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Evaluation of Bread Wheat (*Triticum Aestivum L.*) Genotypes for Stem and Yellow Rust Resistance in Ethiopia

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Abstract: Wheat production in Ethiopia is challenged by different biotic stress. Among these biotic stresses, stem rust (*Puccinia graminis f. sp. Tritici*) and yellow rust (*P. striiformis* Westend. f. sp. *Tritici*) are the most devastating.. Improvement of wheat genotypes through incorporation of resistant genes to stem rust and yellow rust and testing them under hot spot areas is the most economical and environmentally friendly approach to develop resistant cultivars. Field experiment using an augmented design was undertaken at Kulumsa during 2016/17 and 2017/18 cropping season to evaluate the response of 119 elite spring bread wheat genotypes and three checks for stem and yellow rust. Based on the disease severity 71.4% and 96.6% of the genotypes showed the lowest score (0-10%) for stem rust in the first and second cropping season, respectively. About 59.7% and 66.4% of the genotypes were also showed the lowest disease severity (0-10%) for yellow rust during 2016/17 and 2017/18 cropping season, respectively. The genotypes showed significant (≤0.05) difference in Area Under Disease Progress Curve (AUDPC) for stem rust and yellow rust during 2016/17 and 2017/18 cropping season but there was significant difference (≤0.05) in Coefficient of Infection (CI) for stem rust during the first cropping season only. The genotypes exhibited significant difference (≤0.01) and (≤0.001) in CI for yellow rust in the first and second cropping season, respectively. Negative association of grain yield and thousand kernel weight with stem and yellow rust was found in both cropping season. Among the genotypes ASEEL-1//MILAN/PASTOR/3/SHAMISS-3, ZERBA6/FLAG6/3/TAM200/PASTOR//TOBA97, ZERBA-6/FLAG6/3/TAM200/PASTOR//TOBA97, NJOROSD-2/SHIHAB-12 and ICBW 206971//SHUHA-4/CHAM8/3/SIRAJ are highly resistant for both yellow and stem rust in both cropping season.

Keywords: Bread Wheat, Stem Rust, Yellow Rust, Resistance, Susceptible

1. Introduction

Bread wheat (*Triticumaestivum*L.) plays a significant role to food security in the world. It provides more than 21% of the calories and 20% of the protein and its demand in developing world becomes increasing from time to time [10]. Bread wheat is the main cereal crop in Ethiopia, cultivated on about 1.7 million ha with estimated annual production of 4.5 million tons [5]. Ethiopia is the second largest wheat producer in sub Saharan Africa, and wheat is becoming a major crop for improving food security in this country [8, 12]. However, its production is challenged by different biotic stress such as wheat rusts [2, 37].

Stem rust caused by *Puccinia graminis f. sp. Tritici* is one of the fungal diseases which cause severe yield loss in wheat [14]. It is aggravated under warm and moist environmental conditions [18]. Stem rust was detected in Ethiopia in the early 1993 [17]. According to [22] about 40000 ha were infected with wheat stem rust in 2013/2014 cropping season in this country. The stem rust epidemics frequently occurs in the highlands of Ethiopia such as Oromiya, Southern Nation Nationality Peoples, Tigray, and Amhara regions [25] due to the bimodal rainfall patterns which facilitates transferring of inoculums from one season to the next [24, 25] and it may causes 100% yield losses and reduction of grain quality [7, 9] under sever condition.

Yellow rust caused by *P. striiformis* Westend. f. sp. *tritici* (*Pst*) is the most important wheat rust disease which causes 100% yield losses [43] in susceptible varieties. Although, temperate regions with cool and wet weather conditions are suitable for the development of this pathogen [44] since 2000, destructive races of yellow rust adapted to higher temperature [27] have been observed across the world. In Ethiopia yellow rust epidemics has been reported since 1970's [35]. It causes yield loss of 70-100% in susceptible cultivars like Kubsa and Dashen [36] and as well as yield and quality loss in other cultivars [30, 31, 33]. A devastating yellow rust epidemic in Ethiopia affected more than 600,000 ha of wheat in 2010 cropping season [29]. Therefore, it is an economically important disease of wheat in the country [28, 31].

Use of resistant cultivars and chemicals are the major options to control rusts [11, 16]. However, controlling these rust using chemicals is not affordable by resource poor farmers because of high cost and lack of timely supply [1]. Furthermore, chemicals are not environmentally friendly. Genetic resistance is the most suitable approach to control rust diseases in wheat [6]. Although a number of bread wheat cultivars have been released from germplasms introduced from CIMYT and ICARDA, most of the varieties became susceptible for stem and yellow rust within short periods after release [41]. Thus, continuous evaluation of wheat germplasm in stem and yellow rust hot spot areas like Kulumsa is vital to select for adult plant resistance [14]. Therefore, the present study was carried out to evaluate elite bread wheat genotypes from ICARDA in order to identify sources of resistance for stem and yellow rust.

2. Materials and Methods

A field experiment was conducted at Kulumsa Agricultural Research Center of Ethiopian Agricultural Research Institute (EIAR). Kulumsa is located at 8°00'N and 39°07'E, and 2210m above sea level in Arsi Administrative Zone of Oromiya Regional State, 167km South East of Addis Ababa. The agro-climatic condition of the area is wet and receives a unimodal mean annual rainfall of 809.15mm from March to September; however, the peak season is from July to August. The maximum and minimum mean temperature is 23.1 and 9.9°C, respectively [19].

