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Evaluation of Commercial Bread Wheat Cultivars and Monogenic Lines for Their Adult Plant Resistance to Stem Rust

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Abstract: **Wheat is one of the most important food crops in the world and is a major cereal crop cultivated world-wide and contributes substantially to human daily calories and food security. Ethiopia is among the top three wheat producers in Africa, with wheat accounting for 20% of the nation's total cereal production. However, it is highly vulnerable to many diseases, of which stem rust is significantly causing yield loss. In Ethiopia stem rust disease causes yield loss up to 100% when susceptible cultivars planted and the environment is conducive. To elevate the threat of stem rust it is important to identify resistant genes in different sources. Thus, this study was designed to evaluate 21 commercial bread wheat cultivars and 40 monogenic lines against wheat stem rust disease in fields under natural condition. The wheat genotypes were planted in un-replicated plots of 1m long with two rows and 20 cm spacing between rows at research stations of Kulumsa and Melkasa Agricultural Research Centers in four districts of Arsi zones. In this study, cultivars Enkoy, paven 76 and monogenic lines that contain Sr24, Sr26, Sr22 and Sr32 have been found resistant against the prevailing wheat stem rust pathogen population in the study area. Hence, those wheat genotypes that showed adequate level of adult plant resistance can be used in wheat breeding program for stem rust resistance at national or regional levels.**

Keywords: **Evaluation, Cultivars, Monogenic Lines, Wheat, Stem rust, Adult plant, Resistance, Trap nursery.**

1. INTRODUCTION

Wheat is the most widely grown cereal crop (Curtis and Halford, 2014) in more than 122 countries (FAOSTAT 2015). It accounts for over 35% of the world food sources and provides 20% of proteins and calories to humans (Braun *et al.* 2010; Hawkesford*et al*. 2013). Bread wheat and durum wheat are the two main commercial types of wheat and are grown on approximately 215 million hectares annually, with an estimated production of 700 million metric tons (Singh *et al*. 2011). It is used as a major ingredient in food products, a major market commodity which is internationally traded as a cash crop. Wheat is also used for livestock and poultry feed as a by-product of the flour milling industry. It is grown on about 17% of global crop acreage which is about 215 million hectares producing about 630 million tons of grain annually(Singh *et al.*, 2011). Wheat also provides 16% of total dietary calories in the developing countries and about 4.5 billion people in 94 developing countries depend on wheat (Dixon *et al.*, 2009)

Though wheat is a very important cereal crop, its production is threatened by biotic and abiotic factors. Of biotic factors wheat rusts are the major ones. Stem rust is the most damaging disease of the three wheat rusts (Roelfs *et al*., 1992). Currently stem rust is known for causing severe devastations in all wheat- growing countries of the world and it remains the most important disease of wheat worldwide (Watkins, 2005). Historically, several wheat stem rust epidemics have been reported from Africa (eastern, southern and north Africa), Asia, Europe, North and South America (Canada, United

States, Mexico, Paraguay, Argentina, Brazil, Bolivia, Uruguay and Chile), and Australia and New Zealand (CIMMYT, 2005).

Stem rust epidemics was effectively controlled for the last several decades in most wheat growing regions of the world because of the worldwide deployment of effective stem rust resistance genes in wheat varieties (Singh *et al.,* 2006; Jin *et al.,* 2006). However, stem rust has again become a major threat to the world wheat production with a new race of stem rust pathogen, Ug99 (Pretorius *et al.,* 2000). Ug99 pathotypes defeat most of the race-specific resistance genes currently deployed worldwide and are considered to be the most virulent strain of stem rust to emerge in the last 50 years(Stokstad, 2007).At present, among the 58 catalogued resistant genes against stem rust, only less than half of them are effective to Ug99 (McIntosh *et al.*, 2014). Worldwide virulence, for many of these genes is now common; making them useless for crop protection. This is also true in Ethiopia where most of the wheat varieties used by Ethiopian farmers are susceptible to the new race of stem rust pathogen, Ug99 and its derivatives (CIMMYT, 2005)

In Ethiopia, the importance of wheat stem rust was recognized as early as 1930 (Mengistu*et al.,* 1991). Currently, most of bread wheat varieties grown in the country are susceptible to either the previously identified races of stem rust pathogen or the newly evolved race Ug99 and its derivatives.Therefore, replacement of the currently popular susceptible varieties with high yielding resistant varieties is very important and should be the best strategy to protect wheat production in the country. Deployment of resistant varieties is the most effective and environmentally sound method to control this disease. However, an effective deployment of resistance genes for the management of stem rust in wheat production requires knowledge about the resistance status and the diversity of resistance genes in varieties under consideration (Belayneh*et al.,* 2008). Moreover, knowledge on the current status of wheat varieties under cultivation against the prevailing wheat stem races is crucial; as the pathogen is known to evolve its virulence frequently (Jin *et al*., 2009). Therefore, achievement of durable resistance against wheat stem rust requires constant characterization of the pathogen; and identification and deployment of resistance genes that overcome the prevailing virulent races (Belayneh*et al.,* 2008). Thus, evaluation of the current status of available genotypes for their adult plant resistance is important. Hence, this study was initiated with the objective to evaluate commercial bread what cultivars and monogenic lines for their adult plant resistance to wheat stem rust disease.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted in four districts of Arsi and west Arsi zones**:** Gedeb Asasa, Arsi Negele, Arsi Robe and Tiyo districts. The four districts of the study area were selected for their wheat stem rust hot spot areas in Arsi zones. Gedeb Asasa and Arsi Negele districts are found in West Arsi zone whereas Tiyo and Arsi Robe are found in Arsi zone. Gedeb Asasa is located at 7012‟ N and 390 20‟ E, with an elevation of 2300 masl. The mean annual rainfall of the area is 650 mm while the mean minimum and maximum air temperature is 5.6 and 23.60C, respectively. The geographic location of Arsi Negelie is 70 33‟ N, and 380 66‟ E, at an altitude of 1950 masl. The district has mean annual rainfall of 985 mm. with a mean minimum and maximum air temperature of 15 and 25.40C, respectively. Arsi Robe is located at 70 80‟ N, and 39o 70‟ E, with an elevation of 2400 masl. and a mean annual rain fall of 900 mm. Its mean minimum and maximum air temperature is 9.2 and 22.50C, respectively. Tiyo is the district in which Kulumsa Agricultural Research Center (KARC) is located. It is located at 80 N and 390 12‟E, at an altitude of 2200 masl. It has a mean annual rainfall of 820 mm and its minimum and maximum air temperature is 10.1 and 22.70 C, respectively.

