



Evaluation of Advanced Bread Wheat Lines for Field and Seedling Resistance to Stem Rust (*Puccinia graminis* f. sp. *tritici*)

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Abstract: Field-based adult plant resistance assessment at multi-location rust hot spot sites is a crucial job for those plant pathologists screening several wheat lines at a time against the rusts. Rust resistant bread wheat genotypes that have been extracted from previous studies have sustained wheat production in Ethiopia. The objective of this study was to evaluate advanced bread wheat lines extracted from wheat breeding trials against stem rust at adult plant stage under stem rust hot spot sites and at seedling stages in the greenhouse. Eighty three lines were further re-evaluated in consecutive two years. Check varieties were included for comparison. High disease pressure was developed on adult plant in the trial as it has been revealed by high severity on susceptible check varieties. Over years average final rust severity, co-efficient of infection and field reaction have used for differentiating Adult plant resistances. Based on ACI, the 843 genotypes evaluated in initial trial in 2013 were categorized into 10 resistance levels, of which 188 genotypes were in high level resistance category, revealing that various level of adult plant resistance is operating in these test materials. Most of 83 genotypes re-evaluated in consecutive two years after initial stage have sustained low final stem rust severity and coefficient of infection as compared with check varieties. Genotypes were varied by adult plant reaction to stem rust, however, lines ETBW7818, ETBW7819, ETBW7258, ETBW 8008, ETBW 8009, ETBW 8017, ETBW 8027, ETBW 8052, ETBW 8054 and ETBW 8055 concisely showed a reaction of R to R-MR invariably with environments. Of the 83 lines tested at seedling stages against four races, 21 lines exhibited resistance to three races JRCQC, TKTTF, TTKSK and TRTTF whereas 24 lines showed susceptibility to the latter three races. Based on adult reaction, final disease severity and coefficient of infection data, Sixty six bread wheat lines and two cultivars Shorima and Huluka sustained final rust severity $\leq 30\%$ and low ACI are acceptable for rust resistance breeding in wheat. However, 52 lines showed comparable resistance to Shorima or Hulluka are the priority materials to be used for developing resistant cultivars potentially combining non-race specific and race specific genes which is more durable than cultivars with major resistance gene effect and more efficient than sole adult plant resistance. Inherent resistance genes of these lines are unknown and warrant further description.

Keywords: Bread Wheat, *Puccinia graminis*, Adult Plant Resistance, Partial Resistance, Seedling Resistance, All Stage Resistance

1. Introduction

Ethiopia is the second largest wheat producing country in sub-Saharan Africa with two seasons of wheat crops per annum. Crops of *meher* season is planted between June and Aug, and harvested in November/December while the *belg* season crop planting is done in April and harvesting is carried out during July/August [1]. Wheat grains of 4.5 million tons are produced on 1.6 million hectares annually. Yet, productivity of wheat remains low at 2.67t/ha [2]. Low wheat productivity is implicated to biotic and abiotic constraints. Rusts, especially stem rust and yellow rust are most widely distributed in four major wheat producing regions and greatly contribute to the low wheat productivity [3-6]. Stem rust is a major disease in East Africa, and yellow rust is a major disease in 12 countries globally [7]. In Ethiopia, stem rust and yellow rust incur actual yield losses as high as 42-52% and 20-71%, respectively, in the *meher* season [4-5, 8]. These yield loss figures are quite large for a country such as Ethiopia where a great majority of people are food insecure. Two disease management options, genetic resistance and chemical, are the most important rust management strategies in Ethiopia and worldwide [7, 9]. Several wheat genotypes with various levels of resistance backgrounds were derived from previous rust resistance screening efforts were recommended for stem resistance breeding [4, 10].

Variability is high in *graminis* f. sp. *tritici* population in Ethiopia [11-13]. Of several stem rust races in present *graminis* f. sp. *tritici* population in Ethiopia, races TTKSK, TKTTF, TRTTF, JRCQC and TTTTF threats to wheat production currently. Digalu race, TKTTF, destructed the popular bread wheat variety Digalu in Ethiopia and led to up to 100% yield loss in 2013-2015 [13].