One hundred nineteen Elite Spring Bread Wheat genotypes from the International Center for Agricultural Research Center in the Dry Areas (ICARDA) and 3checks (Hidasse, Kingbird and Shorima) obtained from the Kulumsa Agricultural Research Center were used for this study. The checks were used to compare the resistance of these genotypes to stem and yellow rust. The mixture of three bread wheat cultivar (Digelu, Kubssa, Morocco) susceptible for stem and yellow rust were used as spreader and planted in both sides of each block to ensure production of sufficient inoculums to provide uniform infection.

The genotypes were planted using an augmented design in a plot size of 3.0m length, planted in six rows with 0.2m spacing between rows at Kulumsa during cropping season of 2016/201 and 2017/2018. Field managements and agronomic practices were conducted as recommended.

Days to 50% heading and days to 90% physiological maturity were taken. At physiological maturity five random plants within each plot were used to determine plant height. Grain yield and1000 kernel weight were measured.

The modified Cobb's scale [20] was used to assess the disease severity. The reaction response of the genotype's to the infection was scored three times at 12 days interval starting from the mid of September when diseases symptom started. There action types were designated by "R" or resistant (small uredinia surrounded by chlorosis or necrosis); "MR" or moderately resistant (medium size uredinia surrounded by chlorosis or necrosis); "MS" or moderately susceptible (medium large compatible uredinia without chlorosis and necrosis); and "S" or susceptible (large, compatible uredinia without chlorosis and necrosis). The disease severity was scored in the percentage of 0 to100 scale [14].

The disease severity data and host reaction response were combined to calculate the coefficient of infection (CI) following [21] by multiplying severity value with constant values of 0, 0.2, 0.4, 0.6, 0.8, or 1 for host response ratings of immune (I), resistant (R), moderately resistant (MR), intermediate (M), moderately susceptible (MS), or susceptible (S), respectively. Genotypes with coefficient of infections ranging 0 to 20, 20 to 30, 30 to 40, 40 to 60 and 60 to 100 were resistant, moderately resistant, moderately susceptible, moderately susceptible to susceptible and susceptible, respectively. Susceptibility and resistance comparison of the studied genotypes' was done by calculating Area Under Disease Progress Curve (AUDPC) according to the method of [8] as: AUDPC=Σi=1n-1 [(ti+1–ti)(yi+yi+1)/2]. Where "t" is time in days of each reading, "y" is the percentage of affected foliage at each reading and "n" is the number of readings. Diseases severity score and the coefficient of infection were used to compute AUDPC.

Analysis of variance was conducted on different diseases parameters such as AUDPC, CI, and disease severity to determine resistance differences among the studied elite bread wheat genotypes. The data were analyzed using R software [39]. A correlation coefficient was computed to estimate the association between diseases and agronomic traits including yield and yield components.

3. Results

3.1. Responses to Stem and Yellow Rusts

Significant difference (≤0.05) was observed among the tested genotypes for yellow rust during 2017/18 cropping season (Table 1). In contrast the genotypes didn't show significant difference for stem rust in both cropping season. AUDPC and CI for stem rust showed significant variation (≤0.05) among the studied genotypes in the first cropping season (Table 1). The genotypes showed significant difference (≤0.01) and (≤0.001) in CI for yellow rust in the first and second cropping season, respectively (Tables 1 and 2). The Genotypes also exhibited significant variation (≤0.01) in AUDPC for yellow rust in the second cropping season (Table 2). The Checks showed significant variation (≤0.01) only in AUDPC during 2016/17 season for stem rust (Table 1) in contrast there was no significant difference among the checks in CI for stem and yellow rust in both seasons.

The frequency distributions of the yellow rust severity scores for elite bread wheat genotypes for both cropping season are presented in figure 1. About Eighty and Seventy elite genotypes exhibited the lowest scores (0–10%) in the first and second cropping season, respectively (Figure 1). The highest scores (41–50%) for yellow rust were observed for only four genotypes in the second cropping season (Figure 1).

Genotypes, ASEEL-1//MILAN/PASTOR/3/SHAMISS-3, ZERBA6/FLAG6/3/TAM200/PASTOR//TOBA97, ZERBA6/FLAG6/3/TAM200/PASTOR//TOBA97 were among the highly resistant genotypes for both yellow rust and stem rust with severity levels of 0,5, and 5, respectively.

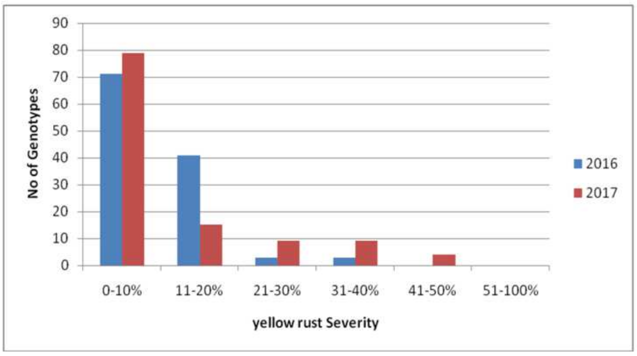

Figure 1. *Histogram of yellow rust severity during 2016 and 2017 cropping season.*

3.2. Variability for Agronomic Traits

The genotypes showed highly significant difference (≤0.001) for days to 50% heading and days to 90% physiological maturity (Table 1) in the first cropping season but in the second cropping season they showed significance variation (≤0.01) and (≤0.05) for days to 50% heading and days to 90% physiological maturity, respectively (Table 2). There was no significant variation among the checks for these traits in both seasons. The studied genotypes also showed significant variation (≤0.05) for plant height during 2016/17 (Table 1).