2.2 Experimental Design

The experiment was arranged in an augmented design

2.3 Experimental Materials and their Sources

In this study 21comercial bread wheat cultivars and 40 monogenic lines (Table 1) together with two check varieties, morocco & PBW343 were used and all of them were obtained from Kulumsa Agricultural Research Centre (KARC), Ethiopia. Kulumsa Agricultural Research Center is located at 169 Km South-east of Addis Ababa at 080 01’10’’N latitude and 390 09’11’’ E longitudes and at elevation of 2200masl. Kulumsa Agricultural Research Center is a center of excellence for wheat production research in the country.

wheat stem rust trap nurseries consisting of 21 commercial cultivars, 40 monogenic lines and universally susceptible wheat variety, "Morocco" as a check and PBW343 as standard check for Ug99 were established at four environmentally different districts (Arsi Robe, Tiyo, Gedeb Asasa and Arsi Negele) in Arsi and West Arsi zones in South East Ethiopia (Table 1). Arsi Robe and Tiyo districts are found in Arsi zone while Gedeb Asasa and Arsi Negele are found in West Arsi zone. These four districts were selected as testing location because they are known hot spot areas for stem rust disease in Arsi zones (Admassu and Fekadu, 2005; Admassu *et al*., 2009; Worku *et al*., 2016)

Arsi Robe testing location is internationally known stem rust testing site and is used for large-scale wheat screening for resistance to stem rust in wheat (Worku *et al*., 2016). Not only Arsi Robe district, but also most Arsi zones in Ethiopia are known hotspot for the development of stem rust epidemics and many stem rust race analysis by researches have been indicated the presence of diversified/varied races with wider virulence spectrum (Admassu and Fekadu, 2005; Admassu *et al*., 2009; Worku *et al*., 2016)

The two nursery sites in Arsi Robe and Gedeb Asasa districts were established at Kulumsa Agricultural Research Center stations whereas the nursery site in Arsi Negele district was established at Melkasa Agricultural Research Center station and the fourth nursery site in Tiyo district was established at Kulumsa agricultural Research Center main station. Each entry was planted in non-replicated plots of 1m long with two rows and 20 cm spacing between rows. The check varieties were planted at every 10^{th} entry. The seed rate was 150 kg/ha; fertilizer and other cultural practices were applied as per recommendation for the area. This experiment was carried out under natural conditions without artificial inoculation.

Table 1: List of commercial cultivars and monogenic lines used to establish wheat stem rust trap nurseries in four districts of east and west Arsi zones in 2008 main cropping season

No	Variety	Sr genes
1	LAKECH	cultivar
2	ISRAEL	cultivar
3	BONDE	cultivar
4	DASHEN	cultivar
5	PAVON 76	cultivar
6	GALAMA	cultivar
7	ENKOY	cultivar
8	WABE (HAR 710)	cultivar
9	TUSIE (HAR 1407)	cultivar
10	TURA	cultivar
11	HAR 2501 (Hawi)	cultivar
12	SIMBA	cultivar
13	KUBSA (HAR 1685)	cultivar
14	DODOTA	cultivar
15	BOBICHO	cultivar
16	SIRBO	cultivar
17	HAR 3116	cultivar
18	FH 11-6-24 (Meraro)	cultivar
19	HAR 1008 (Dure)	cultivar
20	HAR 1889 (Sofumer)	cultivar
21	HAR 1480 (Madda Walabu)	cultivar
22	BARLETA BENVENUTO	Sr 8b
23	BT/WLD	Sr wld-1
24	BTSR30WST	Sr 30
25	BTSRGAMUT	Sr gt
26	CH.SP. (TC3B)	Sr 12
27	Line E/kuz	Sr 31

