible check were planted in plastic pots containing soil, compost and sand in the ratio of 2:1:1, respectively using RCBD (Randomized Complete Block Design) with 3 replications. After 7 days of planting, the seedlings were inoculated with mixture of the currently dominant stem rust races in the field (TKTTF, TTKSK and JRCQC) using standard procedure for inoculation of seedlings as described in previous studies[25]. To create artificial dew and facilitate spore germination, water was sprayed using sprayer. Twenty minutes after inoculation they were placed in dew chamber in dark room (incubation room) covered with polythene plastic sheets for 24 h at 18-22°C. Upon removal from chamber, seedlings were exposed to 3 h of fluorescent light to dry dew on the leaves. Following this, the seedlings were transferred to the greenhouse microclimate rooms where conditions were regulated at 12 h photoperiod, at temperature range of ±25°C and RH of 60 -70%.

Scoring of the Infection Types (IT) commenced two weeks after inoculations (12-15 days) using 0-4 scale as described in previous literature[26]. Where, '0' = Immune, '.' (flack) = Practically immune, '1' = Very resistant, '2' = Moderately resistant to resistant, '3' = Moderately susceptible and '4' = completely susceptible.

Field evaluation for adult plant resistance to stem rust: The fifteen durum wheat genotypes and a composite of 3 susceptible check cultivars; PBW343, Digelu and Arendato (used as a rust infector plants) were planted using randomized complete block design with three replications in two different experimental sites. The field plot size was 1.2×2.5 m where each experimental plot consisted of six rows. The spacing between blocks was 1 m and the spacing between plots and spreader row and within blocks was 0.5 m each, respectively and seeds were drilled in rows at spacing of 20 cm with seed rate of 150 kg ha^{-1}.

Experimental plots were fertilized with Diammonium phosphate (DAP) fertilizer at rate of 100 kg ha^{-1} at planting as source of P (phosphorus). Urea was used as source of N (nitrogen) at rate of 150 kg ha^{-1} and applied in splits where the first half at planting and the remaining half a month after planting. All crop management practices such as; cultivation, weeding etc., carried out as desired. Two rows of infector plants (susceptible varieties) were planted across the borders and between the replications. After 30 days of planting the infector plants were inoculated with the spore mixtures of the stem rust races.

Disease severity recording in the field commenced after establishment of the rust in the infector rows. Recording of rust severity was made using the modified Cobb's scale[27-29] where, 0% = Immune and 100% = Completely susceptible. The field assessment of stem rust data recording done six times from each experimental plot randomly starting from booting stage until the crop attains its physiological maturity. The Average Coefficient of Infection (ACI) was calculated by multiplying the severity data obtained for each genotype and the constant value assigned for host response as described earlier[29]. The area under disease progress curve was computed using the formula developed[30] as described:

$$AUDPC = \sum_{i=1}^{n-i}\left[1/2(X_{i+1} + X_i)(t_{i+1} - t_i)\right]$$

Where:

X_i = Average coefficient of infection of the ith observation

X_{i+1} = Average coefficient of infection of the i+1th observation

t_{i+1}-t_i = Number of days between the ith observation and the i+1th observation

Data analysis

Analysis of variance: The data for disease parameters at two sites were subjected to analysis of variance using GenStat 16th edition statistical software package (VSN International Ltd, London, UK) following the procedures described in previous studies[31]. The differences between treatment means was compared using Least Significant Difference (LSD) test at 5% level of significance when the ANOVA showed the presence of significant difference between genotypes.

RESULTS

Results from the experiments entailing assessment of slow rusting resistance genes for stem rust studies between durum wheat genotypes were conducted both in greenhouse and field conditions. The greenhouse seedling test and field assessment data for stem rust resistance has been subjected to Analysis of Variance (ANOVA) and demonstrated highly significant difference between genotypes for both (ASR and APR) types of genetic resistance.

Seedling reaction test: Results from the greenhouse experiment showed that the durum wheat genotypes varied in their reaction. To confirm the results of the seedling tests, the greenhouse experiment was repeated three times following the same procedure and the result was similar. The seedling test data ranged between infection types '1' and '4'. Summary of the greenhouse experiment data is presented in Table 2.