Significant difference (≤0.05) was observed among the genotypes for thousand kernel weight in both cropping seasons (Tables 1 and 2) but there was no significant difference among the genotypes for grain yield during both cropping seasons.

3.3. Association Among Traits

The Pearson's correlation coefficient analysis showed that days to 50% flowering, days to maturity, plant height, thousand kernels weight and grain yield were negatively correlated with yellow and stem rust in the first cropping season (Table 3). In the second cropping season grain yield and thousand kernel weight were negatively associated with stem and yellow rust (Table 3).

About eighty five and one hundred fifteen genotypes out of the studied genotypes showed the lowest score (0-10%) for stem rust in 2016/17 and 2017/18 cropping season, respectively (Figure 2). In both cropping season the genotypes did not show more than 30% severity level for stem rust (Figure 2).

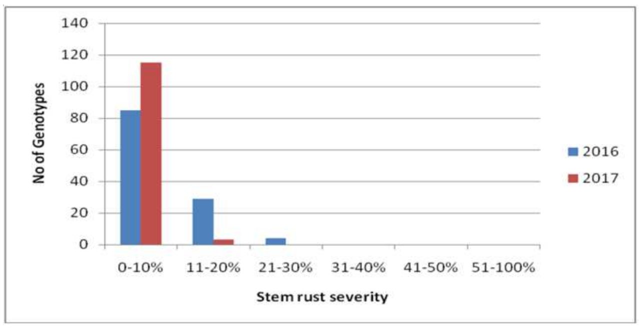

Figure2. *Histog ram of stem rust severity during 2016 and 2017 cropping season.*

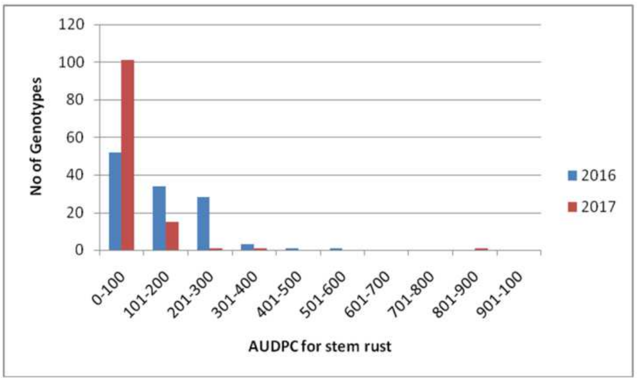

Figure 3. *Histogram of Area Under Disease progress Curve for stem rust during 2016 and 2017 cropping season.*

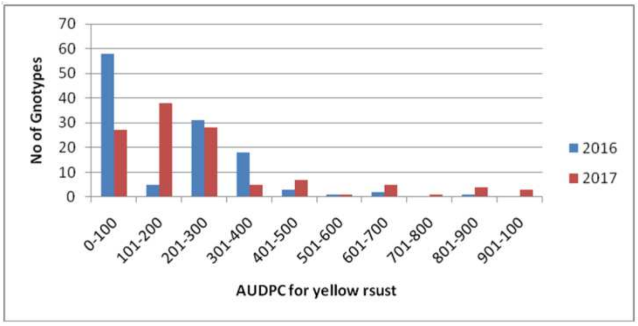

Figure 4. *Histogram of Area Under Disease progress Curve for yellow rust during 2016 and 2017cropping season.*

Table 1. *Analysis of variance for the various traits of the genotypes during 2016/17 cropping season at Kulumssa.*

		Stem Rust		Yellow Rust								
Source of Variation	**Df**	**CI**	**AUDPC**	**CI**	**AUDPC**	**DH**	**DM**	**PH (cm)**	**TKW (g)**	**GY (Kg/plot)**	**YR**	**SR**
Block (Adj)	3	2.2^{ns}	4200^{ns}	8.4^{ns}	26475^{ns}	137.2^{ns}	6.1^{ns}	0.3^{ns}	1.61^{ns}	0.13^{ns}	81.0^{ns}	33.3^{ns}
Treat (Adj)	121	30.7*	10405*	21.2**	30639	34.4***	38.3***	96.2*	22.12*	1.363*	14.6^{ns}	44.8^{ns}
Controls	2	100.3^{ns}	32025**	0.3^{ns}	8400^{ns}	32025^{ns}	4.1^{ns}	120.6*	42.62*	6.9**	14.6^{ns}	214.6**
AugmentedVsControls	1	5.3^{ns}	4811^{ns}	27.6*	66327	18.9*	126.1^{ns}	0.52^{ns}	8.19**	174.9^{ns}	1.5^{ns}	0.4^{ns}
Augmented	118	36.7*	11836*	22.4**	32552^{ns}	38.6***	41.6***	106.6*	22.27*	1.29^{ns}	84.3^{ns}	50.4^{ns}
Residual	6	6.1	2025	2.1	12000	1.9	1.4	22.8	5.1	0.36	18.7	14.6

Wherens, ***,**and*, non significant, Significantly different at 0.001, 0.01 and 0.05, respectively. Df=Degree of freedom, CI=Coefficient of infection, AUDPC=Area under disease progress curve, DH=Days to 50% heading, DM=Days to maturity, PH=Plant Height, TKW=Thousand kernel weight, GY=grain yield, YR=yellow rust and SR=stem rust.