28	CNS (TC2B)/LINE E	Sr 9g
29	CNS SR32 AS	Sr 32
30	COMBINATION VII	Sr 17+ 13
31	EAGLE	Sr 26
32	ENTRELARGO DE MONTIJO (W3560)	
33	FED.*2/ SRTT3	Sr tt + Sr 10
34	H44 DERIV	Sr H
35	ISR11RA	Sr 11
36	ISR5SB	Sr 5
37	LCSR19MG	Sr 19
38	LINE A SELN.	Sr 14
39	MARQUIS (W2)	Sr7b,18,19,20
40	MEDEA AP9D	Sr 9d
41	(MQ2)*G2919	Sr35
42	PELISS	Sr PL
43	PUSA/EDCH	Sr 29
44	SWSR22T.B.	Sr 22
45	TAF-2	Sr 44
46	TETRA CANTHTCH/Ag. SQUARROSA (RL5045)	Sr 33
47	VERNSTEIN	Sr 9e
48	W2691 SRTT1	Sr 36
49	W2691 SRTT2	Sr 37
50	W2691SR10	Sr 10
51	W2691SR13	Sr 13
52	W2691SR15NK	Sr 15
53	W2691SR28KT	Sr 28
54	W2691SR9B	Sr 9b
55	BT SR24Ag	Sr 24
56	LCSR25ARS	Sr 25
57	WRT 238-5	Sr 27
58	PERLUDE*4/2/MARQUIS*6/KHAPSTEIN	Sr 7a
59	CnSSrTmp	Sr Tmp
60	ISr6-Ra	Sr 6
61	ISr8-Ra	Sr 8a
62	Morocco	Check
63	PBW343	Standard check

2.4 Disease assessment and data collection

Stem rust disease severity and host reaction to the disease infection were scored three times during the growing season. Severity was recorded as a percentage, according the modified Cobb's scale; 0%=Immune, and 100%=fully susceptible (Peterson *et al.* 1948). This recording process relies upon visual observations and it is common to use the following intervals: Trace, 5, 10, 20, 40, 60, 100% infection. The host response to the disease infection was recorded using the description of Rolefs *et al.*, (1992) and it was noted using the following letters: R=resistant; visible chlorosis or necrosis, no uredia are present; MR= moderately resistant; small uredia are present and surrounded by either chlorotic or necrotic areas; MS= moderately susceptible; medium size uredia are present and possibly surrounded by chlorotic areas; S= susceptible; large uredia are present, generally with little or no chlorosis and no necrosis. Severity and field response readings are usually combined and calculated to form coefficient of infection. Thus, the recorded severity and disease reaction of each tester wheat genotypes were converted into coefficients of infection, by multiplying severity and an assigned value for the field response, as suggested by Stubbs *et al.* (1986); where I=0; R=0.2; MR=0.4; MS=0.6 and S=1; the constant value was further modified to include infection responses of resistant to moderately resistant (R-MR=0.3) moderately resistant to moderately susceptible (MR-MS=0.6) and moderately susceptible to susceptible (MS-S=0.9).

Infection responses overlapping between any particular two categories were denoted using a dash. For instance, "MR-MS" denoted an infection response class that overlapped the MR and MS categories, and was sometimes recorded as M by some researchers

2.5 Data analysis

Field data were analyzed using descriptive methods and the wheat genotypes were evaluated for their adult plant resistance and categorized into different levels of resistance based on their disease reaction (Ali *et al*., 2008; Hei *et al*., 2015; Saleem *et al*., 2015; Singh *et al*., 2017), highest severity (Singh *et al*., 2015) and coefficient of infection (Ali *et al*., 2009).

3. RESULT AND DISCUSSION

Twenty one commercial bread wheat cultivars and forty monogenic lines (Sr genes) were evaluated against stem rust disease under field condition in four locations, namely Gedeb Asasa, Arsi Negele, Arsi Robe and Tiyo Research stations during main growing season of 2008. Evaluation of the commercial bread wheat cultivars and monogenic lines was done using disease reaction, highest severity (Singh *et al*., 2008, 2015) and coefficient infection (Ali *et al*., 2009).

3.1 Field reaction of commercial bread wheat cultivars against stem rust disease

3.1.1 Evaluation of bread wheat cultivars based on their disease reaction

The data collected from the field and presented in Table 4 revealed that, one (1) bread wheat cultivar showed immune disease reaction (Rated 0), another one bread wheat cultivar showed moderately resistant disease reaction (Rated MR), two other bread wheat cultivars showed moderately susceptible to susceptible reaction and all the rest bread wheat cultivars showed susceptible disease reaction (Table 2). This indicates that out of the 21 evaluated commercial bread wheat cultivars only two (9.52%) bread wheat cultivars showed adequate adult plant resistance (rated 0 to MR (Singh *et al*., 2008; 2015). On the other hand, out of the 21 commercial bread wheat cultivars, 19 (90.5%) bread wheat cultivars showed inadequate adult plant resistance (rated MS-S to S) which means majority of the evaluated bread wheat cultivars showed susceptible reaction. This condition is an alarm to replace Ethiopian bread wheat cultivars with new disease resistant cultivars so as to protect resource poor farmers in the country.

