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Wheat Leaf Rust (*Puccinia triticina*) Epidemics and Host Plant Response in South Tigray, Ethiopia

Teklay Abebe Teferi
TARI, Alamata Agricultural Research Centre, P.O. Box 56, Alamata, Ethiopia

ABSTRACT

Leaf (brown) rust has been an important wheat disease in Ethiopia. Periodic epidemics are ongoing with grain losses up to 75%. Surveys were conducted in the Tigray area from 2010-2013 to monitor the spatial and temporal dynamics of the leaf rust pathogen population and host response. It was based on inspection of wheat fields randomly selected at 5-10 km intervals along accessible routes. Total 66, 52, 61 and 70 fields were examined in 2010-2013 with prevalence level of 35, 12, 20 and 17%, respectively. The disease incidence and severity reached 100% on Raya-Azebo and Raya-Alamata districts at many locations. The overall mean incidences and severities from 2010-2013 were 24 and 18%, 5 and 20%, 7 and 15% and 13 and 27%, respectively. Fifteen leaf rust differential hosts were found effective to the pathogen populations and could be used as potential sources for the development of resistant varieties.

Key words: Leaf rust, puccinia triticina, wheat, host plant resistance

INTRODUCTION

Cereals in general are the major stable crops in Ethiopia constituting about 78 and 85% of the total cultivated area and total production, respectively. Among which, wheat is one of the major cereals of great economic importance in the country. More than 1.7 Mha of land is allocated for wheat production per year with average productivity of not more than 2.4 t ha^{-1} (CSA., 2013). However, with improved varieties, 5-6 t ha^{-1} productivity is common on research stations and model farmers (MoA., 2011).

Sustainable productivity of wheat is of paramount importance in the context of many biotic and abiotic factors that limit its production. Among the several constraints, for low productivity, the prevalence of number of pathogens infecting the crop is of supreme importance. Diseases are the major threat to wheat production and they are taking heavy toll of the crop in the country and elsewhere in the world (Huerta-Espino *et al*., 2011). The most widely prevalent, notorious and shifty enemies on wheat are the three rusts viz., stem rust (*Puccinia graminis* f.sp. *tritici*), leaf rust (*P. triticina*) and yellow rust (*P. striformis*), which masquerade serious threat to the stability of its production worldwide (Huerta-Espino *et al*., 2011; Admasu *et al*., 2013; Singh *et al*., 2014) and Ethiopia (Eshetu, 1985; Ayele *et al*., 2001; Badebo *et al*., 2008; Shimelis and Pretorius, 2005; Abebe *et al*., 2013; Denbel, 2014). Leaf rust also brown rust caused by *Puccinia triticina* Eriks is a wheat disease of major historical and economic importance worldwide and is the most widespread of three types of rusts causing significant yield losses over large geographical areas (Roelfs *et al*., 1992; Kolmer, 2013; Dadrezaie *et al*., 2013; Singh *et al*., 2014). Yield loss due to leaf rust is variable because of differences in weather conditions, cultivar susceptibility and availability of inoculum. The general consensus is that most of the grain yield losses attributed to leaf rust are due to infection of the flag leaf, which is thought to be responsible for greater than

70% of grain filling. However, grain losses have been significant and estimated to reach 30-70% or even greater on susceptible varieties (Murray *et al*., 1994; Ordonez *et al*., 2010).

In Ethiopia, leaf rust is a wheat disease of major historical and economic importance (Eshetu, 1985; Badebo *et al*., 2008). Yield losses due to leaf rust may be as high as 75% in cases of severe infections (Shimelis and Pretorius, 2005; Badebo *et al*., 2008). In Tigray region, leaf rust is among the top three most important fungal diseases affecting wheat production (Badebo *et al*., 2008). Furthermore, the importance and distribution of diseases in general and leaf rust in particular varied as the result of climate change, pathogen structure and the resistance level of variety grown. Therefore, disease monitoring and surveillance are of paramount significant for sustainable wheat production and tackle food insecurity. In addition, the overall importance of the disease across years and performance of commercial varieties is required. Hence, this report presented the results on the distribution and intensities of leaf rust and the response of commercial wheat cultivars and differentials to the pathogen population in Tigray region.

MATERIALS AND METHODS

Description of the study areas: Tigray forms the northernmost reaches of Ethiopia and is located between 36 and 40°C East longitude and 12.15 and 14°57' North latitude. The region shares common borders with Eritrea in the north, the State of Afar in the east, the State of Amhara in the south and Sudan in the west. The region has six administrative zones; of which, 44% of the area and 46% of the production comes from South Tigray zone (CSA., 2013). Table 1 presents detailed information on the coordinates and climatic conditions of each district during the survey years (2010-2013).

