Epidemics of *Pucciniastriiformis* F. Sp. *Tritici* in Arsi and West Arsi Zones of Ethiopia in 2010 and Identification of Effective Resistance Genes

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Abstract
Stripe rust of wheat is one of the most important wheat production constraints in Ethiopia. The 2010 main season has witnessed the importance of the disease as widespread epidemic occurred throughout the major wheat producing areas that resulted in complete crop failure and as a result two popular varieties Kubsa and Galama were withdrawn from production. In order to monitor stripe rust of wheat, wheat diseases survey are conducted annually and rust trap nurseries are planted in selected wheat producing areas. In the current study, survey was conducted to evaluate the performance of the released cultivars to the major epidemic on farmers' wheat fields. Rust trap nurseries were also planted in major representative areas of the Arsi zone to evaluate the performance of the commercial cultivars and also the stripe rust differentials. A total of 120 wheat fields were covered during the survey. Stripe rust of wheat was the most prevalent disease across the three routes. It was found in 84% of the fields inspected. The incidence and the severity of stripe rust of wheat varied according to locations, varieties, planting dates and the crop growth stage. The highest stripe rust incidence and severity was recorded on Kubsa which is the dominant bread wheat cultivar in all the three routes. Stripe rust was quite high at altitudes ranging from 2144 to 2497m above sea level. Bread wheat cultivars such as Digalu, MadaWallabu and K62954A and Tusie were found to be resistant under farmers' field condition and can serve as important sources of resistance to the stripe rust races prevailing in Ethiopia. Of the three test locations, Meraro has the widest virulence spectrum for stripe rust of wheat and as a result most of the stripe rust differentials were not effective to the stripe rust populations prevailing at Meraro. Kulumssa and Arsi Robe have comparable virulence spectrum and almost equal number of effective and ineffective genes were identified during the season in both locations. In general, compared to the other cropping seasons, the virulence spectrum of stripe rust has increased in 2010 in all locations and the number of effective genes identified is very low in all locations. The virulence spectrum of stripe rust at Meraro has always been wide because of the favorable environmental condition. Genes *Yr5*, *Yr15* and *YrSP* were effective across all the test locations. These genes can be recommended to be utilized in the development of stripe rust resistant varieties that are effective to the Ethiopian stripe rust populations in the major wheat producing areas in Ethiopia.
Keywords: effective genes, incidence, severity, stripe rust, trap nursery, virulence.

1. Introduction

Stripe rust of wheat (*Pucciniastriiformis*f.sp. *tritici*) is one of the most important fungal diseases of wheat and the major production bottleneck in the major wheat producing regions of Ethiopia (Ayele*et al*., 2008a). Arsi and Bale regions of the country are the known hotspots for the epidemics of stripe rust of wheat (Negassa, 1986). Even though there is seasonal variability in the occurrence of stripe rust in Bale highlands, the main and long rainy season is ideal for stripe rust development (Bekele*et al*., 2002). 58% of yield loss was recorded at Bekoji in 1988 due to stripe rust epidemics on Dashen. Grain yield losses of 30 to 96% have been recorded on susceptible bread wheat varieties in Bale (Hailu and Fininsa, 2007). Grain yield loss of 71% has been recorded on susceptible bread wheat variety Wabe in Bale (Hailu and Fininsa, 2009). Stripe rust also reduced the germination ability and kernel weight of Dashen by 72 and 56% respectively (Ayele and Wondimu, 1992). Surveys conducted in the last two decades showed that stripe rust has been widely distributed in all bread wheat producing areas of the country almost in all seasons affecting almost all improved cultivars at various levels (Ayele*et al*., 2008a). Stripe rust also reduced the germination ability and kernel weight of Dashen by 72 and 56% respectively (Ayele and Wondimu, 1992). The highest level of stripe rust infection was observed at altitudes between 2150-2850m above sea level. In Ethiopia, since the inception of wheat breeding in 1950s several improved wheat cultivars have been released for farmers. However, they were being withdrawn from production due to their susceptibility to the three wheat rusts as a result of the recurrent evolution of new rust races in East African countries including Ethiopia. Monitoring the threatening pathogens and races, inventory of the resistance genes utilized in the current wheat cultivars are among the major objectives of successful breeding program. In view of the above fact, the current wheat stripe rust survey was conducted as a feedback to quantify the incidence and severity of stripe rust of wheat and also to evaluate the reaction of commercial cultivars under onfarm condition and stripe rust differentials to stripe rust epidemics in the major wheat producing districts of Arsi and west Arsi zones of Ethiopia.