Of the rust resistance types, resistance controlled by major R-genes is not long lasting, not durable [14] due to new races evolving in pathogen populations causing rusts through climatic changes [15], sexual and para-sexual recombination [16-17] and migration of the virulent forms into new regions [7, 18] and defeating resistance genes deployed to commercial varieties. Partial resistance which is determined by minor genes and expressed under field condition is considered durable in combating wheat rust as compared to resistance determined by aforementioned R-genes although both resistance types have a complementary effect on

extending rust management durability. Resistance sources to rusts are searched at regular bases by pathologists and breeders. From 2013 to 2015, several bread wheat advanced lines extracted from wheat breeding trials were evaluated for stem rust resistance at stem rust hot spot sites and at seedling stages. This paper presents the findings of this study.

2. Materials and Methods

2.1. Field Screening for Adult Plant Resistance

In main wheat growing season, *locally called meher* season in 2013, 843 bread wheat genotypes, composed of 836 advanced lines from wheat breeding program: observation nurseries and yield trials, 5 known commercial cultivars (K6295-4A, Kakaba, Alidoro, Danda'a and Digalu, two susceptible check varieties Kubsa and PBW343 and resistant cultivars of recent release Shorima and Huluka) were included planted in two – four rows (1m x 0.4-0.8m) at stem rust hot spot sites. Eighty three genotypes were retained from 2013 field screening nursery and were further evaluated in 2014 and 2015. The ETBW code number and pedigree of the 83 materials evaluated over years are given in Table 1. Natural stem rust epidemic was enhanced by two spreader rows composed of mixed susceptible cultivars PBW343, Kubsa and Morocco in 2013 and 2014, and mixture of Digalu and the aforementioned susceptible cultivars in 2015. Spreader rows were planted in perpendicular to the test entries [19].

Weeds were managed by two times hand weeding. Modified-Cobb scale was used for measuring severity in combination with field reaction [20]. Coefficient infection was calculated by multiplying disease severity with field infection response values 0.0, 0.2, 0.4, 0.8 and 1.0, representing immune, resistant (R), moderately resistant (MR), moderately susceptible (MS) and susceptible (S) reactions, respectively [21]. Multiple infection responses were calculated by double-weighting of the first infection response. In 2013, resistance of genotypes were compared using average coefficients of infection. Field reaction, average final rust severity and coefficient of infection, previously used by various authors such as [22] for comparing test genotypes and the checks further evaluated in 2014 and 2015.

Table 1. ETBW Code and pedigree of 83 bread wheat lines evaluated against stem rust at adult plant stage and seedling plant stage.

ETBW Code*	Pedigree
6114	SOKOLL//SUNCO/2*PASTOR
6109; 6130	SOKOLL/EXCALIBUR
6939	UTIQUE 96/FLAG-1
7058	ROLF07//TAM200/TUI/6/WBLL1/4/HD2281/TRAP#1/3/KAUZ*2/TRAP//KAUZ/5/TACUPETO F2001
7258	SABA/FLAG-1
6212	QAFZAH-23/SOMAMA-3
6688	PBW343*2KUKUNA//PARUS/3/PBW343*2/KUKUNA
7580	CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/HAR311
7590	MILAN/S87230//BAV92/3/AKURI #1
7591; 7592	WBLL1*2/TUKURU//CROSBILL #1