Out of the 21 commercial bread wheat cultivars, only cultivar Enkoy showed immune reaction in all testing locations. Bread wheat cultivar that showed moderately resistant disease reaction with adequate level of adult plant resistance was Paven 76, which is considered to have Sr2 complex stem rust resistant gene (Singh *et al*., 2005). Bread wheat cultivars HAR3116 and Meraro showed moderately susceptible to susceptible reaction whereas commercial bread wheat cultivars Lakech, Israel, Bonde, Dashen, Galama, Wabe, Tuse, Tura, Hawi, Samba, Kubsa, Dodota, Bobicho, Sirbo, Dure, Sifumer and Madawalabu showed completely susceptible disease reaction and took 76.19% of the tested commercial bread wheat cultivars. Bread wheat cultivars Enkoy and Paven 76 can be used in the wheat-breeding program for stem rust resistance both at national and regional levels. It is well known that cultivar 'Enkoy' was withdrawn from production following the serious outbreak of stem rust epidemics in 1992/93 cropping season (Temesgen *et al.*, 1994). However, recently, including the year of this study (2008 main cropping season) it became resistant to the prevailing stem rust pathogen population and this might be due to reduction of the amount of previously virulent inoculum on it through time due to lack of appropriate host. As to some researchers, those bread wheat cultivars showed MR-MS to MS-S (HAR3116 and Meraro) disease reaction can be grouped into those cultivars having adequate level of adult plant resistance. For example, Singh *et al* (2005) reported that wheat lines with variable field infection responses of MR-MS to MS-S are expected to possess genes that confer partial resistance.

Furthermore, virulence was observed on, 19 (90.5%) commercial cultivars at all testing locations. These varieties were, Lakech, Israel, Bondie, Dashen, Galama, Wabe, Tusie, Tura, Hawi, Simba, Kubsa, Dodota, Bobicho, Sirbo, HAR 3116, Meraro, Dure, Sofumer and Maddawalabu. Commercial cultivars on which virulence was observed at three testing locations were six in number and comprised of 28.6% of the total commercial cultivars tested. They were cultivar Lakech, Israel, Wabie, Tura, HAR3116 and Madda walabu. Those cultivars on which virulence was observed only at two testing locations were Pavon 76 and Meraro at Arsi Robie and Tiyo (Kulumsa) locations, respectively.

The virulence spectrum of the prevailing pathogen population on commercial cultivars at each testing location was variable. For example, at Arsi Negelie testing location, virulence was observed only on 12 (57.1%) of the total commercial wheat cultivars while it was observed on 19 (90.5%) of the total, at Arsi Robie testing location. Similarly, no virulence was observed on 8 (38.1%) of the cultivars in Arsi Negelie and only on two of them in Arsi Robie. The 12 commercial cultivars on which virulence was observed at Arsi Negelie testing location were, Bondie, Dashen, Galama, Tusie, Tura, Hawi, Kubsa, Dodota, Bobicho, Sirbo, Meraro and Sofumer while they were Lakech, Israel, Bondie, Dashen, Pavon 76, Galama, Wabie, Tusie, Tura, Hawi, Simba, Kubsa, Dodota, Bobicho, Sirbo, HAR3116, Meraro and Madda walabu cultivars at Arsi Robie testing locations. In contrast to the above, no virulence was observed on commercial cultivars Lakech, Israel, Enkoy, Wabie, HAR3116, Meraro, Dure and Maddawalabu at Arsi Negelie testing location and on variety Enkoy and Dure at Arsi Robie testing location. The magnitude of virulence spectrum at Gedeb Asasa and Tiyo testing locations was almost similar, i.e., at Gedeb Asasa location virulence was observed on 18 (85.7%) of the 21 commercial cultivars while at Tiyo location it was on 19 (90.5%) of the total commercial cultivars. On the other side, no virulence was observed on cultivars Enkoy, Pavon 76 and Meraro at Gedeb Asasa testing locations and on variety Enkoy and Tura at Tiyo testing location.

In general, the widest virulence spectrum on commercial cultivars (90.5%) was observed at Arsi Robie and Tiyo testing locations, followed by Gedeb Asasa (85.7%) and Arsi Negelie (57.1%) locations. Therefore, the occurrence of virulence on 90.5% of the total commercial wheat varieties tested at the four trap nursery sites indicates that the virulence spectrum of the pathogen population on the tested commercial cultivars was wider or broader in the study area during 2008 cropping season. Moreover, because the virulence was observed on majority of the tested bread wheat cultivars, the condition can be an alarm for replacement of the susceptible commercial bread wheat cultivars grown in the study area.

3.1.2 Evaluation of bread wheat cultivars based on highest severity

As the data collected from field (Table 4) indicates there was a wide variation in disease severity ranging from 0-70%. Based on severity data the tested bread wheat cultivars were categorized into immune (0% severity), resistant to moderately resistant (11-20% severity), moderately resistant (21-30% severity), moderately susceptible (41-50% severity) and moderately susceptible to susceptible (51-70% severity) (Singh *et al.*, 2015).

In the present study, among the 21 commercial bread wheat cultivars, one cultivar (Enkoy) showed 0% severity with disease reaction immune. Two bread wheat cultivars (Paven 76 and HAR3116) showed 15-20% severity with disease reaction ranging from moderately resistant and moderately susceptible (MR-MS) to moderately susceptible and susceptible (MS-S). One bread wheat cultivar (Meraro) showed 30% severity with disease reaction moderately susceptible to susceptible (MS-S). Four bread wheat cultivars showed 41-50% severity with disease reaction completely susceptible (S). Thirteen bread wheat cultivars showed 51-70% severity with disease reaction completely susceptible (S). In general, evaluation of the tester commercial bread wheat cultivars based on severity indicated that those bread wheat cultivars with severity ranging from 0-40% can be considered as cultivars with adequate level of adult plant resistance whereas those bread wheat cultivars with severity ranging from 41-70% can be considered as cultivars with inadequate level of adult plant resistance. Therefore, commercial bread wheat cultivars: Enkoy, Paven 76, HAR3116 & Meraro (19.05%) showed 0-40% severity and are considered as bread wheat cultivars with adequate level of adult plant resistance while bread wheat cultivars: Bonde, Dashen, Tuse, Maddawalabu, Lakech, Israel, Galama, Wabe, Tura, Hawi, Simba, Kubsa, Dodota, Bobicho, Sirbo, Dure, Sofumer showed 41-70% severity and are considered as bread wheat cultivars with inadequate level of adult plant resistance.