Genotypes possessing only adult plant resistance character (genes) showed intermediate (3) or fully susceptible (4) reaction in the seedling tests. Based on the 0-4 scoring scale, only two cultivars (Ginchi and Quami) showed resistance reactions IT 1 consistently, the two promising genotypes (DW-NVT-OHMA-16/17-set-1-#11 and DW-NVT-OHMA-16/17-set-1-#3) showed resistance to moderately resistance reaction IT 2, five genotypes (Boohai, Denbi, Hitosa, Tesfaye and Yerer) showed moderately susceptible reaction IT 3, the rest six genotypes (Alemtena, Asasa, Mangudo, Mekuye, Ude and Utuba) showed susceptible reaction IT 4 to stem rust that is comparable to the standard susceptible check cultivar 'Morocco' (Table 2).

Field experiment: The field assessment data for stem rust resistance has been subjected to Analysis of Variance (ANOVA) and demonstrated highly significant difference between genotypes in both locations. The Analysis of Variance (ANOVA) for AUDPC showed highly significant ($p \leq 0.01$) differences among genotypes and the Analysis of Variance (ANOVA) for all Average Coefficient of Infection (ACI) showed highly significant ($p \leq 0.01$) differences and the disease severity data showed significant difference at both locations (Appendix 1).

Table 2: Area under disease progress curve estimated from the field assessment data evaluated at 2 locations in 2017/18 cropping season and the respective seedling test data obtained from greenhouse study of the fifteen durum wheat genotypes

	Area under disease progress curve		
Genotypes	Black soil	Light soil	Seedling result
Alemtena	26	27	4
Asasa	23	38	4
Boohai	26	32	3
Denbi	29	29	3
DW-NVT-OHMA-16/17-set-1-#11	24	35	2
DW-NVT-OHMA-16/17-set-1-#3	27	33	2
Gichi	28	19	1
Hitosa	28	26	3
Mangudo	27	34	4
Mekuye	25	30	4
Quami	22	16	1
Tesfaye	25	44	3
Ude	33	28	4
Utuba	23	20	4
Yerer	28	31	3
Check (PBW343, Digalu and Arendato)	83	69	4

Appendix Table 1: Mean square for measures of stem rust at black soil

Mean square									
SV	df	[1]ACI-1	ACI-2	ACI-3	ACI4	ACI-5	ACI-6	Severity	AUDPC
Resource replacement	2	0.333	5.812	128.58	17.33	1.75		0.001264	28.56
Treatment	14	46.8**	248**	716.2**	655**	902.13**	622**	0.0076**	622.94**
Error	28	0.97	5.324	23.96	15.11	10.19	228.6	228.6	45.12
Grand mean		1.29	6.44	12.92	15.08	15.38	29.2	0.16	29.94
LSD		1.630	3.847	8.162	6.482	5.324	25.21	0.065	11.201
CV (%)		75.7	35.8	37.9	25.8	20.8	51.7	23.6	22.4

*Significant at 5% level, **Significant at 1% level, [1]ACI-1, 2, 3 , 4, 5 and 6: Average coefficient of infection 1st, 2nd, 3rd 4th, 5th and 6th, respectively, AUDPC: Area under disease progress curve, LSD: Least significant difference, CV: Coefficient of variation and SV: Sustainability value

Appendix Table 2: Mean square for measures of stem rust at light soil

Mean square									
SV	df	[1]ACI-1	ACI-2	ACI-3	ACI-4	ACI-5	ACI-6	Severity	AUDPC
Resource replacement	2	1.083	1.750	2.47	9.25	42.25			5.15
Treatment	14	71.9**	109**	253.90**	341.96**	458.5**	622**	1155*	450.**
Error	28	1.794	9.661	17.46	28.27	33.72	228.6	470	66.06
Grand mean		1.83	3.19	7.17	12.50	16.38	29.2	39.3	31.8
L.S.D		2.234	5.183	6.967	8.866	9.683	25.21	36.15	13.55
CV(%)		73.1	97.5	58.2	42.5	35.5	51.7	55.1	25.6

*Significant at 5% level, **Significant at 1% level, [1]ACI-1, 2, 3 , 4, 5 and 6: Average coefficient of infection 1st, 2nd, 3rd 4th, 5th and 6th, respectively, [2]AUDPC: Area under disease progress curve, LSD: Least significant difference, CV: Coefficient of variation and SV: Sustain ability value

Appendix Table 3: Average coefficient of infection, severity and with the corresponding area under disease progress curve in black soil