ETBW Code*	Pedigree
8006; 8009; 7807; 7809; 7998; 8003; 8008; 7808	SERI.1B//KAUZ/HEVO/3/AMAD/4/FLAG-2
8012; 8017; 8018; 8027, 8015; 8022; 8021; 8023; 8024; 8014; 8016; 8019; 8020	PAVON 76/FLAG-3
8028	QAFZAH-16/ICARDA-SRRL-5
8042; 8043; 8044	QAFZAH-22/3/MON'S//ALD'S//TOWPE'S'
8055	SOMAMA-9/ICARDA-SRRL-2
6161	CROC_1/AE.SQUARROSA
6861	(213)//PGO/10/ATTILA*2/9/KT/BAGE//FN/U/3/BZA/4/TRM/5/ALDAN/6/SERI/7/VEE#10/8/OPATA WAXWING*2/HEILO
6921	ALTAR 84/AE.SQUARROSA (221)
7523	//3*BORL95/3/URES/JUN//KAUZ/4/WBLL1*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
7207	PBW343*2/KHVAKI//JUCHI
7567; 7568	CHAM-4/SHUHA'S/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB
7681	KFA/2*KACHU
7810	OASIS/KAUZ//4*BCN*2/3/PASTOR/4/HEILO/5/PAURAQ
7814; 7813	ENKOY/FLAG-5
7815; 7819; 7817; 7816; 7818	KBG-01/FLAG-7
7853	K6295-4A/FLAG-8
7912	BABAX/LR39//BABAX/4/BJY/COC//PRL/BOW/3/FRTL/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/KENNEDY
7915	CHIH95.7.4//INQALAB 91*2/KUKUNA
7966; 7962; 7965	W15.92/4/PASTOR//HXL7573/2*BAU/3/WBLL1
7976; 7977	DIGELU/(BOW/FENGKANG15)
8045; 8052; 8054; 8048; 8049; 8051	K6295-4A/ETBW4919
6696	QAFZAH-35/AMIR-2
6847	PBW343*2/KUKUNA//SRTU/3/PBW343*2/KPASTOR
6911	ROLF07*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
7008	REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/PVN
7092	QAFZAH-5/ANGI-2//BOW #1/FENGKANG 15
7100	ALD/CEP75630//CEP75234/PT7219/3/BUC/BJY/4/CBRD/5/TNMU/PF85487
7189	OASIS/KAUZ//4*BCN/3/PASTOR/4/KAUZ*2/YACO//KAUZ
7255	NS732/HER//MILAN/SHA7
7496	AGUILAL/FLAG-3
7539	WBLL1*2/BRAMBLING//KACHU
7554; 7582	SERI.1B*2/3/KAUZ*2/BOW//KAUZ*2/5/REH/HARE//2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES
7587	SAUAL/YANAC//SAUAL
7820	FRNCLN/BECARD
7825	FLAG-6/ICARDA-SRRL-6
	AMIR-2/TAJAN

* ETBW Code= Ethiopian Bread Wheat Code Number

2.2. Greenhouse Seedling Evaluation

Five seeds of each 83 bread wheat lines listed in Table 1 were raised to five seedlings in pots in the greenhouse. Urediospores of rust races TKTTF, TTKSK, TRTTF and JRCQC with different virulence spectrum (Table2) were suspended in capsules and sprayed on seven day old seedlings using the methods and procedures developed by [23] and then placed in dew chamber for 18 hrs dark at 18 to 22°C followed by the exposure of the materials to light for 3 to 4 hrs in order to provide condition for infection. Then the seedlings were transferred to the growth room in the green

house where conditions were regulated at 12 hr photoperiod, 18 to 25 °C and 60 to 70% relative humidity. Stem rust infection types were noted at 14 days after inoculation using 0 to 4 rating scale; scorings of 0-2 and 3-4 values in 0-4 scale represented resistance and susceptible infection types, respectively. Race TKTTF is new stem rust race which has caused sudden epidemic in Bale zone in 2013 and further spread to Arsi and West-Shewa zone and resulted in severe epidemics and damaged the Digalu cultivar [13]. The race is a dominant stem rust race in current pathogen population in Ethiopian wheat production agro-ecologies.

Table 2. Virulence spectra of the test four stem rust races used for screening the germplasm at seedling plant stage.

Races	Virulence	A virulence
TKTTF	5, 21, 9e, 7b, 6, 8a, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN	11, 24, 31
TRTTF	5, 21, 9e, 7b, 11, 6, 9g, 36, 9b, 30, 17, 9a, 9d, 10, Tmp, 38, McN	8a, 24, 31
TTKSK	5, 21, 9e, 7b, 11, 6, 8a, 9g, 9b, 30, 17, 9a, 9d, 10, 31, 38, McN	36, Tmp, 24
JRCQC	21, 9e, 11, 6, 9g, 17, 9a, 9d, McN	5, 7b, 8a, 36, 9b, 30, 10, Tmp, 24, 31, 38

3. Results

3.1. Field Screening for Adult Plant Resistance

Excellent stem rust epidemic pressures were built within the trial at each test location. Stem rust resistance status of 843 genotypes was assessed using average coefficients of infection (ACI) in 2013 and categorized into different resistance groups based on this disease parameter, Figure 1. Out of the total genotypes, 109 and 79 genotypes were grouped into high level of resistance in terms of ACI values,