3.1.3 Evaluation of bread wheat cultivars based on coefficient of infection

Coefficient of infection (CI) was calculated by multiplying disease severity and constant values of disease reaction. Using coefficient of infection as evaluation parameter, for adult plant resistance (slow rusting resistance) cultivars with coefficient of infection values of 0-20, 21-40 and 41-60 were considered as having high, moderate and low levels of resistance (Ali *et al*., 2009). In this work, three commercial bread wheat cultivars (Enkoy, Paven 76 & HAR3116) were scored CI values of 0-20 and were considered as having high level of slow rusting resistance (APR) and one commercial bread wheat cultivars (Meraro) was scored CI values of 21-40 and was considered as having moderate level of slow rusting resistance (APR). Large number (17) of the commercial bread wheat cultivars were scored CI values of 41-60 and were considered as having low level of slow rusting resistance (APR). The commercial bread wheat cultivars that were

considered as having low level of slow rusting resistance (APR) were: Bonde, Dashen, Tuse, Maddawalabu, Lakech, Israel, Galama, Wabe, Tura, Hawi, Simba, Kubsa, Dodota, Bobicho, Sirbo, Dure & Sofumer. The commercial bread wheat cultivars that showed adequate levels of adult plant plant resistance in all APR evaluation parameters were cultivar Enkoy and Paven 76 and these cultivars can be used in breeding programs for wheat stem rust disease resistance.

3.2 Field reaction of wheat monogenic lines against stem rust disease

3.2.1 Evaluation of wheat monogenic lines based on disease reaction

Disease reaction data, of monogenic lines shown in Table 4 revealed that stem rust resistant genes: Sr24 and Sr26 showed immune disease reaction in all testing locations while Sr22 and Sr32 showed immune disease reaction in three testing locations. Sr22 resistant gene showed resistant disease reaction at one testing location (Arsi Robe location) while it showed immune disease reaction at three testing locations (Arsi Negele, Gedeb Asasa and Tiyo testing locations). Similarly, Sr32 resistant gene showed moderately resistant disease reaction at one testing location (Gedeb Asasa testing location) while it showed immune disease reaction at three testing locations (Arsi Negele, Arsi Robe & Tiyo testing locations). Stem rust resistant genes: Sr7b, 18, 19, 20, Sr44, Sr33, Sr10, Sr13, Sr27, Sr7a,Sr6 and line W3560 showed moderately susceptible disease reaction whereas Sr8b, Srwld-1, Sr30, Srgt, Sr12, Sr31, Sr9g Srtt+10, SrH, Sr11, Sr5, Sr19, Sr14, Sr9d, Sr35, SrPL, Sr29, Sr9e, Sr37, Sr15, Sr9b, Sr25, SrTmP and Sr8a showed completely susceptible disease reaction. When we classify the tested monogenic lines into resistant and susceptible groups, four monogenic lines BTSR24Ag, Eagle, SWSR22T.B and CNSSR32AS that consists of Sr24 (rated I), Sr26 (rated I), Sr22 (rated R) and Sr32 (rated MR) stem rust resistant genes, respectively were found to be resistant lines whereas 36 monogenic lines consisting of stem rust resistance genes: Sr7b, 18, 19, 20, Sr44, Sr33, Sr10, Sr13, Sr27, Sr7a,Sr6, W3560, Sr8b, Srwld-1, Sr30, Srgt, Sr12, Sr31, Sr9g Srtt+10, SrH, Sr11, Sr5, Sr19, Sr14, Sr9d, Sr35, SrPL, Sr29, Sr9e, Sr37, Sr15, Sr9b, Sr25, SrTmP and Sr8a were found to be susceptible (rated MS to S). These monogenic lines can be classified into two: Ten lines (25% of the total) were showed moderately susceptible disease reaction and twenty six lines (75% of the total) were showed completely susceptible disease reaction. On the other hand, of the total 40 tested monogenic lines only 10% were found to be resistant to the prevailing stem rust pathogen population under natural field condition while 90% of the tested lines were found to be susceptible. Moreover, among the 40 monogenic lines with no virulence in all testing locations were SWR22T.B, BTSR24Ag, Eagle and CNS SR32, carrying resistance genes Sr22, Sr24, Sr26, and Sr32, respectively. Therefore, these resistance genes would be useful if they are included in breeding programs for wheat stem rust resistance either at regional or national level.