Table2. *Analysis of variance for the various traits of the genotypes during 2017/18 cropping season at Kulumssa.*

Source of Variation	**Df**	Stem Rust		Yellow Rust								
		CI	**AUDPC**	**CI**	**AUDPC**	**DH**	**DM**	**PH (cm)**	**TKW (g)**	**GY (Kg/plot)**	**YR**	**SR**
Block (Adj)	3	25.6^{ns}	7300^{ns}	4^{ns}	9875^{ns}	4.6^{ns}	6.9^{ns}	3.8^{ns}	5.06^{ns}	0.014^{ns}	25.0^{ns}	27.8^{ns}
Treat (Adj)	121	20.7^{ns}	8316^{ns}	72.3***	46515*	44.7*	39.6*	75.7*	23.15*	0.374^{ns}	116.2*	31.2^{ns}
Controls	2	22.3^{ns}	7275^{ns}	0.3^{ns}	5925^{ns}	1.7^{ns}	31^{ns}	248.1**	85.69**	7.21**	2.1^{ns}	27.1^{ns}
Augmented Controls	1	37.0^{ns}	28596^{ns}	28.3*	944^{ns}	10.3^{ns}	0.8^{ns}	279.8***	8.19**	11.713**	0.4^{ns}	78.0^{ns}
Augmented	118	20.3^{ns}	8154^{ns}	76.5***	49141**	49.4**	42.8*	70.9^{ns}	22.34*	0.159^{ns}	124.1*	30.8^{ns}
Residual	6	20.6	7375	3	6725	7.0	9.9	19.5	3.66	0.34	31.3	29.9

Where ns, ***,**and *, non significant, Significantly different at 0.001, 0.01 and 0.05, respectively. Df=Degree of freedom, CI=Coefficient of infection, AUDPC=Area under disease progress curve, DH=Days to 50% heading, DM=Days to maturity, PH=Plant Height, TKW=Thousand kernel weight, GY=grain yield, YR=yellow rust and SR=stem rust

Table 3. *Pearson's correlation coefficients among the different diseases and agronomic traits during 2016/17 (Above diagonal) and 2017/18 (Below diagonal) cropping season.*

		YR	**SR**	**DH**	**DM**	**PH**	**TKW**	**GY**
YR	1	1	-0.01^{ns}	-0.33**	-0.19*	-0.01^{ns}	-0.25**	-0.07^{ns}
SR	-0.45^{ns}	1	1	-0.27**	-0.19*	-0.13^{ns}	-0.3^{ns}	-0.04^{ns}
DH	-0.17^{ns}	0.13^{ns}	1	1	0.79**	0.37**	-0.9^{ns}	0.11^{ns}
DM	-0.14^{ns}	0.21*	0.76**	1	1	0.61**	-0.9^{ns}	0.11*
PH	0.9^{ns}	0.51^{ns}	0.16^{ns}	0.04^{ns}	1	1	0.11^{ns}	0.24**
TKW	-0.15^{ns}	-0.02^{ns}	0.73^{ns}	0.13^{ns}	0.05^{ns}	1	1	0.09^{ns}
GY	-0.35**	-0.12^{ns}	0.48^{ns}	0.11^{ns}	-0.01^{ns}	0.37**	1	1

Where ** and *, Significantly different at 0.01 and 0.05, respectively. DH=Days to 50% heading, DM=Days to maturity, PH=Plant Height, TKW=Thousand kernel weight, GY=grain yield, YR=yellow rust and SR=stem rust.

Table 4. *Stem and yellow rust terminal diseases scores, coefficient of infection (CI) of resistant elite spring bread wheat genotypes planted during 2016/17 and 2017/18 cropping season at Kulumsa.*

Pedigree	**2016 (Stem Rust)**		**2017 (Stem Rust)**		**2016 (Yellow Rust)**		**2016 (Yellow Rust)**	
	Disease score	**CI**	**Disease score**	**CI**	**Disease score**	**CI**	**Disease score**	**CI**
KAUZ/STAR/3/MUNIA/ALTAR84//MILAN/4/LEITH-1	15MS	12	0	0	15MR	6	10MR	4
22SAWSN142/3/PASTOR//MUNIA/ALTAR84/4/SHAMISS-3	10MR	4	10S	10	0	0	10MR	4
PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA	5MR	2	0	0	0	0	15MR	6
PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA	10MS	8	0	0	15MR	6	5MR	2
KIRITATI/4/SERI.1B*2/3/KAUZ*2/BOW//KAUZ/5/SHUHA-4/CHAM-8	0	0	10MS	8	0	0	10MR	4
FARIS22/4/BOW/PRL//BUC/3/WH576/5/NINGMAI9558//CHIL/CHUM18	10MR	4	10MS	8	20MR	8	10MR	4
P1.861/RDWG//ESWYT99#18/ARRIHANE/3/PFAU/MILAN	10MS	8	5MS	4	20MR	8	40MS	32
PFAU/MILAN//ABIER-2/3/SHUHA3//TURACO/CHIL	10MS	8	5MS	4	5MR	2	25MR	10
OPATA/RAYON//KAUZ/3/ESWYT99#18/ARRIHANE/4/SOSSI-3	10S	10	5MR	2	10MR	4	10MR	4
HIDASSE	10MS	8	5MS	4	10MR	4	20MR	8
OPATA/RAYON//KAUZ/3/ESWYT99#18/ARRIHANE/4/SOSSI-	25S	25	0	0	10MR	4	10MR	4
FARIS22/4/BOW/PRL//BUC/3/WH576/5/NINGMAI9558//CHIL/CHUM18	10MS	8	5MS	4	15MR	6	5MR	2