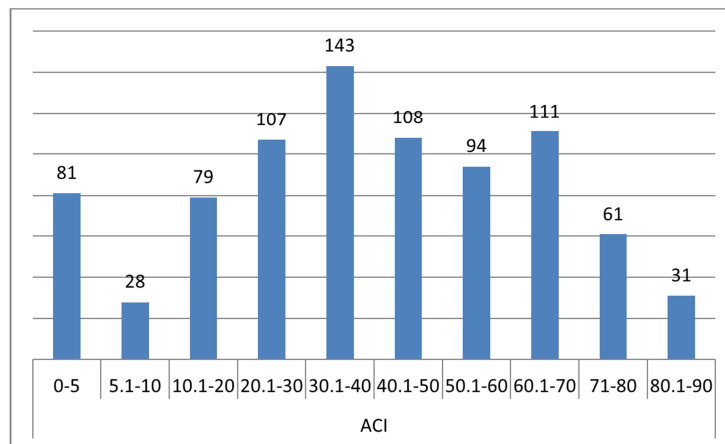


Figure 1. Stem rust resistance diversity of 843 advanced bread wheat lines and varieties as classified based on average coefficient of infection (ACI) of two locations, meher season, 2013.

Eighty three genotypes retained from 2013 field screening activity and further evaluated under field conditions at stem rust hot spot sites were compared using average final rust severity, coefficient of infection and adult plant response derived from the disease data generated during 2013-2015. The results are summarized in Tables 3, 4 and 5, based on variability of seedling plant reactions to the four test stem rust races menacing wheat production.

Final rust severity, a cumulative result of all resistance factors involved and inhibiting the progress of disease epidemic [25] and coefficient of infection values recorded on all lines as a whole have been lower than the most susceptible checks indicated in Table 3.

The check cultivars Digalu, Kubsa, Alidoro, Kakaba, and PBW343 had sustained high final rust severity ranging from 39-85.4% and ACI ranging from 34.8-81.5. The others three checks Danda'a, K6295-4A and Hulluka had the intermediate severity (17.8-28.5%) and ACI (14.4-34.8) whereas variety shorima had the lowest both final stem rust severity (6%) and ACI as low as 3 (Table3). Except lines ETBW 6921 (Table 3), ETBW 7580 (Table4) and ETBW7189, ETBW 7587 (Table5), all the 83 lines had lower final rust severity than check varieties Digalu, Kubsa, Alidoro, Kakaba and PBW343 whereas lines ETBW 6161, ETBW 6696 and ETBW 7539 had a comparable or low level of severity to the rest three check varieties Danda'a, K6295-4A and Hulluka. Of all 83 lines evaluated 52 lines: 13, 17 and 22 lines presented in Tables 3, 4 and 5, respectively, showed lower or comparable disease parameters values recorded on Shorima variety that has an effective resistance gene Sr 24, effective stem

rust resistance gene against all major races currently prevailing in Ethiopia. Among these materials with low final rust severity and coefficient of infection, 48 lines were sister lines from various crosses: 13, 8, 6 and 5 lines were from PAVON76/FLAG-3, SERI.1B//KAUZ/HEVO/3/AMAD/4/FLAG-2, QAFZAH-35/AMIR-2 and K6295-4A/FLAG-8 crosses, respectively, whereas each 3 lines were from each QAFZAH-22/3/MON'S/ALD'S//TOWPE'S, DIGELU/(BOW/FENGKANG15). Each two lines were from each SOKOLL/EXCALIBUR, WBL1*2/TUKURU//CROSBILL#1, KFA/2*KACHU, KBG-01/FLAG-7 and SAUAL/YANAC//SAUAL crosses. According to [26], final rust severity, an epidemiological parameter, can effectively measure slow rusting; a kind of partial resistance in wheat.

Genotypes reaction to stem rust at adult plant stages showed variation. Few lines such as ETBW7818 and ETBW7819 had exhibited resistance reaction (R) while other lines such as ETBW7258, ETBW 8008, ETBW 8009, ETBW 8017, ETBW 8027, ETBW 8052, ETBW 8054 and ETBW 8055 showed R-MR response invariably with locations and years. The rest of the lines had various combinations of disease reactions. Lines exhibited MS or S type infection and had lower disease progress than the susceptible checks (Tables 3, 4, 5) are expected to possess resistance genes that confer partial resistance to stem rust which is in line with findings of the other authors such as [27].