The pathogen population in the study area also showed wide virulence spectrum on monogenic lines tested at the trap nurseries. For example, virulence was observed on resistance genes Sr8b, Sr30, Srgt, Sr12, Sr9g, srtt+10, SrH, Sr11, Sr5, Sr9d, Sr35,Sr33, Sr9e, Sr9b,Sr6, Sr8a, Sr29, Sr37 and Sr14 at all testing locations while virulence was observed on resistance genes SrPL, Sr44, Sr15, Sr27 and SrTmp at three testing locations. Virulence is also observed on resistance genes Srwld-1, Sr17+13, Sr7b, Sr18, Sr19, Sr20, Sr10 and Sr13 at two testing locations whereas virulence on W3560, Sr19, Sr36, Sr28, Sr25 and Sr7a was observed only at one testing location. Hence, as described previously in this section, 36 monogenic lines, out of 40 were susceptible to the prevailing pathogen population at one or the other locations, covering 90% of the total monogenic lines used to establish the wheat stem rust trap nurseries at the four locations.

In addition, virulence spectrum of the prevailing pathogen population on monogenic lines at each testing location was variable. For example, at Tiyo testing location, virulence was observed on resistance genes Sr8b, wld-1, Sr30, Srgt, Sr12, Sr31, Sr9g , Sr17+13, Srtt+10, SrH, Sr11, Sr5, Sr14, Sr7b.18.19.20, Sr9d, Sr35, SrPL, Sr29, Sr44, Sr33, Sr9e, Sr36, Sr37, Sr13, Sr15, Sr9b, Sr27, Sr7a, SrTmp, Sr6, Sr8a, while virulence was not observed on resistance genes Sr32, Sr26, W3560, Sr19, Sr22, Sr28, Sr24, Sr7a and Sr10. At Arsi Robie testing location, virulence was observed on resistance genes Sr8b, Srwld-1, Sr30, Srgt, Sr12, Sr31, Sr9g, W3560, Srtt+10, SrH, Sr11, Sr5, Sr14, Sr7b.18,19,20, Sr9d, Sr35, SrPL, Sr29, Sr44, Sr33, Sr9e, Sr37, Sr10, Sr15, Sr9b, Sr27, Sr7a, SrTmp, Sr6 and Sr8a whereas virulence was not observed on resistance genes Sr32, Sr17+13, Sr26, Sr19, Sr22, Sr36, Sr13, Sr28, Sr24 and Sr25. At Gedeb Asasa testing location, virulence was observed on resistance genes Sr8b, Sr30, Srgt, Sr12, Sr31, Sr9g, Sr17+Sr10, Srtt+10, SrH, Sr11, Sr5, Sr14, Sr9d, Sr35, SrPL, Sr29, Sr44, Sr33, Sr9e, Sr37, Sr10, Sr13, Sr15, Sr28, Sr9b, Sr27, SrTmp, Sr6, Sr8a while no virulence was observed on resistance genes Srwld-1, Sr32, Sr26, W3560, Sr19, Sr7b.18.19.20, Sr22, Sr36, Sr24, Sr25 and Sr7a. Similarly, at Arsi Negelie testing location, virulence was observed on resistance genes Sr8b, Sr30, Srgt, Sr12, Sr31,

Sr9g, Srtt+10, SrH, Sr11, Sr5, Sr19, Sr14, Sr9d, Sr35, Sr29, Sr33, Sr9e, Sr37, Sr9b, SrTmp, Sr6 and Sr8a whereas virulence was not observed on resistance genes Srwld-1, Sr32, Sr17+13, Sr26, W3560, Sr7b.18.19.20, SrPL, Sr22, Sr44, Sr36, Sr10, Sr13, Sr15, Sr28, Sr24, Sr25, Sr27 and Sr7b.

Therefore, among the testing locations in the four districts, the widest virulence spectrum of the pathogen population on monogenic lines was observed in Tiyo testing location (Kulumsa), followed by Arsi Robie and Gedeb Asasa locations while the least virulence spectrum was observed at Arsi Negele location. Totally, 31 (77.5%), 30 (75%), 29 (72.5%) and 22 (55%) resistance genes showed susceptible reaction at Tiyo, Arsi Robie, Gedeb Asasa and Arsi Negelie testing locations, respectively.

3.2.2 Evaluation of wheat monogenic lines based on highest severity

Similar to commercial bread wheat cultivars, the monogenic lines also showed a wide variation of severity ranging from 0-80%. Based on severity data, the tested monogenic lines were classified into immune (0% severity), highly resistant (trace to 5% severity), resistant (6-10% severity), resistant to moderately resistance (11-20% severity), moderately resistant (21-30% severity), moderately resistant to moderately susceptible (31-40), moderately susceptible (41-50% severity), moderately susceptible to susceptible (51-70% severity) and susceptible (80-100% severity) (Singh *et al.*, 2015).

Among the 40 tested monogenic lines, two lines, BTSR24Ag and Eagle showed 0% severity with immune disease reaction. Other two lines, SWR22T.B and CNS SR32 showed trace-5% severity with disease reaction ranging from resistant (R) to moderately resistant (MR).