Genotype	[1]ACI-1	ACI-2	ACI-3	ACI-4	ACI-5	ACI-6	Severity	AUDPC
Alemtena	0.00^{a}	4.67^{a-c}	9.33^{ab}	10.00^{abc}	10.00^{ab}	6.67^{a}	25^{ab}	26^{ab}
Asasa	0.67^{a}	4.00^{cd}	4.67^{ab}	7.33^{a}	8.00^{a}	20.70^{ab}	32^{abc}	23^{ab}
Boohai	1.33^{a}	5.33^{a-d}	8.67^{ab}	10.70^{ac}	8.67^{ab}	9.00^{a}	23^{abc}	26^{ab}
Denbi	0.00^{a}	4.00^{a-d}	10.67^{ab}	12.00^{abc}	12.00^{abc}	10.70^{a}	30^{abc}	29^{ab}
DW-NVT-OHMA-16/17-set-1-#11	0.67^{a}	6.00^{cd}	6.67^{ab}	14.00^{bc}	9.33^{ab}	8.67^{a}	22^{abc}	24^{ab}
DW-NVT-OHMA-16/17-set-1-#3	1.33^{a}	6.00^{cd}	8.00^{ab}	10.70^{abc}	13.33^{ab}	22.70^{ab}	27^{abc}	27^{ab}
Ginchi	0.00^{a}	2.67^{abc}	6.67^{ab}	11.30^{abc}	12.00^{abc}	25.00^{ab}	37^{bc}	28^{ab}
Hitosa	0.00^{a}	6.67^{d}	13.33^{b}	12.70^{abc}	11.30^{abc}	10.70^{a}	32^{abc}	28^{ab}
Mangudo	0.00^{a}	3.33^{a-d}	12.00^{ab}	15.33^{c}	16.00^{c}	37.00^{b}	30^{c}	27^{ab}
Mekuye	0.00^{a}	6.67^{d}	12.00^{ab}	12.00^{abc}	10.00^{ab}	19.00^{ab}	32^{abc}	25^{ab}
Quami	0.67^{a}	4.67^{a-d}	5.33^{ab}	8.00^{ac}	11.00^{abc}	16.00^{ab}	28^{a}	22^{a}
Tesfaye	0.00^{a}	5.33^{bcd}	12.67^{ab}	12.00^{abc}	12.00^{abc}	27.00^{ab}	38^{bc}	25^{ab}
Ude	0.00^{a}	4.00^{a-d}	9.33^{ab}	10.70^{abc}	9.33^{ab}	6.70^{a}	27^{ab}	33^{b}
Utuba	0.00^{a}	2.67^{abc}	10.67^{ab}	13.30^{abc}	11.00^{abc}	9.00^{a}	28^{abc}	23^{ab}
Yerer	0.00^{a}	1.67^{ab}	6.67^{ab}	11.30^{abc}	11.00^{abc}	28.00^{ab}	28^{bc}	28^{ab}
Check (PBW343, Digalu and Arendato)	16.00^{b}	40.00^{e}	70.00^{c}	70.00^{d}	80.00^{d}	100.00^{c}	70^{d}	83^{c}

[a-e]: 5 and 1% significant level, [1]ACI-1, 2, 3 , 4, 5 and 6: Average coefficients of infection 1st, 2nd, 3rd 4th, 5th and 6th, respectively, AUDPC: Area under disease progress curve, LSD: Least significant difference, CV: Coefficient of variation

This indicated the presence of sufficient genetic variability for the level of resistance/susceptibility among the genotypes investigated. Adult plant resistant genotypes were identified on the bases of their Area under Stem Rust Progress Curve (AUDPC), disease severity and average coefficient of infection at the two locations in addition to their susceptible disease reaction at seedling stage (IT 3+ to 4) and relatively resistance reactions observed at adult stage in the field (Table 2, Appendix 2, 3).

Area under stem rust progress curve and average coefficient of infection: At black soil the disease severity for the durum wheat genotypes showed moderately resistance disease reaction except two genotypes (Tesfaye and Ginchi) that showed moderately resistance to moderately susceptible (MR-MS) reaction (Appendix 3) whereas, the area under Disease Progress Curve (AUDPC) for all 15 genotypes showed moderately resistance reaction (Table 2).