Pedigree	2016 (Stem Rust)		2017 (Stem Rust)		2016 (Yellow Rust)		2016 (Yellow Rust)	
	Disease score	CI	Disease score	CI	Disease score	CI	Disease score	CI
WBLL1*2/BRAMBLING//ZAFIR-3	20MS	16	10MS	8	10MR	4	10MR	4
WEAVER/TSC//WEAVER/3/WEAVER/4/WAXWING/5/DURRA-8	10MS	8	0	0	0	0	10MR	4
REBWAH13/3/CMH81.38/2*KAUZ//ATTILA/4/URES/BOW//OPATA/3/HD2206/HORK'	30MS	24	10MS	8	0	0	10MR	4
WATAN-6/ETBW4919//ZAKIA-14	5MR	2	0	0	0	0	5MR	2
KAUZ/STAR//ETBW4920/3/QAMAR-2	5MR	2	0	0	0	0	10MR	4
ASEEL-1//MILAN/PASTOR/3/SHAMISS-3	0	0	0	0	0	0	10MR	4
ZERBA-6/FLAG6/3/TAM200/PASTOR//TOBA97	0	0	5MS	4	0	0	5MR	2
KINGBIRD	10MS	8	5MR	2	5MR	2	15MR	6
ZERBA-6/FLAG6/3/TAM200/PASTOR//TOBA97	5MR	2	5MS	4	0	0	5MR	2
ZERBA-6/FLAG6/3/TAM200/PASTOR//TOBA97	0	0	0	0	0	0	5MR	2
SUDAN#3/SHUHA-6//FLAG-5/7/CHAM-	10MR	4	0	0	10MR	4	10MR	4
TEMPORALERAM87*2/KONK//VENAC	15MS	8	10MS	8	0	0	5MR	2
KINGBIRD/IZAZ-11	5MS	4	0	0	0	0	10MR	4
KINGBIRD/IZAZ-11	10MS	8	5MS	4	5MR	2	10MR	4
KINGBIRD/IZAZ-11	15MS	12	0	0	0	0	10MR	4
KINGBIRD/IZAZ-11	15MS	12	0	0	0	0	10MR	4
KINGBIRD/IZAZ-11	15MS	12	5MR	2	15MR	6	15MR	6
SHORIMA	0	0	0	0	15MR	6	15MR	6
MILAN/SHA7/3/THB/CEP7780//SHA4/LIRA/4/SHA4/CHIL/5/FARIS-6	10MS	8	0	0	15MR	6	10MR	4
22SAWSN-142/3/PASTOR//MUNIA/ALTAR84/4/SHAMISS-3	20S	20	5MS	4	0	0	10MR	4
22SAWSN-142/3/PASTOR//MUNIA/ALTAR84/4/SHAMISS-3	10MS	8	0	0	15MR	6	30MS	24
22SAWSN-142/3/PASTOR//MUNIA/ALTAR84/4/SHAMISS-3	15MS	12	5MS	4	5MR	2	10MR	4
SKAUZ/2*STAR//ACHTAR/INRA	15MS	12	5MR	2	15MR	6	10MR	4
QT6581/4/PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/5/PAVON76/JADIDA-2	10MS	8	0	0	20MR	8	10MR	4
QT6581/4/PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/5/PAVON76/JADIDA-2	15MR	6	0	0	0	0	10MR	4
SHARP/3/PRL/SARA//TSI/VEE#5/5/VEE/LIRA//BOW/3/BCN/4/KAUZ/6/QAFZAH-4/3/VEE#7//MT773/EMU'S'	10MR	4	5MS	4	0	0	15MR	6
PBW343/FLAG-4//QADANFER-4	0	0	5MR	2	15MR	6	20MR	8
HIDASSE	10MR	4	5MS	4	15MR	6	15MR	6
DEBEIRA/FLAG-6//SHUHA-1/DORG-1	10S	10	0	0	10MR	4	10MR	4
PFAU/MILAN//ABIER-2/3/SHUHA3//TURACO/CHIL	0	0	0	0	5MR	2	20MR	8
RABIH-10/ETBW4922//KAUZ'S'/FLORKWA-1	5MR	2	0	0	20MS	16	40MR	16
THELIN/WAXWING//ATTILA*2/PASTOR/3/INQALAB91*2/TUKURU9Y-0B	10MR	4	5MS	4	15MR	6	10MR	4
THELIN/WAXWING//ATTILA*2/PASTOR/3/INQALAB91*2/TUKURU9Y-0B	5MR	2	5MS	4	15MR	6	10MR	4
SUDAN#3/SHUHA-6//FLAG5/3/PFAU/MILAN	0	0	0	0	5MR	2	5MR	2
THELIN/WAXWING//ATTILA*2/PASTOR/3/INQALAB91*2/TUKURU9Y-0B	10MS	8	10MR	4	10MR	2	10MR	4
ATTILA/3*BCN//MILAN/DUCULA/7/BACANORA86/6/SN64/HN4//REX/3/EDCH/MEX/4/SLS'S'/5/BOW'S'	10MS	12	0	0	0	0	10MR	4
HUBARA-1//ACHTAR/INRA1764/7/CHAM-8/6/SAKER'S'/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	0	0	0	0	15MR	6	35MR	14
KINGBIRD	10MS	8	15MS	12	15MR	6	10MR	4
HUBARA-1//ACHTAR/INRA1764/7/CHAM-8/6/SAKER'S'/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	0	0	15MS	12	10MR	4	25MR	10
PFAU/MILAN//FUNGMAI24/3/ATTILA*2/CROW	15MS	12	5MR	2	0	0	5MR	2
WEAVER/TSC//WEAVER/3/WEAVER/4/WAXWING/5/DURRA-8	10MR	4	0	0	20MR	8	50MS	40
WEAVER/TSC//WEAVER/3/WEAVER/4/WAXWING/5/DURRA-8	5MR	2	10MS	8	20MR	8	50MS	40
REBWAH13/3/CMH81.38/2*KAUZ//ATTILA/4/URES/BOW//OPATA/3/HD2206/HORK'	10MS	8	0	0	20MR	8	25MR	10
KOUKAB-1/ETBW4920//PAVONF76	5MR	2	0	0	15MR	6	20MR	8
CHAM-8/RUTH-3//ZAIN-2	15MS	12	5MR	2	10MR	4	10MR	4
ZERBA-6/FLAG6/3/TAM200/PASTOR//TOBA97	0	0	0	0	0	0	5MR	2
SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE/5/SKAUZ/BAV92	0	0	0	0	0	0	5MR	2
SHORIMA	0	0	5MS	4	10MR	4	20MR	8
MO88/MILAN//ETBW4922/3/(4)EALME4SA-464	0	0	5MS	4	20MR	8	25MR	10
FARIS-17//PFAU/MILAN/3/SOSSI-3	0	0	0	0	15MR	6	10MR	4
TRAP#1/BOW//PFAU/3/MILAN/4/ETBW	0	0	0	0	0	0	5MR	2
SUDAN#3/SHUHA-6//FLAG-5/7/CHAM-8/6/SAKER'S'/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	0	0	5MS	4	10MR	4	10MR	4