Elevene lines, Combination VII, Entrelargo de montijo (W3560), LCSR19MG, Line A seln, VERNSTEIN, W2691 SRTT1, W2691SR10, W2691SR13, W2691SR15NK, W2691SR28KT and LCSR25ARS showed 10% severity with disease reaction ranging from moderately susceptible (MS) to susceptible (S). Eight lines, CH.SP. (TC3B), ISR5SB, Marquis (W2), TAF-2, W2691SR9B, WRT 238-5, Perlude*4/2/Marquis*6/Khapsten and CnSSrTmp showed 15-20% severity with disease reaction ranging from moderately susceptible (MS) to susceptible (S). Another eight lines, Barleta Benvenuto, BTSRGAMUT, CNS (TC2B)/Line E, ISR11RA, MEDEA AP9D, MQ(2)5*G2919, Tetracanthtch/ ag.squarrosa(RL5045) and ISr6-Ra showed 30% severity with disease reaction ranging from moderately susceptible (MS) to susceptible (S). Two lines, PELISS & ISr8-Ra showed 40% severity with susceptible disease reaction. Four lines, FED.*2/ SRTT3, H44 DERIV, PUSA/EDCH and Bt/wld showed 50% severity with completely susceptible disease reaction. Similarly, other two lines, BTSR30WST and Line E/kvz showed 60% and 80% severity respectively, with susceptible disease reactions.

Therefore, monogenic lines with severity, ranging from 0-40% can be considered as lines with adequate level of adult plant resistance whereas those monogenic lines with severity ranging from 41-100% can be considered as lines with inadequate level of adult plant resistance. Thus, monogenic lines: BTSR24Ag, Eagle, SWR22T.B, CNS SR32 (with 0-5% severity), Combination VII, Entrelargo de montijo (W3560), LCSR19MG, Line A seln, VERNSTEIN, W2691 SRTT1, W2691SR10, W2691SR13, W2691SR15NK, W2691SR28KT, LCSR25ARS (with 10% severity), CH.SP. (TC3B), ISR5SB, Marquis (W2), TAF-2, W2691SR9B, WRT 238-5, Perlude*4/2/Marquis*6/Khapsten, CnSSrTmp (with 15-20% severity), Barleta Benvenuto, BTSRGAMUT, CNS (TC2B)/Line E, ISR11RA, MEDEA AP9D, MQ(2)5*G2919, Tetracanthtch/ag.squarrosa (RL5045), ISr6-Ra (with 30% severity), PELISS & ISr8-Ra (with 40% severity) were found to be lines with adequate level of adult plant resistance while monogenic lines: FED.*2/ SRTT3, H44 DERIV, PUSA/EDCh, Bt/wld (with 50% severity), BTSR30WST and Line E/kvz showed 60% and 80% severity respectively, were found to be lines with inadequate level of adult plant resistance.

3.2.3 Evaluation of bread wheat cultivars based on coefficient of infection

Depending on coefficient of infection as evaluation parameter for adult plant resistance (slow rusting resistance) monogenic lines with coefficient of infection values of 0-20, 21-40 and 41-60 were considered as having high, moderate and low levels of resistance (Ali *et al*., 2009). In this study, 25 monogenic lines: CNS SR32 AS, Combination VII, Eagle, Entrelargo de montijo (W3560), ISR5SB, LCSR19MG, Line A seln., Marquis(W2), SWSR22T.B, TAF-2, Tetracanthtch/ag.squarrosa(RL5045), VERNSTEIN, W2691 SRTT1, W2691SR10, W2691SR13, W2691SR15NK, W2691SR28KT, W2691SR9B, BT SR24**Ag,** LCSR25ARS, WRT 238-5, Perlude*4/2/Marquis*6/Khapsten, CnSSrTmp,

ISr6-Ra and CH.SP. (TC3B) were scored CI values of 0-20 and were considered as having high level of slow rusting resistance (APR) and nine lines: Barleta Benvenuto, BTSRGAMUT, CNS (TC2B)/Line E, ISR11RA, MEDEA AP9D, MQ(2)5*G2919, PELISS, W2691 SRTT2 and ISr8-Ra were scored CI values of 21-40 and were considered as having moderate level of slow rusting resistance (APR). Other six lines: FED.*2/ SRTT3, H44 DERIV, PUSA/EDCH, Line E/kvz, Bt/wld and BTSR30WST were scored CI values of 41-80 and were considered as having low level of slow rusting resistance (APR).

Table 2: Severity and field reaction of commercial bread wheat cultivars and monogenic lines at four research stations in four districts of Arsi zones in 2008 main cropping season