Table 3. Reaction of 21 bread wheat lines to stem rust (severity, reaction, ACI) at adult plant stage and susceptible group to TKTF, TTKSK and TRTF races at seedling stage (3- to 3+).

ETBW Code	Severity	ACI	Reaction range	Seedling reaction to four stem rust races			
				TKTF	TTKSK	TRTF	JRCQC
ETBW 6130	1.36	0.86	R-MSS	3 ⁻	3 ⁻	3 ⁻	;1
ETBW 6161	17.27	14.72	MRMS-S	3 ⁻	3	3 ⁻	;1
ETBW 6861	3.36	1.60	R-MS	3 ⁻	3 ⁻	3 ⁻	;1 ⁺
ETBW 6921	37.50	31.24	MS-S	3 ⁻	2 ⁺	3 ⁻	;
ETBW 7523	12.82	10.29	RMR-S	3 ⁻	3 ⁻	3 ⁻	2 ⁻
ETBW 7207	13.27	8.34	MR-S	3 ⁻	3 ⁻	3 ⁻	;1 ⁺
ETBW 7567	5.18	3.63	MRMS-S	3 ⁻	3 ⁻	3 ⁻	3
ETBW 7681	11.09	8.06	MR-S	3	3 ⁻	3 ⁻	;1
ETBW 7808	1.82	0.3	R-MS	3 ⁻	3 ⁻	3 ⁻	;1 ⁺
ETBW 7810	1.36	0.30	R-S	3 ⁻	3 ⁻	3 ⁻	3 ⁻
ETBW 7814	0.82	0.15	R-MS	3	3 ⁻	3 ⁻	;1 ⁺
ETBW 7815	2.55	0.43	R-S	3 ⁻	3 ⁻	3 ⁻	;1
ETBW 7817	0.36	0.12	R-S	3	3 ⁻	3 ⁻	;1
ETBW 7853	0.91	0.31	R-MS	3 ⁻	3 ⁻	3 ⁻	;1
ETBW 7912	14.73	13.39	R-SMS	3 ⁻	3 ⁻	3 ⁻	;1 ⁺
ETBW 7915	9.80	16.75	MR-S	3 ⁻	3 ⁻	3 ⁻	;2
ETBW 7966	2.18	1.11	R-MSS	3 ⁻	3	3 ⁻	;
ETBW 7976	2.18	0.68	R-MS	3 ⁻	3 ⁻	3 ⁻	;1 ⁺
ETBW 8015	4.55	2.25	R-S	3 ⁻	3 ⁻	3 ⁻	;2
ETBW 8022	1.27	0.23	R-S	3 ⁻	3 ⁻	3 ⁻	;1 ⁺
ETBW 8045	2.91	0.94	R-MS	3 ⁻	3 ⁻	3 ⁻	3 ⁻
Digalu	44.92	33.84	MR-S	-	-	-	-
K6295-4A	17.98	33.23	MSS-SMS	-	-	-	-
Kubsa	48.89	39.79	S	-	-	-	-
Alidoro	72.79	70.70	SMS	-	-	-	-
Danda'a	28.50	34.80	MSS-S	-	-	-	-
Kakaba	39.41	43.99	MS-S	-	-	-	-
PBW343	85.36	81.46	MRMS	-	-	-	-
Shorima	5.52	2.94	RMR-MSS	-	-	-	-
Huluka	17.85	14.42	RMR-MS	-	-	-	-

ACI=Average coefficient of infection; -= no data

Table 4. Reaction of twenty-four bread wheat lines to stem rust (severity, reaction, ACI) at adult plant stage and resistant group to TKTF, TTKSK, TRTF and JRCQC races at seedling plant stages (0-2+).