2.Materials and Methods

2.1 Wheat stripe rust virulence survey

Wheat stripe rust virulence survey was conducted in three predetermined routes of Arsi and West Arsi zones.
RouteI*.Kulumssa→Sagure→Bekoji→Meraro→Asassa→Lole→Kofele→Kersa*
Route II*. Kulumssa→Dhera→Huruta→Diksis→ArsiRobe→Endoto→ Habe→ Bele→ Seru*
Route III*. Kulumssa→Sire→Rea→Moye→Aseko→Chole*
Wheat fields near road sides were evaluated for the presence of stripe rust of wheat at five kilometers interval. From each field both the incidence and severity of stripe rust was recorded. The severity of stripe rust was recorded based on the modified Cobb's scale (Peterson *et al*., 1948). Other important information such as the altitude, latitude and longitude were gathered from each field using the GPS. Information on the type of the wheat variety and the precursor crops was also obtained.

2.2 Wheat stripe rust trap nurseries and differentials

Commercial wheat cultivars and stripe rust differentials were planted in two rows of 1m length at Bekoji, Arsi Robe and Meraro. A spreader row consisting of susceptible checks of Morocco and PBW343 were mixed in equal proportion to catch virulence for the *Yr27* gene and other genes of stripe rust. Fertilizer was applied at the recommended rate for each location where the trap nurseries were planted. Scoring was done three times during the growing season of 2010 and only the maximum score per location was included in the report. The Modified Cobb's scale was used for scoring the severity of stripe rust of wheat (Peterson *et al*., 1948) and the response was recorded according to Roelfs*et al*. (1992).

3.Result

3.1 Wheat Stripe Rust Virulence Survey

A total of 120 wheat fields were covered during the survey; the first being early in the season where stripe rust infection started at tillering stage in Gedeba-Asassa district and the second at later growth stages in other districts of Arsi and west Arsi zones. Of the 120 wheat fields, 109 wheat fields were in Arsi zone and the remaining 11 fields were in west Arsi zone. Three survey routes identified were covered in the survey. In route I a total of 33 wheat fields were inspected; in route II, a total of 61 wheat fields were assessed and in route III, 26 wheat fields were examined. Stripe rust of wheat was the major disease during the season and its prevalence was 84% across the three routes. The incidence and the severity of stripe rust of wheat varied according to locations, varieties, planting dates and the crop growth stage. At the early growth stages (ZGS30-ZGS37) the incidence and severity of stripe rust was low though a susceptible variety such as Kubsa was planted and or the area was extremely highland (3000m above sea level) with favorable condition for stripe rust development. But at later growth stages (ZGS37-ZGS87), both the incidence and severity of stripe rust was high depending upon altitude and resistance level of the bread wheat cultivar grown. The highest stripe rust incidence and severity was recorded on Kubsa which is the dominant bread wheat cultivar in all the three routes. The severity of stripe rust on Kubsa ranged from 0 (at Jingo Kelesa, Dele Feker and BadosaBetela) where Kubsa was at the early growth stages to 100S when Kubsa was at later growth stages in various locations covered in the survey. Kubsa, Galama and MadaWallabu were the major bread wheat cultivars during the growing season. Kubsa accounted for 28% of the wheat fields covered in the survey whereas 21% and 18% of the wheat area was allocated to the production of Galama and MadaWallabu respectively. Tusie was encountered in five wheat fields. Sofummer and Digalu were encountered only in four and three wheat fields respectively. Even though some of the varieties were resistant to the 2010 stripe rust epidemics, the inoculum load of stripe rust was high and an incidence of 100% was recorded among the stripe rust resistant cultivars such as MadaWallabu and Sofummer. 62 (52%) of the fields displayed an incidence of 100%. However, the severity of stripe rust varies from variety to variety; from altitude to altitude; from location to location; from growth stage to growth stage; etc. Kubsa fields which were sprayed sustained a severity of 60S and Galama fields that were fungicide protected also sustained a severity of 80-100S. Galama was more susceptible to the stripe rust epidemics compared to Kubsa. Whenever proper application of fungicide was made, complete control of stripe rust of wheat was achieved in super susceptible cultivars such as Galama. Unsprayed fields of Digalu, Tusie and K62954A were also free from stripe rust infection in some localities and generally the stripe rust pressure on those cultivars were very low compared to the susceptible cultivars in the season. Kubsa wheat fields that were not sprayed situated at an altitude of less than 2000 m asl displayed low level of incidence and severity of stripe rust regardless of the crop growth stage. The severity of stripe rust on MadaWallabu varied from location to location depending on altitude and growth stage of the variety. A maximum severity of 20S was recorded on MadaWallabu at an altitude of 2410 m asl. In an area with an altitude of 2809 m above sea level an incidence of 100% and a severity of 20SMS were recorded on MadaWallabu.