			Severity and field reaction types				Highest disease severity	CI
No	Variety	Sr-gene	Arsi Negele	Arsi Robe	Gedeb Asasa	Tiyo		
1	Lakech		0	60S	10MS	5S	60S	60
2	Israel		0	60S	5MS	TS	60S	60
3	Bonde		20S	50S	30S	30S	50S	50
4	Dashen		10S	50S	10MS	15MS	50S	50
5	Pavon 76		10MS	5MS	5MR	15MS-	15MR-MS	13.5
6	Galama		10S	60S	30S	30S	60S	60
7	Enkoy		0	0	0	0	0	Immune
8	Wabe		0	70S	10S	10S	70S	70
9	Tusie		20S	50S	10S	10MS	50S	50
10	Tura		30S	60S	5S	0	60S	60
11	Morocco		50S	80S	50S	70S	80S	80
12	Hawi		30S	70S	10S	TMS	70S	70
13	Simba		40S	60S	5S	TMS	60S	60
14	Kubsa		20MS-S	60S	10MS-S	20S	60S	60
15	Dodota		20S	70S	10S	40S	70S	70
16	Bobicho		10MS-S	60S	20S	40S	60S	60
17	Sirbo		5S	70S	20S	40S	70S	70
18	HAR 3116		0	15MS-S	5MS	5MS	15MS-S	13.5
19	Meraro		0	30MS-S	5MR	20MS-S	30MS-S	27
20	Dure		20S	60S	5S	5S	60S	60
21	Sofumer		30S	70S	20S	40S	70S	70
22	PBW343		50S	80S	50S	70S	80S	80
23	Madda walabu		0	50S	5MS-S	10S	50S	50
24	Barleta Benvenuto	Sr 8b	30S	10MS-S	10MR-MS	15S	30S	30
25	Bt/wld	Sr wld-1	0	50S	0	5S	50S	50
26	BTSR30WST	Sr 30	30S	60S	50S	10MS-S	60S	60
27	BTSRGAMUT	Sr gt	10MS	30S	15MS	5MS-S	30S	30
28	CH.SP. (TC3B)	Sr 12	20S	20MS-S	20MS-S	15S	20S	20
29	Line E/kvz	Sr 31	60S	30MS-S	80S	40S	80S	80
30	CNS (TC2B)/Line E	Sr 9g	30S	10MS	10MS-S	5S	30S	30
31	CNS SR32 AS	Sr 32	0	0	5MR	0	5MR	2
32	Combination VII	Sr 17+ 13	5MR	0	10MS	5MS	10MS	6
33	Morocco		50S	80S	50S	70S	80S	80
34	Eagle	Sr 26	0	0	0	0	0	Immune
35	Entrelargo de montijo (W3560)		0	5MS	0	0	10MS	3
36	FED.*2/ SRTT3	Sr tt + Sr10	20S	50S	30S	15S	50S	50
37	H44 DERIV	Sr H	10MS-S	50S	10MS	10MS	50S	50
38	ISR11RA	Sr 11	20S	30S	10S	30S	30S	30
39	ISR5SB	Sr 5	5S	20S	10S	5S	20S	20
40	LCSR19MG	Sr 19	10S	0	0	0	10S	10
41	Line A seln.	Sr 14	5S	5MR-MS	5MS	10S	10S	5
42	Marquis(W2	Sr7b,18,19,20	0	20MS	0	5S	20MS	12
43	MEDEA AP9D	Sr 9d	TS	30S	20MS-S	5MS	30S	30
44	PBW343		50S	80S	50S	70S	80S	80
45	MQ(2)5*G2919	Sr 35	20MS	20MS-S	30S	5S	30S	30

46	PELISS	Sr PL	0	40S	20MS-S	5S	40S	40
47	PUSA/EDCH	Sr 29	10MS	20S	50S	5MS	50S	50
48	SWSR22T.B.	Sr 22	0	TR	0	0	TR	0.2
49	TAF-2	Sr 44	5MR	10S	20MS	5MS-S	20MS	12
50	Tetracanthtch/ag.squarrosa(RL5045)	Sr 33	30MS	20MS-S	10S	10S	30MS	18
51	VERNSTEIN	Sr 9e	10S	5S	5MS-S	10S	10S	10
52	W2691 SRTT1	Sr 36	0	0	0	10S	10S	1
53	W2691 SRTT2	Sr 37	20S	40S	30S	15S	40S	40
54	W2691SR10	Sr 10	0	TMS	10MS	TR-MS	10MS	6
55	Morocco		50S	80S	50S	70S	80S	80
56	W2691SR13	Sr 13	0	0	5MS	10MS	10MS	3
57	W2691SR15NK	Sr 15	0	10S	10S	10S	10S	10
58	W2691SR28KT	Sr 28	0	TR	10S	0	10S	1
59	W2691SR9B	Sr 9b	20S	10MS-S	20S	15S	20S	20
60	BT SR24Ag	Sr 24	0	0	0	0	0	Immune
61	LCSR25ARS	Sr 25	0	0	0	10S	10S	10
62	WRT 238-5	Sr 27	0	15MS	TS	15MS	15MS	9
63	Perlude*4/2/Marquis*6/Khapsten	Sr 7a	0	20MS	0	0	20MS	12
64	CnSSrTmp	Sr Tmp	TS	10MS-S	5MR-MS	15S	15S	15
65	ISr6-Ra	Sr 6	20S	30MS	20MS-S	10S	30MS	18
66	ISr8-Ra	Sr 8a	20S	40S	10MS	20S	40S	40
67	PBW343		50S	80S	50S	70S	80S	80

4. CONCLUSION

The wheat genotypes showed variation in resistance reaction, ranging from immune to moderately resistant and there were also genotypes with low to moderate severity and coefficient of infection. This study identified some wheat genotypes with high level of adult plant resistance to stem rust from 21 commercial bread wheat cultivars and 40 monogenic lines. Those wheat cultivars and monogenic lines with high level of adult plant resistance to stem rust were commercial bread wheat cultivars such as Enkoy, Paven 76 & monogenic lines such as those carrying stem rust resistant genes Sr24, Sr26, Sr22, Sr32. These genotypes can be useful in wheat improvement programs. Furthermore, identification of resistant wheat genotypes to stem rust for use in wheat breeding is essential because of the rapid evolution of the pathogens. Thus, the bread wheat cultivars and monogenic lines identified from this study with high levels of adult plant resistance may be exploited for stem rust resistance in Ethiopian wheat breeding program. However, further testing for stability is important.

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