Entry Code	Severity	ACI	Reaction	Seedling reaction to four stem rust races			
				TKTF	TTKSK	TRTF	JRCQC
ETBW 6114	2.73	2.37	MR-MSS	;	;1	;1	;
ETBW 6109	2.09	1.32	RMR-MS	2-	2-	2-	2 ⁻
ETBW6939	11.17	11.10	MR-S	2-	2-	2+	;1+
ETBW7058	5.64	6.29	MR-MSS	2-	2-	2	;1
ETBW7258	0.33	0.15	R-MR	2-	2-	2+	;1
ETBW 6212	9.18	7.99	MS-MSS	1 ⁺	;1	;1 ⁺	;1
ETBW 6688	6.91	4.78	MR-MSS	2 ⁻	;1 ⁺	;1 ⁺	;1
ETBW 7580	51.67	32.82	MR-S	1 ⁺	;1 ⁺	;1 ⁺	1 ⁺
ETBW 7590	6.09	6.51	MR-MSS	1 ⁺	;1 ⁺	;1 ⁺	;1
ETBW 7591	5.55	6.61	MR-S	1 ⁺	;1	;1 ⁺	;
ETBW 7819	0.09	0.03	R	;1	;2	2 ⁻	;1 ⁺
ETBW 8006	2.18	0.36	R-MS	;1	2 ⁺	;1	;1
ETBW 8009	3.00	0.56	R-MR	;2	;2 ⁻	2 ⁻	;1
ETBW 8012	4.00	1.09	R-MS	;2 ⁻	;1 ⁺	2 ⁻	;1
ETBW 8017	4.45	0.83	R-MR	;1	2 ⁺	;1 ⁺	0
ETBW 8018	3.36	0.79	R-MS	2 ⁺	2 ⁺	2 ⁺	;1
ETBW 8027	1.18	0.25	R-MR	2 ⁻	2	2 ⁺	2 ⁺
ETBW 8028	2.18	0.56	R-MS	2 ⁻	2 ⁺	2 ⁺	2 ⁺
ETBW 8042	0.36	0.25	R-MS	;1 ⁺	;1 ⁺	2 ⁺	2 ⁺
ETBW 8043	4.64	1.83	R-MSS	2	2 ⁺	2 ⁺	;1 ⁺
ETBW 8044	3.82	0.78	RMR-SMS	;1	;2 ⁻	2 ⁺	2 ⁻
ETBW 8049	0.67	0.37	MR-MSS	;2	;1	2 ⁺	2 ⁺
ETBW 8051	1.82	0.58	R-MS	2 ⁺	2 ⁺	2	1 ⁺
ETBW 8055	2.55	1.28	R-MR	;1	;1	2 ⁺	2 ⁺

ACI=Average coefficient of infection

Table 5. Reaction of 38 bread wheat lines to stem rust (severity, reaction, ACI) at adult stage groups of lines with variable reaction to four stem rust races at seedling plant stages.

Entry Code	Severity in %	ACI	Reaction	Seedling reaction to four stem rust races			
				TKTTF	TTKSK	TRTTF	JRCQC
ETBW 6696	15.64	16.29	R-SMS	2-	3-	2+	2-
ETBW 6847	8.18	8.94	MR-S	;1	3-	2-	;1
ETBW 6911	11.00	9.75	MSMR-S	3-	2+	3-	;
ETBW 7008	12.83	15.89	MR-SMS	3-	2+	3-	3-
ETBW 7092	8.09	5.69	RMR-MSS	3-	;2-	2	;
ETBW 7100	2.73	0.31	RMR-MS	2+	3-	2-	;
ETBW 7189	29.33	14.55	R-S	;2	3-	2-	;1+
ETBW 7255	1.00	0.72	R-MS	2-	3-	2+	;1
ETBW 7496	14.73	10.52	MR-S	3-	;1	3-	0
ETBW 7539	15.27	14.29	RMR-S	2-	2+3-	3-	3-
ETBW 7554	4.73	3.62	MR-MSS	2+	2+	2+	3-
ETBW 7568	7.91	4.93	MR-S	2+	3-	2+	2-
ETBW 7582	14.91	9.26	RMR-S	2	3-	;1+	1+
ETBW 7587	22.91	16.02	MR-S	3-	2+C	3-	3-
ETBW 7592	6.55	7.88	MR-S	2+	3-	2-	;1
ETBW 7807	1.36	0.29	R-MS	3-	2+	3-	;1+
ETBW 7809	0.50	0.32	R-MS	2+	3-	;2	;1+
ETBW 7816	1.27	0.66	R-MSS	2+	3-	3-	;
ETBW 7818	0.09	0.03	R	;2	3-	2-	;1+
ETBW 7820	1.64	1.27	R-SMS	3-	2+	2+	;
ETBW 7825	2.91	0.82	R-MS	3-	2+3	2+	;2
ETBW 7962	7.18	7.56	R-S	1+	3-	2-	;1+
ETBW 7965	1.82	1.06	R-MS	2	2+3-	2+	;1
ETBW 7977	1.27	0.40	R-S	2-	3-	;2	2+
ETBW 7998	5.18	3.05	MR-S	2+	3-	2-	;
ETBW 8003	5.36	5.17	MR-MSS	;1+	3-	;1+	;1
ETBW 8008	1.36	0.17	R-MR	;2	3-	;1+	1+
ETBW 7813	0.75	1.20	R-MSMR	2	3-	3-	;1
ETBW 8014	6.18	3.48	R-S	2+	3-	2+	;1+
ETBW 8016	2.55	0.64	R-MS	2+	3-	2+	;1
ETBW 8019	1.73	0.34	R-MS	;2	3-	3-	2
ETBW 8020	2.18	0.46	R-MS	2	3-	3-	;1+
ETBW 8021	1.00	0.54	R-S	3-	;2+	3-	3-
ETBW 8023	1.36	0.22	R-MS	3-	3-	2-	;1+
ETBW 8024	1.36	0.32	R-S	3-	3-	2+	3-
ETBW 8052	2.73	0.73	R-MR	2+	2+	3	2+
ETBW 8054	3.00	0.68	R-MR	;1+	;1+	2+	3-
ETBW 8048	1.33	0.69	RMR-MS	2-	;2	3-	3-