Pedigree	2016 (Stem Rust)		2017 (Stem Rust)		2016 (Yellow Rust)		2016 (Yellow Rust)	
	Disease score	CI	Disease score	CI	Disease score	CI	Disease score	CI
KA/NAC//SERI/RAYON/3/GOUMRIA-14	5MR	2	5MR	2	15MR	6	15MR	6
BABAX/LR42//BABAX*2/3/VIVITSI/4/SERI.1B*2/3/KAUZ*2/BOW//KAUZ	0	0	0	0	20MR	8	10MR	4
KINGBIRD/3/NESMA*2/14-2//2*SAFI-3	15S	15	0	0	20MR	8	25MR	10
P1.861/RDWG//ESWYT99#18/ARRIHANE/3/PFAU/MILAN	20S	20	10MS	8	0	0	10MR	4
P1.861/RDWG//ESWYT99#18/ARRIHANE/3/PFAU/MILAN	20MS	16	0	0	15MR	6	10MR	4
HIDASSE	10MS	8	5MR	2	10MR	4	15MR	6
FLORKWA-2/NJOROSD2/5/QT6581/4/PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN	20MS	8	20MS	16	15MR	6	5MR	2
SUDAN#3/SHUHA-6//FLAG5/3/PFAU/MILAN	10MS	8	0	0	0	0	5MR	2
SUDAN#3/SHUHA-6//FLAG-5/3/PFAU/MILAN	5MR	2	0	0	0	0	5MR	2
ATTILA*2/AMAD//ENKOY/3/PFAU/MILAN	5MR	2	5MS	4	5MR	2	10MR	4
ABU-REYAA-1/LEITH-1	30MS	24	0	0	25MR	10	35MS	28
PFAU/MILAN//MOONTASIR-3	10MR	4	5MR	2	0	0	5MR	2
CHAM-8/RUTH-3	25MS	16	5MR	2	10MR	4	10MR	4
SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE/5/SKAUZ/BAV92	20MS	16	0	0	10MR	4	10MR	4
ZAIEM-8/KBG-01	15MS	12	10MS	8	0	0	10MR	4
KINGBIRD	20MS	16	5MS	4	15MR	6	15MR	6
WBLL4//OAX93.24.35/WBLL1/4/SHUHA-1/3/MON'S'/ALD'S'//ALDAN'S'/IAS58	20MS	16	0	0	20MR	8	15MR	6
CHAM-10/3/PASTOR//MUNIA/ALTAR84/4/PFAU/MILAN	15MS	12	5MR	2	40MS	32	30MR	12
ZAFIR-3/TAZA-1/6/ND/VG9144//KAL/BB/3/YACO/4/CHIL/5/KAUZ*2//TC*6/RL5406(RL6043)/3/KAUZ	15MS	12	5MS	4	30MR	12	5MR	2
ABU-REYAA-1/LEITH-1	15MS	12	0	0	0	0	30MR	12
SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE/5/SKAUZ/BAV92	20MS	16	5MS	4	5MR	2	10MR	4
OPATA/RAYON//KAUZ/3/ETBW4922/4/MI	10MR	4	0	0	0	0	20MR	8
PFAU/MILAN//FLAG-3/3/NEJMAH-9	10MR	4	50MS	40	15MR	6	10MR	4
SHIHAB-19/KHIDER1/5/YANAC/3/PRL/SARA//TSI/VEE#5/4/CROC-1/AE. SQUARROSA(224)//OPATA	10MS	8	5MS	4	20MR	8	10MR	4
HUITES/4/CS/TH. SC//3*PVN/3/MIRLO/BUC/5/ETBW4922/6/QADANFER-4	10MS	8	5MR	2	20MSMR	16	40MS	32
SHORIMA	0	0	5MR	2	15MR	6	15MR	6
HUITES/4/CS/TH. SC//3*PVN/3/MIRLO/BUC/5/ETBW4922/6/QADANFER-4	0	0	5MR	2	0	0	10MR	4
FLORKWA-2/85Z1284//ETBW4920/3/LOULOU-18	15MS	12	0	0	0	0	5MR	2
PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA	10MS	8	0	0	0	0	10MR	4
PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA	5MR	2	0	0	0	0	5MR	2
PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA	10MR	4	5MS	4	0	0	10MR	2
PASTOR//HXL7573/2*BAU/3/SOKOLL/WBLL1/4/SAFI-1//NS732/HER/3/SAADA	0	0	5MS	4	15MR	6	10MR	2
KRICHAUFF/2*PASTOR//SHUHA8/DUCU	0	0	10MS	8	15MR	6	5MR	2
WAXWING*2/KUKUNA//SHUHA-4/CHAM-	0	0	0	0	15MR	6	10MR	4
TEVEE-1/STAR'S'//ETBW4920/3/TEPOCA+LR34/2*BORL95	0	0	5MS	4	5MR	2	15MR	6
HIDASSE	5MR	2	5MR	2	20MR	8	15MR	6
22SAWSN-142/ETBW4921/6/HPO/TAN//VEE/3/2*PGO/4/MILAN/	10MR	4	0	0	0	0	15MR	6
THELIN/WAXWING//ATTILA*2/PASTOR/3/INQALAB91*2/TUKURU9Y-0B	0	0	5MS	4	10MR	4	15MR	6
HUBARA-1//ACHTAR/INRA1764/7/CHAM-8/6/SAKER'S'/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	5MR	2	0	0	0	0	25MR	10
NJOROSD-2/SHIHAB-12	0	0	5MR	2	0	0	5MR	2
NJOROSD-7/3/VEE/TSI//F134.71/CROW	0	0	5MR	2	15MR	6	40MS	32
SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE/5/SKAUZ/BAV92	0	0	0	0	15MS	12	10MR	4
MO88/MILAN//ETBW4922/3/(4)EALME4SA-464	0	0	10S	10	15MR	6	10MR	4
ICBW206971//SHUHA-4/CHAM8/3/SIRAJ-	0	0	5MR	2	0	0	5MR	2
ALMAZ-26//ACHTAR/INRA1764/3/QAMAR-6	0	0	5MR	2	15MR	6	5MR	2
KINGBIRD	15MS	8	5MS	4	20MR	8	15MR	6