Appendix Table 4: Average coefficient of infection, severity and area under disease progress curve in light soil

Genotype	[1]ACI-1	ACI-2	ACI-3	ACI-4	ACI-5	ACI.6	Severity	[2]AUDPC
Alemtena	0.00^{a}	0.00^{a}	5.33^{a}	12.67^{abc}	16.00^{b-e}	9.33^{ab}	30^{ab}	27^{a-d}
Asasa	2.00^{a}	4.00^{ab}	6.00^{a}	11.33	13.33^{a-e}	31.00^{abc}	33^{bcd}	38de
Boohai	0.00^{a}	2.00	6.00^{a}	6.67^{a}	16.67^{b-e}	27.00^{abc}	45^{abc}	32^{b-e}
Denbi	0.00^{a}	4.00^{ab}	8.00^{ab}	12.67^{abc}	17.33^{cde}	9.33^{ab}	33^{ab}	29^{a-d}
DW -#11	0.00^{a}	0.00^{a}	2.67^{a}	7.33^{ab}	18.00^{cde}	33.00^{abc}	31^{bcd}	35de
DW-# 3	0.00^{a}	0.667^{a}	2.67^{a}	10.00^{ab}	11.33^{a-e}	28.00^{abc}	47^{abc}	33^{cde}
Gichi	1.333^{a}	1.333^{a}	4.00^{a}	4.67^{a}	6.00^{a}	13.00^{abc}	32^{ab}	19^{ab}
Hitosa	0.00^{a}	2.67^{ab}	6.67^{ab}	14.00bc	18.67^{de}	9.33^{ab}	28^{ab}	26^{a-d}
Mangudo	0.00^{a}	0.00^{a}	2.67^{a}	11.33^{abc}	12.00^{a-e}	36.00^{bc}	30^{bcd}	34de
Mekuye	1.333^{a}	0.00^{a}	5.33^{a}	7.33^{ab}	9.33^{abc}	31.00^{abc}	23^{bcd}	30^{bcd}
Quami	1.333^{a}	0.67^{a}	2.80^{a}	6.67^{ab}	7.33^{abc}	4.67^{a}	18^{a}	16^{a}
Tesfaye	0.00^{a}	5.33^{b}	13.33^{b}	19.33c	19.33^{e}	40.00^{c}	35^{cd}	44^{e}
Ude	1.333^{a}	2.67^{ab}	4.67^{a}	12.00^{abc}	12.00^{a-e}	7.33^{ab}	30^{ab}	28^{a-d}
Utuba	1.333^{a}	1.33^{ab}	2.67^{a}	6.00^{ab}	8.67^{abc}	12.00^{abc}	20^{ab}	20^{abc}
Yerer	0.667^{a}	1.33^{ab}	2.00^{a}	8.00^{ab}	16.0^{b-e}	26.00^{abc}	42^{abc}	31^{b-e}
Check	20.000^{a}	25.00^{c}	40.00^{c}	50.00	60.00^{f}	100.00^{d}	100^{d}	69^{f}

$^{a-f}$: 5 and 1% significant level, [1]ACI-1, 2, 3 , 4, 5 and 6: Average coefficient of infection 1st, 2nd, 3rd 4th, 5th and 6th, respectively, [2]AUDPC: Area under disease progress curve, LSD: Least significant difference, CV: Coefficient of variation, DW#3: DW-NVT-OHMA-16/17-set-1-#3 and DW#11: DW-NVT-OHMA-16/17-set-1-#11

At light soil, Three genotypes (Asasa, Tesfaye and DW-NVT-OHMA-16/17-set-1-#11) showed MR-MS reaction while the remaining genotypes demonstrated resistance to moderately resistance reaction (Appendix 4). On the other hand for disease severity, four of the genotypes (Boohai, Yerer, Tesfaye and DW-NVT-OHMA-16/17-set-1-#3) showed MR-MS reaction while majority of the genotypes showed resistance to moderately resistance reaction (Table 2). Average coefficient of infection showed moderately resistance reaction for all fifteen genotypes at both locations (Appendix 3 and 4).

The highest values of both AUDPC (83 in black soil and 69 in Light soil) and disease severity (100 in both black soil and 70 in light soil) was recorded on the spreader plots that were constituted from susceptible genotypes 'Digelu', 'PBW343' and 'Arendato' (Table 2, Appendix 3, 4). Whereas, disease severity of the experimental treatments (15 durum wheat genotypes) was less compared with the susceptible genotypes since the highest corresponding values of both AUDPC (33 in black soil and 38 in light soil) and disease severity (38 in black soil and 45 in light soil) were much less than half of the values observed for the susceptible genotypes (Table 2, Appendix 3, 4).