ACI=Average coefficient of infection

3.2. Greenhouse Seedling Evaluation

The 83 test genotypes reaction to stem rust races at seedling plant stages showed variation. The results are summarized in the aforementioned Tables 3, 4, 5, based on their variable reactions to the four stem rust races. Twenty four lines ETBW6114, ETBW6109, ETBW 7058, ETBW 6939, ETBW 7258, ETBW6212, ETBW6688, ETBW7580, ETBW7590, ETBW7591, ETBW7819, ETBW8006, ETBW8009, ETBW8012, ETBW8017, ETBW8018, ETBW8027, ETBW8028, ETBW8042, ETBW8043, ETBW8044, ETBW8049, ETBW8051 and ETBW 8055 shown in Table 4 have displayed seedling resistance (reaction of 0 to 2+) to TKTTF, TTKSK, TRTTF and JRCQC races invariably. Twenty one bread wheat genotypes susceptible to three prevailing stem rust races, TKTTF, TTKSK and TRTTF and resistant to JRCQC at are shown in Table 3 of which ETBW 8045 was an exceptional in response, showed susceptibility to all four races. Of the lines shown in Table 5,

thirty two lines were resistant to race JRCQC, but, showed variable reactions to the remaining three stem rust races.

4. Discussion

Ethiopia is one of the countries where stem rust epidemic is most frequently occurring [4, 28]. A number of stem rust epidemics have been experienced over many years [4, 6, 13, 29] in association with failure of single Sr-resistance gene of major effect deployed to commercial cultivars that lacked adequate genetic diversity in their backgrounds and selecting for virulent races in *Puccinia graminis* f. sp. *tritici* population. Since 2003, virulent new stem rust races such as TTKSK, TKTTF, TRTTF, JRCQC and TTTTF have been prevailed in Ethiopian *Puccinia graminis* population [11-12] and have threatened wheat production. Moreover, virulent races could continue to evolve not only in *P. graminis* f. sp. *tritici* population for this matter, but also in stem rust races existing in wheat-puccinia pathosystem as demonstrated by

TTKSK race which evolved into several races within the Ug99 race [13, 17] that adapt to resistant varieties and resulted in severe epidemics and reduce wheat yields.

Among currently existing stem rust races prevail in Ethiopia, race TKTTF is the most predominant and destructive race that significantly halting several resistance genes (Table 2) and the production of the popular bread wheat varieties in major wheat producing areas of the country. The spread and effect of this menace stem rust races is counteracted mainly by growing resistant varieties and fungicide options. Wheat germplasm screening for stem rust resistance is mainly achieved by measuring seedling infection types (resistance) in greenhouse and adult plant reaction, rust severity, ACI and area under disease progress curve derived from adult plant stages under field conditions. The disease parameters we used are similar to many other researchers. Various authors [22, 30-32] used final rust severity, coefficient of infection and area under the disease progress for identifying genotypes possessing partial resistance and all stage resistance in wheat.