Stripe rust was quite high at altitudes ranging from 2144 to 2497m asl. Out of the total 120 fields inspected, only 35 (29%) fields were sprayed with fungicides at unknown rates of application.

Table 1. Incidence, severity and prevalence of stripe rust of wheat on major wheat cultivars in Arsi and West Arsi zones of Ethiopia in 2010 season

No.	Variety	Altitude range (masl)	Number of fields	Prevalence (%)	Incidence Range (%)	Severity Range (%)
1.	Kubsa	1660-2689	34	28	0-100	Tr-100
2.	Galama	2295-3000	25	21	40-100	5-100
3.	MadaWallabu	2377-3070	22	18	Tr-100	Tr-20
4.	Tusie	2378-2607	5	4	0-100	Tr-10
5.	Unidentified	2403-3100	5	4	5-100	5-100
6.	K-variety	2477-3011	5	4	10-100	5-80
7.	Mixture	1807-2790	5	4	5-100	Tr-30
8.	Sofummer	2343-2456	4	3	10-100	Tr-40
9.	Digalu	2171-2457	3	2.5	0-10	0-10
10.	Pavon-76	2042-3045	3	2.5	10-100	Tr-20
11.	Hawi	2463-2471	2	1.7	50-100	50-N
12.	K62954A	3003	2	1.7	0-10	0-5
13.	Simba	2451-2626	2	1.7	100	40-80
14.	Enkoy	2934	1	0.8	5	TMS/MR
15.	Batu	2162	1	0.8	60	30
16.	Supremo	2452	1	0.8	0	0

3.2 **Reaction of stripe rust differentials to stripe rust of wheat in 2010 season**

At Kulumssa virulence was detected for stripe rust resistance genes *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17*, *Yr18*, *YrA*, *Yr18+*, *Yr21*, *Yr25*, *Yr27*, *Yr27+*, *Yr27+Yr18*, *Yr28*, *Yr29* and *Yr31*. Effective genes identified during the season were *Yr2+Yr25*, *Yr3+*, *Yr4+*, *Yr5*, *Yr2+Yr6*, *Yr2+Yr6+Yr25*, *Yr10*, *Yr15*, *YrSD+Yr25*, *YrSO*, *YrND(3)*, *Yr32*, *YrSP* and *Yr31*+APR (Pastor).

At Arsi Robe virulence was detected for *Yr1*, *Yr2*, *Yr6*, *Yr6+Yr20*, *Yr7*, *Yr9*, *Yr17*, *YrA*, *Yr18*, *Yr18+*, *YrA+Yr18*, *Yr21*, *Yr25*, *Yr27*, *Yr27+*, *Yr27+Yr18*, *Yr28*, *Yr29* and *Yr31* genes. Whereas genes *Yr2+Yr25*, *Yr3+*, *Yr4+*, *Yr5*, *Yr2+Yr6*, *Yr2+Yr6+Yr25*, *Yr2+Yr9*, *Yr10*, *Yr15*, *YrSD+Yr25*, *YrSO*, *YrND(3)*, *YrCV*, *Yr32* and *YrSP*were effective to the stripe rust populations prevailing in Arsi Robe area.