DISCUSSION

The present study was conducted to assess durable sources of adult plant resistance of durum wheat genotypes. The results from seedling reaction test revealed that four genotypes; Ginchi, Quami, DW-NVT-OHMA-16/17-set-I-#3 and DW-NVT-OHMA-16/17-set-I #11 carried effective ASR genes to Ug99 and its variants with ITs 1, 1+, 2 and 2, respectively. Five genotypes (Boohai, Denbi, Hitosa, Tesfaye and Yerer) showed moderately susceptible reaction IT 3; the rest six genotypes (Alemtena, Asasa, Mangudo, Mekuye, Ude and Utuba) showed susceptible reaction IT 4 to stem rust. The greenhouse and field evaluation data together showed that 11 genotypes (Alemtena, Yerer, Asasa, Denbi, Hitosa, Mangudo, Mekuye, Ude, Boohai, Tesfaye and Utuba) had source of only adult plant resistance character to stem rust since they showed intermediate to susceptible seedling reactions to stem rust races and comparably low AUDPC values. Debebe[32] and Aida[33] reported that selection of genotypes having low AUDPC values with terminal disease score of less than 20S is normally accepted for practical purposes where the aim is to utilize slow rusting resistance as one of the durable resistance strategies. Therefore, these result indicated that all these 15 durum wheat genotypes carried resistance genes to stem rust effective under field conditions (Table 2).

Several studies showed that genotypes carrying only slow rusting resistance genes or APR genes are usually susceptible at the seedling stage (devoid of effective seedling resistance genes) but become resistant as the plant matures[34,35]. Therefore, these 11 genotypes (Alemtena, Yerer, Asasa, Denbi, Hitosa, Mangudo, Mekuye, Ude, Boohai, Tesfaye and Utuba) may possess more than two adult plant resistance genes since their field assessment results confirmed their adult plant resistance character (Table 2, Appendice 3, 4). Significant number of findings[17-21] indicated that presence of a single or couple of APR genes in a cultivar may not provide sufficient resistance levels in high disease pressure areas, however, they mentioned that cultivars with high levels of resistance were developed by pyramiding 3-5 APR genes. Durable resistance can be explained that a consistent resistance reaction of

a plant displayed across locations/environments for several years of cultivation under favorable condition to a disease development[36]. Durable resistance to rusts can be achieved through a combination of both APR and ASR genes deployed to a single commercial cultivar[20,21]. Since durable resistance is mostly associated with APR or slow rusting genes characterized by susceptible response to seedling tests, it is therefore, important to have seedling reaction test to identify adult plant resistance character.

In general, it is possible to surmise that those genotypes that exhibited field resistance to stem rust at both locations but with seedling reactions ranged from 3-4 lacks effective ASR genes[37,38], hence, they can be good sources of APR genes. Therefore, these genotypes have to be selected as donor parent for incorporating durable resistance in durum wheat improvement program. For effective and precise breeding outcome knowledge of identity of the APR genes present in these genotypes is essential; hence, genotyping/screening of these 11 genotypes with the already known molecular markers of the APR genes; *Sr2*, *Sr55*, *Sr56*, *Sr57* and *Sr58* is imperative. The outcome of these studies could be used as a preliminary source of information to develop high yielding stem rust resistant durum wheat cultivars for future breeding program particularly for durable resistance wheat breeding through gene pyramiding approaches using molecular marker assisted selection.

CONCLUSION

This study depicted that 11 genotypes; Alemtena, Yerer, Asasa, Denbi, Hitosa, Mangudo, Mekuye, Ude, Boohai, Tesfaye and Utuba had source of only adult plant resistance character to stem rust. Therefore, these genotypes have to be selected as donor parent for incorporating durable resistance in durum wheat improvement program.

SIGNIFICANCE STATEMENT

This study discovered that the 11 durum wheat genotypes possessed acceptable level of field resistance to stem rust composed of adult plant resistance genes. On the other hand, the known pleiotropic APR genes are originated in bread wheat, this study might indicate the presence of other (uncharacterized) APR genes in durum wheat germplasm because the level of resistance displayed showed possession of at least three APR genes in each of the cultivars investigated.