Pedigree	2016 (Stem Rust)		2017 (Stem Rust)		2016 (Yellow Rust)		2016 (Yellow Rust)	
	Disease score	CI	Disease score	CI	Disease score	CI	Disease score	CI
NJOROSD-7/3/VEE/TSI//F134.71/CROW	5MR	2	5MS	4	0	0	5MR	2
BABAX/LR42//BABAX*2/3/VIVITSI/4/SERI.1B*2/3/KAUZ*2/BOW//KAUZ	0	0	10MS	10	30MR	12	40MS	32
NESMA*2/14-2//2*SAFI-3/4/PASTOR//HXL7573/2*BAU/3/WBLL1	0	0	0	0	15MR	6	15MR	6
SUDAN#3/SHUHA-6//FLAG-5/3/PFAU/MILAN	10MS	8	0	0	35MR	14	5MR	2
MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/NESMA*2/14-2//2*SAFI-3	10MR	4	5MS	4	0	0	15MR	6
SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/ETBW4921/6/SAMIRA-9	0	0	10MS	10	10MR	4	5MR	2
QT6581/4/PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/5/PAVON76/JADIDA-2	10MS	8	5MR	2	10MR	4	20MR	8
QT6581/4/PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/5/PAVON76/JADIDA-2	5MR	2	5MR	2	10MR	4	25MR	10
MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/NESMA*2/14-2//2*SAFI-3	5MR	2	5MS	4	0	0	10MR	4
SHORIMA	0	0	5MR	2	20MR	8	15MR	6
QT6581/4/PASTOR//SITE/MO/3/CHEN/AEGILOPSSQUARROSA(TAUS)//BCN/5/PAVON76/JADIDA-2	0	0	5MR	2	10MR	4	15MR	6
WAXWING*2/VIVITSI//SHUHA-	15MR	6	5MS	4	0	0	40MS	32
BABAX/LR42//BABAX*2/3/KUKUNA/4/AT	10MR	4	5MR	2	10MR	4	10MR	4
BABAX/LR42//BABAX*2/3/KUKUNA/4/ATTILA*2/CRO	10MR	4	10MS	8	10MR	4	10MR	4
FARIS-17//PFAU/MILAN/3/SOSSI-3	0	0	0	0	20MR	8	40MS	28
ZAFIR-3/TAZA-1/6/ND/VG9144//KAL/BB/3/YACO/4/CHIL/5/KAUZ*2//TC*6/RL5406(RL6043)/3/KAUZ	15MS	12	5MS	4	0	0	5MR	2
WBLL1//TEVEE/KAUZ/3/MILAN/SHA7//POTAM*3KS811261-5	15MS	12	5MR	2	0	0	10MR	4
SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE/5/SITTA/BUCHIN//CHIL/BOMB	10MS	8	5MS	4	10MR	4	10MR	4
FLORKWA-2/85Z1284//ETBW4920/3/LOULOU-18	0	0	5MR	2	0	0	0	0
SKAUZ/2*STAR/5/JUN//MAYA/MON/3/PGO/4/MILAN/6/TEMPORALERAM87*2/KONK	0	0	5MS	4	35MR	14	50MS	40
SOKOLL/WBLL1/4/SERI.1B//KAUZ/HEVO/	10MS	8	5MR	2	20MS	16	30MR	12