At Meraro*Yr1*, *Yr2*, *Yr4+*, *Yr6*, *Yr2+Yr6*, *Yr6+Yr20*, *Yr7*, *Yr8*, *Yr9*, *Yr17*, *YrSO*, *YrND*, *YrCV*, *YrA*, *Yr18*, *Yr18+*, *YrA+Yr18*, *Yr21*, *Yr25*, *Yr27*, *Yr27+*, *Yr27+Yr18*, *Yr28*, *Yr29* and *Yr31* were not effective genes of stripe rust in the season. However, *Yr4+*, *Yr5*, *Yr2+Yr6+Yr25*, *Yr2+Yr9*, *Yr10*, *Yr15*, *YrSD+Yr25* and *YrSP* were effective stripe rust resistance genes.

Of the three test locations, Meraro has the widest virulence spectrum for stripe rust of wheat and as a result most of the stripe rust differentials were not effective to the stripe rust populations prevailing at Meraro. Kulumssa and Arsi Robe have comparable virulence spectrum of stripe rust and almost equal number of effective and ineffective genes were identified during the season in both locations. In general, compared to the other cropping seasons, the virulence spectrum of stripe rust has increased in 2010 in all locations and the number of effective genes identified is very low in all locations. The virulence spectrum of stripe rust at Meraro has always been wide because of the favorable environmental condition that prevailed there and the cereal monoculture (in terms of growing susceptible cultivars such as Kubsa and Galama) that is widely practiced in Arsi and West Arsi zones which are among the major wheat-producing zones of the country.

Table 2. Reaction of stripe rust differentials to stripe rust of wheat at Kulumssa, Arsi Robe and Meraro in Ethiopia

Entry	Cultivar/genotype	Yr-gene	Kulumssa	Arsi Robe	Meraro
1.	Yr1/6*Avocet S	*Yr1*	30S	70S	90S
2.	Kalyansona	*Yr2*	20S	70S	90S
3.	Heines VII	*Yr2+*	TR	0	10S
4.	Vilmorin 23	*Yr3a,4a+*	TR	TMS	10MS
5.	Hybrid 46	*Yr4*	TR	0	10S
6.	Yr5/6*Avocet S	*Yr5*	TR	0	0
7.	Triticumspelta	*Yr5*	TR	0	0
8.	Yr6/*6 Avocet S	*Yr6*	60S	80S	90S
9.	HeinesKolben	*Yr6+1*	TR	0	20S
10.	Heines Peko	*Yr6+*	TR	0	0
11.	Fielder	*Yr6,Yr20*	60S	60S	60S
12.	Yr7/6*Avocet S	*Yr7*	60S	80S	90S
13.	Lee	*Yr7*	5MS/S	5MR	80S
14.	Reichersberg 42	*Yr7+*	5S	0	5MS
15.	Thatcher	*Yr7*	50S	5SMS	60S
16.	Yr8/6*Avocet S	*Yr8*	20S	TMS	30S
17.	Compair	*Yr8*	5R	TS	20S
18.	Yr9/6*Avocet S	*Yr9*	60S	70S	90S
19.	Fed.4/Kavkaz	*Yr9*	40S/MS	70S	60S
20.	Clement	*Yr9+Yr2+*	5S	0	5S
21.	Federation	*Yr9*	60S	80S	90S
22.	Yr10/6*Avocet S	*Yr10*	0	5MSMR	30S
23.	Moro	*Yr10*	0	0	5S
24.	Yr15/6* Avocet S	*Yr15*	0	0	0
25.	Yr17/6* Avocet S	*Yr17*	60S	60S	80S
26.	StrubesDickopf	*YrSD, Yr25*	5R	0	0
27.	Suwon 92xOmar	*YrSO*	5R	0	5S
28.	Nord Desprez	*YrND*	5R	0	10S
29.	YrCV/6*Avocet S	*YrCV*	10S	TR	20S
30.	Carstens V	*Yr32*	5R	0	10S
31.	YrSP/6*Avocet S	*YrSP*	5MR	0	5S
32.	Spaldings Prolific	*YrSP*	5R	TR	TMS
33.	Avocet 'R'	*YrA*	60S	90S	90S
34.	Inia66	*YrA*	60S	90S	80S
35.	Avocet 'S'	-	80S	90S	80S
36.	Tres/6*AVS		5R	0	0
37.	Yr18/3 Avocet S	*Yr18*	20S/MS	60S	90S
38.	Jupateco 'R'	*Yr18+*	40S/MS	40S	90S
39.	Jupateco 'S'		60S	60S	90S
40.	Anza	*YrA,Yr18*	60S	N	90S
41.	Cook	*APR*	5MR	5RMR	60S
42.	Lemhi	*Yr21*	80S	80S	90S
43.	TP981		70S	60S	90S
44.	TP1295	*Yr25*	70S	50S	90S
45.	Yr27/6*Avocet S	*Yr27*	70S	20S	80S
46.	Ciano 79	*Yr27*	20S	15MS	40S
47.	Attila CM85836-50Y	*Yr27+*	60S	30S	80S
48.	Opata 85	*Yr27+Yr18*	50S	70S	90S
49.	Avocet-YrA*3/3/Altar84/AE.SQ//Opata	*Yr28*	60S	30S	90S
50.	Lalbahadur/Pavon 1BL	*Yr29*	70S	60S	90S
51.	Avocet-YrA*3/Pastor	*Yr31*	50S	80S	90S
52.	Pastor	*Yr31+APR*	5MR	10MSMR	5MS
53.	Morocco		70S	80S	80S