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REFERENCE

1. FAOSTAT., 2014. International wheat production statistics. International Grains Council Figures from the Report "Grain Market Report". FAO., Rome
2. CSA., 2016. Report on area, production and farm management practice of belg season crops for private peasant holdings. The Federal Democratic Republic of Ethiopia Central Statistical Agency, Addis Ababa.
3. Bekele, E., 1984. Analysis of regional patterns of phenotypic diversity in the Ethiopian tetraploid and hexaploid wheats. Hereditas, 100: 131-154.
4. Khanna, K.R., 1991. Biochemical Aspects of Crop Improvement. CRC Press, Boka Raton, Ann Arbor and Boston.
5. Gooding, M.J. and W.P. Davies, 1997. Wheat Production and Utilization Systems, Quality and the Environment. Cambridge University Press, UK.
6. Hailu, B., M. Wilferd and N. Workneh, 1991. Research Conducted on Wheat Production Constraints in Ethiopia. In: Wheat Research in Ethiopia: A Historical Perspective, Gebre-Mariam, H., D.G. Tanner and M. Hulluka (Eds.). Institute of Agricultural Research, Addis Ababa, Ethiopia, ISBN-13: 9789686127577, pp: 30-50.
7. FAOSTAT., 2016. Crop prospects and food situation. Food and Agriculture Organization of the United Nations Statistics Division, FAO., Rome.
8. Hovmøller, M., S.K. Nayar, M. Prasher and S.C. Bharadwaj, 2010. Manual of current techniques in wheat rusts. Research Bill No. 2, Regional Station, Directorate of Wheat Research, Flowerdale.
9. Sawhney, R.N., 1995. Genetics of Wheat-Rust Interaction. In: Plant Breeding Reviews, Volume 13, Janick, J. (Ed.)., John Wiley and Sons Inc., USA., pp: 294-330.
10. Chen, X.M., 2005. Epidemiology and control of stripe rust [*Puccinia striiformis* f. sp. *tritici*] on wheat. Can. J. Plant Pathol., 27: 314-337.
11. Pardey, P.G., J.M. Beddow, D.J. Kriticos, T.M. Hurley and R.F. Park *et al*., 2013. Right-sizing stem-rust research. Science, 340: 147-148.