From 2013-2015, we have evaluated bread wheat genotypes under heavy stem rust disease pressure developed in the nursery as indicated by high epidemic pressure recorded on susceptible check varieties and spreader rows. High disease pressure developed under condition enabled us to differentiate the genotypes into different resistance categories at adult plant growth stages, and simultaneously proving that screening procedure of wheat germplasm against stem rust at stem rust hot spot multi-location is dependable, despite some escape risks associated with such procedure.

Severity and ACI data generated by present study have revealed that the levels of stem rust resistance of most of the lines are better than resistance of susceptible check varieties PBW343, a variety selecting to TTKSK; Kubsu and Digalu varieties, selecting to TKTTF. Germplasm exhibiting susceptibility at seedling stage and having lower final rust severity, lower ACI and AUDPC than the susceptible checks are expected to have adult plant resistance, a type of partial or slow rusting resistance. Genotypes showed such combinations of disease scores were observed.

Out of 83 genotypes evaluated over years, 52 lines showed lower or comparable disease parameters values recorded on recently released bread wheat varieties Shorima or Hulluka in which the presence of Sr 24 has been confirmed recently (Bekele et. al., unpublished data). Thus, these materials showed lower disease values than these checks probably could have Sr 24 resistance gene in their backgrounds in addition to others unknown resistance genes. Sr24 is resistant to TKTTF and TTKSK races at seedling plant stage in Ethiopia [30]. According, [33], Sr 24 also gave effective resistance to 16 stem rust races prevailing in Ethiopia including TTKSK and TTTTF races. In China, Sr24 is effective to races TKTTF, TTTTF, and other races [34-35]. Nevertheless, virulence to *Sr24* such as TTKST are common in the *P. graminis* f. sp. *tritici* population in Kenya [3, 36-38] that are potentially to spread to Ethiopia where they are currently absent. Thus, deploying of wheat cultivars with sole Sr24 resistance to farmers is not advised.

Test genotypes such as ETBW 7580, ETBW 6939, ETBW 7058, ETBW 7523, ETBW 7912, ETBW 6161, ETBW 6921, ETBW 7915, ETBW 7207, ETBW 7681, ETBW 6696, ETBW 7008, ETBW 7496, ETBW 7539, ETBW 7189, ETBW 7587 and ETBW 8014 had showed final rust severity fluctuation due to environments, reflecting the behaviour of adult plant resistance.

According to [24], lines with ACI values of 0-20, 21-40 and 41-60 are regarded as possessing better, moderate and low levels of partial yellow rust resistance, respectively. Likewise, germplasm that had low seedling infection, low severity, ACI and high resistance reaction (R-MR) are commonly taken as all-stage resistant germplasm that is governed by race-specific resistance genes. Thus, based on these diseases parameter values, partial and race specific resistances are operating in various lines of bread wheat genotypes evaluated.

Developing resistant varieties combining both all-stage resistance and partial resistance determined by race specific and minor genes, respectively, is a priority research area for breeders in Ethiopia. Varieties with combination of resistance genes could be more durable and more effective than varieties with sole all-stage or adult plant resistance types. Therefore, 52 lines that had disease records characterizing indicating the presence of aforementioned of two types of resistances and still comparable to recently released varieties Shorima or Hulluka, the priority materials to be used for developing cultivars that could combining non-race specific and race specific genes and keep more durable [39] stem rust resistance than the resistance gene with major effect and more effective than adult plant resistance commonly affected by environmental variables.

5. Conclusion

Several bread wheat genotypes evaluated had the merits of the true partial/ adult plant resistance and race specific Sr-gene/s. Although Sixty six lines possessed final rust severity $\leq 30\%$ and low ACI are acceptable for rust resistance breeding in wheat, 52 lines showed comparable resistance to Shorima or Hulluka are the priority materials to be used for developing cultivars combining non-race specific and race specific genes which is more durable than cultivars with major resistance gene effect. Stem rust resistance breeding programs working with parents' of known stem rust resistance gene/s is more efficient in stacking known Sr-resistance genes into a single cultivar. Thus, identification of stem rust resistance gene/s inherent in these resistant genotypes is relevant.

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