R=Resistant, MR=Moderately Resistant, MS=Moderately Susceptible, S=Susceptible, N=Necrosis, APR=Adult Plant Resistance

4. Discussion

Ethiopian small-scale wheat farmers did not commonly apply fungicides to control stripe rust of wheat. This has been demonstrated in the 2010 stripe rust epidemic season where a few fields covered in the survey were sprayed with fungicides to control the epidemic. In addition, in those fields where fungicide was applied, the effectiveness was observed to be low. This might be attributed to the lower rate of the fungicide applied than the recommended one; the fungicides might have lost their useful life (expired) or the applied fungicide may not be the one registered and recommended for stripe rust control. A lot of work needs to done with respect to awareness creation on the importance of fungicide intervention whenever rust diseases occur at epidemic proportion throughout the country as the experience of 2010. The resistance of MadaWallabu to the current epidemics of stripe rust may be attributed to the effective *Yr32* gene (Woubit, 2009) rendering resistance to the Ethiopian pathotypes of stripe rust. In addition, the stripe rust differential cultivar carrying the *Yr32* gene (Carstens V) was effective to the prevailing pathotypes of stripe rust in at least the three test locations and hence it was possible to conclude its effectiveness.

Woubit (2009) found *Yr5*, *Yr15* and *Yr26* genes effective against 20 stripe rust races originating from Ethiopia, Germany and France. Similarly bread wheat cultivars such as Wabe and Tusie were also effective to the 20 stripe rust pathotypes collected from the three countries but none of the two cultivars are known to carry the three effective stripe rust resistance genes (Woubit, 2009). Rate of stripe rust development varies from variety to variety in relation to the resistance level of the cultivars (Hailu and Fininsa, 2007).

Sharma-Poudyal*et al*. (2013) reported the effectiveness of *Yr5* and *Yr15* genes to international collections of stripe rust originating from different parts of the world and they have also recommended the use of these two race specific genes in combination with other race-non-specific resistance genes in wheat breeding programs. Stripe rust isolates collected from Kenya in 2006 season were also avirulent to *Yr5*, *Yr15*, *Yr24* and *YrSP* genes (Sharma-Poudyal*et al*., 2013). Because both Ethiopia and Kenya share common epidemiological zones in the east Africa (Nagarajan*et al*., 2012), genes including *Yr5*, *Yr15* and *YrSP* were effective to the stripe rust populations in wheat producing regions of both countries.