4. Discussion

Though wheat is an important crop in Ethiopia, its production has been challenged by yellow and stem rust diseases causing up to 100% yield losses in some years in the main wheat growing belts of the country. To date, more than 80 bread wheat varieties of CIMMYT and ICARDA origin have been released in Ethiopia. However, currently only few varieties such as Kubsa, Kekeba, Medawelabu etc are grown with the application of fungicides. Development and deployment of resistant varieties is one of the key strategy to control rust diseases for the very fact that it is cheaper and friendly to the environment. However, because of the co-evolution of the host and the pathogen, resistance of the varieties get broken shortly (on average 5years) after release leading to the boom and bust cycle to continue. Development of resistant varieties with major and minor gene combinations helps to extend the duration of the variety in its resistance form. To this end, elite spring bread wheat genotypes from ICARDA were evaluated at Kulumsa research center to identify genotypes resistance to both rusts. In the present study although the spreader rows were infected with the heavy stem and yellow rust disease pressure during the years 2016/17 and 2017/18, most of the genotypes remained resistant for both diseases. The genotypes that showed less severity level (≤10%) for stem and yellow rust may contain major genes of stem rust such as SR2, SR24, SR25 and yellow rust such as Yr5, Yr10, Yr15, Yr18 with many other minor gene combinations. The currently identified resistant genotypes have been also evaluated at Merchouch station in Morocco and Terbol station of ICARDA in Lebanon against the Yr27 and the warrior races of yellow rust. These genotypes showed high level of resistance in both locations indicating that they do combine resistance for both races. The results revealed that lowest and highest AUDPC was attained on genotypes that showed lowest and highest disease severity, respectively. These results are in line with findings of [35]. Most of the studied genotypes showed that late infection and slow growth of the pathogen. Such disease resistance potential are best qualities of a slow rusting genotypes [42] and resulted low values of AUDPC [23].

The negative association between yellow and stem rust showed that high yellow rust disease severity tended to show low stem rust severities due to low photosynthetic area [32] under sever yellow rust infection. The negative correlation of stem and yellow rust with grain yield and thousand kernel weight revealed that the two rusts directly affects the grain quality leading to shriveling of wheat grains [28].

5. Conclusion and Recommendation

The current study has clearly indicated the presence of genetic variability for resistance to stem and yellow rusts within the elite genotypes of ICARDA origin. Among the many genotypes, we have identified ASEEL1//MILAN/PASTOR/3/SHAMISS3, ZERBA6/FLAG6/3/TAM200/PASTOR//TOBA97, ZERBA6/FLAG6/3/TAM200/PASTOR//TOBA97, NJOROSD-2/SHIHAB-12 and ICBW206971//SHUHA 4/CHAM8/3/SIRAJ as the top 5 genotypes with high level of resistance for both yellow rust and stem rust diseases. These genotypes shall be included in the national/regional variety trials for further evaluation to their adaptation and agronomic performance in the major wheat growing regions of Ethiopia for potential release. These genotypes are also recommended for parentage purposes in the wheat breeding programs at ICARDA and Kulumsa and other breeding programs in the region. Ethiopia is the hot spot for rust diseases and hence there is change of races frequently. It is therefore important to continue development and deployment of resistant varieties across different regions with application of fungicides to reduce the disease pressure. Pyramiding of major genes with minor genes through the application of molecular markers and key location phenotyping should be key strategies to continue in order to develop high yielding varieties with durable resistance to the major rusts.

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