12. Temesgen, K., G. Bekele, Y. Balcha and B. Ayele, 1995. Status of Wheat Rusts in the Major Wheat Producing Regions of Ethiopia. In: Breeding for Disease Resistance with Emphasis on Durability, Daniel, D.L. (Ed.). Central and Southern Africa, Njoro, Kenya, pp: 180-184.
13. Belachew, A., 2002. Breeding Bread Wheat with Multiple Disease Resistance and High Yield for the Ethiopian Highlands: Broadening the Genetic Basis of Yellow Rust and Tan Spot Resistance. Cuvlier Verlag, Gottingen.
14. Suenaga, K., R.P. Singh and H.M. William, 2001. Tagging of slow rusting genes for leaf rust, Lr34 and Lr46, using microsatellite markers in wheat. JIRCAS Res. Highlights, 9: 8-9.
15. Ahamed, M.L., S.S. Singh, J.B. Sharma and R.B. Ram, 2004. Evaluation of inheritance to leaf rust in wheat using area under disease progress curve. Hereditas, 141: 323-327.
16. Bhavani, S., D.P. Hodson, J. Huerta-Espino, M.S. Randhawa and R.P. Singh, 2019. Progress in breeding for resistance to Ug99 and other races of the stem rust fungus in CIMMYT wheat germplasm. Front. Agric. Sci. Eng., 6: 210-224.
17. Bariana, H.S. and R.A. McIntosh, 1995. Genetics of adult plant stripe rust resistance in four Australian wheats and the French cultivar 'Hybride de Bersee'. Plant Breed., 114: 485-491.
18. Lillemo, M., X.M. Chen and R.P. Singh, 2005. Leaf Rust Resistance Gene *Lr34* is Involved in Powdery Mildew Resistance of CIMMYT Bread Wheat Line Saar. In: Wheat Production in Stressed Environments, Buck, H.T., J.E. Nisi and N. Solomon (Eds.)., Mar del Plata, Argentina, pp: 17-26.
19. Singh, R.P, J. Huerta-Espino, S. Bhavani, S.A. Herrera-Foessel and D. Singh *et al*., 2010. Race non-specific resistance to rust diseases in CIMMYT spring wheats. Euphytica, 179: 175-186.
20. Singh, R.P., D.P. Hodson, J. Huerta-Espino, Y. Jin and S. Bhavani *et al*., 2011. The emergence of Ug99 races of the stem rust fungus is a threat to world wheat production. Ann. Rev. Phytopathol., 49: 465-481.
21. Bansal, U.K., A.G. Kazi, B. Singh, R.A. Hare and H.S. Bariana, 2014. Mapping of durable stripe rust resistance in a durum wheat cultivar Wollaroi. Mol. Breed., 33: 51-59.
22. Pretorius, Z.A., R.P. Singh, W.W. Wagoire and T.S. Payne, 2000. Detection of virulence to wheat stem rust resistance gene *Sr31* in *Puccinia graminis*. f. sp. *tritici* in Uganda. Plant Dis., 84: 203.2-203.2.
23. McIntosh, R.A. and Z.A. Pretorius, 2011. Borlaug global rust initiative provides momentum for wheat rust research. Euphytica, 179: 1-2.
24. IUSS Working Group WRB., 2006. World reference base for soil resources 2006: A framework for international classification, correlation and communication. World Soil Resources Reports No. 103. FAO., Rome.
25. McIntosh, R.A., C.R. Wellings and R.F. Park, 1995. Wheat Rusts: An Atlas of Resistance Genes. CSIRO Publications, Australia.
26. Stakman, E.C., D.M. Stewart and W.Q. Loeggering, 1962. Identification of physiological races of *Puccinia graminis* var. *tritici*. US. Department of Agriculture, Agricultural Research Service, E617, pp: 1-54.
27. Peterson, R.F., A.B. Campbell and A.E. Hannah, 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res., C26: 496-500.
28. Roelfs, A.P., R.P. Singh and E.E. Saari, 1992. Rust Diseases of Wheat: Concept and Methods of Disease Management. CIMMYT, Mexico, DF., Pages: 81.
29. IPO. and CIMMYT., 1999. Rust scoring guide. Research Institute for Plant Protection (IPO), Wageningen, Netherlands and International Maize and Wheat Improvement Center (CIMMYT), Mexico.
30. Campbell, C.L. and L.V. Madden, 1990. Introduction to Plant Disease Epidemiology. John Wiley and Sons Inc., New York, USA., ISBN-13: 9780471832362, Pages: 532.
31. Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley Sons, New York, USA., ISBN: 978-0-471-87092-0, Pages: 704.
32. Debebe, M., 2003. Evaluation of bread wheat genotypes (*Triticum aestivum*) for slow rusting resistance, yield and yield related traits. M.Sc. Thesis, School of Graduate Studies of Alemaya University, Ethiopia.
33. Zewdu, A., 2005. Identification of source of slow rusting resistance stem rust in bread wheat (*Triticum aestivum*). M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.
34. Mallard, S., D. Gaudet, A. Aldeia, C. Abelard, A.L. Besnard, P. Sourdille and F. Dedryver, 2005. Genetic analysis of durable resistance to yellow rust in bread wheat. Theor. Applied Genet., 110: 1401-1409.
35. Ellis, J.G., E.S. Lagudah, W. Spielmeyer and P.N. Dodds, 2014. The past, present and future of breeding rust resistant wheat. Front. Plant Sci., Vol. 5. 10.3389/fpls.2014.00641
36. Bariana, H.S., 2003. Breeding for Disease Resistance. In: Encyclopedia of Applied Plant Sciences, Thomas, B., B.G. Murray and D.J. Murphy (Eds.)., Academic Press, Oxford, pp: 244-253.
37. Parlevliet, J.E. and A. van Ommeren, 1988. Accumulation of partial resistance in barley to barley leaf rust and powdery mildew through recurrent selection against susceptibility. Euphytica, 37: 261-274.
38. Bariana, H., K. Forrest, N. Qureshi, H. Miah, M. Hayden and U. Bansal, 2016. Adult plant stripe rust resistance gene *Yr71* maps close to *Lr24* in chromosome 3D of common wheat. Mol. Breed., Vol. 36, No. 7. 10.1007/s11032-016-0528-1.