Genes *Yr9* and *Yr27* are the most exploited and deployed ones in CIMMYT wheat breeding program and most of the national wheat breeding programs such as Ethiopia whose source of germplasm is CIMMYT developed and released bread wheat cultivars that carry the two stripe rust resistance genes (Ayele*et al*., 1990) and as a result most of the bread wheat cultivars in Ethiopia are susceptible to the prevailing stripe rust pathotypes with virulence to *Yr9* and *Yr27* genes. Virulence for the differential carrying *Yr10* gene was previously reported at Asassa and a moderately susceptible reaction was recorded at Kulumssa and Meraro (Ayele*et al*., 1998). However, this gene was effective at Arsi Robe to the prevailing pathotypes of stripe rust (Ayele*et al*., 1998). Contrary to the current finding, *Yr1* and *Yr17* genes were effective at Asassa, Arsi Robe, Bekoji and Meraro during 1996 season (Ayele*et al*., 1998). Abebe*et al*., (2013) reported the effectiveness of *Yr5*, *Yr10*, *Yr15*, *Yr26* and *YrSP* genes in the northern part of Ethiopia.

Bread wheat varieties such as ET13-A2, Tusie, Tura, Wetera, Sirbo and Simba and breeding lines including HAR2534, HAR2561 and HAR2563 had resistance reactions to two pathotypes of stripe rust (6E16A and 6E22A) and were therefore, recommended to be utilized in stripe rust resistance breeding programs (Shimelis and Pretorius, 2005). However Ayele*et al*. (2008b) reported the susceptibility of ET13A2 to stripe rust pathotype 6E22 originating from Germany. Kubsa which was released in1995 was reported to be susceptible to stripe rust of wheat after it was released for commercial production (Ayele*et al*., 1998). Enkoy and K6295-4A were considered as slow rusting cultivars and they were found resistant to stripe rust of wheat both in the seedling and adult plant growth stages (Ayele*et al*., 1998). Besides, bread wheat cultivars such as Digalu, MadaWallabu and K62954A and Tusie can serve as important sources of resistance to the stripe rust races prevailing in Ethiopia as they were resistant under farmers' fields condition.

The severity of stripe rust epidemics was high in all highland wheat producing regions and it was also severe in the lowland areas of the country. A case in point could be Dhera sub-station, which is a drought prone area and wheat breeding lines are screened for drought tolerance and moisture stress. The severity of stripe rust was high at Dhera during 2010 season. This probably indicates that the aggressive strain of stripe rust of wheat (Milus*et al*., 2009) which has been evolved recently could have been established in Ethiopia. The discovery of the aggressive strain of stripe rust from stripe rust samples collected from different wheat growing areas of Ethiopia has been reported by Hovmoller (2011). This aggressive race has been reported to have additional virulence for *Yr10* and *Yr24* genes (Hovmoller, 2011). Another *Yr27*-virulent race with combined virulence for *Yr1*, *Yr2*, *Yr6*, *Yr7*, *Yr9* and *Yr27* genes and an intermediate reaction on Hybrid46 (*Yr4*)was predominant in the 2010 epidemic in Ethiopia (Hovmoller, 2011).

Digalu was also found to be susceptible to stripe rust at the base of mount Chilalo (> 2500 meters above sea level). Similarly, MadaWallabu was extremely susceptible in high altitude areas of Arsi zone where the altitude exceeds 2800 meters above sea level. It was in 1998 that race 230E158 virulent on Kubsa was detected in Arsi and Bale regions of Ethiopia (Ayele, 2002). This race was also virulent on other CIMMYT originated bread wheat cultivars in Arsi and Bale regions. All the 20 bread wheat cultivars evaluated for resistance to stripe rust race 230E158 were found susceptible in the seedling stage (Ayele*et al*., 2008a). The stripe rust races in Ethiopia have broader virulence spectra and have resulted in the breakdown of many of the resistance genes in wheat cultivars commonly grown (Ayele*et al*., 2008a). Getinet*et al*., (1990) reported Asassa, Bekoji and Sinana to represent the widest virulence spectra. This report is in agreement with the current finding in that two locations Bekoji and Meraro have the widest virulence spectrum to stripe rust of wheat.

5. Conclusion and Recommendation

Breeding for stripe rust resistance in wheat should be a top priority. Bread wheat cultivars including Digalu, MadaWallabu, K62954A and Tusie can serve as important sources of resistance to the stripe rust races prevailing in Ethiopia and they should be included in the crossing blocks of the national wheat breeding research project.

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