Leaf rust surveillance and monitoring: Wheat leaf rust disease surveys were conducted in five districts of South Tigray from 2010-2013 cropping seasons. The survey trips were made following the main roads and accessible routes in each survey district. During the surveys, in each available wheat field, stops were made at 5-10 km intervals based on vehicle odometers. The leaf rust assessment was made along the two diagonals (in an "X" pattern) of the fields using 0.5×0.5 m (0.25 m^2) quadrants. A minimum of five stops were made in each wheat field depending on the farm size. In each field, plants within the quadrants were counted and recorded as diseased/infected and healthy/non-infected and different parameters were measured as follows after averaged. Disease Incidence (DI) was the proportion of leaf rust infected plants to the total number of plants in the quadrant assessed and it is calculated as:

$$\text{DI (\%)} = \frac{\text{No. of diseased plants}}{\text{Total No. of plants within quadrant (assessed)}} \times 100$$

Table 1: Coordinates and climatic conditions of the districts in the survey years in tigray

		Coordinates (range)		Weather condition (range)	
District	Altitude range (m)	Latitude (N)	Longitude (E)	Rain fall (mm)	Temperature (°C)
Raya-Alamata	1494-2512	12°21'-12°23'	039°20'-039°34'	450-750	12-26
Emba-Alaje	1902-2764	12°52'-12°59'	039°26'-039°33'	481-940	17-28
Enda-Mekoni	2288-2977	12°44'-12°49'	039°31'-039°32'	486-838	11-22
Ofla	1848-2727	12°29'-12°39'	039°16'-039°42'	846-916	11-25
Raya-Azebo	1517-1772	12°39'-12°47'	039°38'-039°42'	422-697	16-29

Sources for rain fall and temperature is Ethiopian meteorological agency (2014)

Severity was scored visually using modified Cobb's scale (Peterson *et al.*, 1948) and host plant response (Roelfs *et al.*, 1992). The prevalence of the disease was computed using the number of fields affected divided by total number of fields assessed and expressed as a percentage. The surveys were made when the crop Growth Stage (GS) was on average between the medium milk and early maturity stages according to Zadoks *et al.* (1974). The results of the survey were summarized by districts and response of cultivars to the disease.

Disease monitoring using trap plots: Thirty six leaf rust differential hosts were planted in 2013 and 2014 main cropping seasons in areas having natural epidemics of leaf rust populations. Each entry was planted in two rows of 1 m length and spaced 20 far apart. Two entries (Morocco and PBW343) were used at every 20 entries as susceptible checks and spreader. Disease severity was noted using the modified Cobb scale (Peterson *et al.*, 1948) and plant response using the method of Roelfs *et al.* (1992).

RESULTS

Prevalence, incidence and severity of leaf rust by district: Leaf rust was found to be the most widely distributed and importance wheat disease across all routes. The results of wheat disease surveys conducted for four consecutive seasons in 66, 52, 61 and 70 fields revealed that the prevalence, incidence and severity of leaf rust varied from lower to complete infection of wheat fields. The overall prevalence of the disease in the five districts was 35 and 12% from 2010-2011 years, respectively (Table 2). The disease was more prevalent in the Raya-Azebo, Raya-Alamata and Emba-Alaje districts with a prevalence of 81, 56 and 27% in 2010, respectively. In contrast, the prevalence was low (13%) in the Ofla district, while, absent in Enda-Mekoni district. In general, the distribution and intensity of the disease was lower during the second year (2011) as compared to the first year (2010). During 2011, the prevalence of the disease was blow 20% in all districts except Ofla which was nonexistent. The maximum possible disease incidence and severity (100%) was noted in Raya-Azebo, Raya-Alamata and Emba-Alaje districts in 2010 (Table 2). The highest

Table 2: Prevalence and intensity of leaf rust in five districts of South tigray from 2010-2011

			Incidence		Severity (%)	
District	Fields inspected	Prevalence (%)	Range	Mean	Range	Mean
2010						
Raya-Azebo	16	81	0-100	57	5-100	25
Raya-Alamata	9	56	0-100	52	5-100	26
Ofla	16	13	0-30	01	Tr-5	Tr
Enda-Mekoni	14	0	0	0	0	0
Emba-Alaje	11	27	0-100	18	10-100	14
Total/mean	66	35	0-100	24	Tr-100	18
2011						
Ofla	16	0	0	0	0	0
Emba-Alaje	11	18	0-100	18	20-80	50
Enda-Mekoni	8	13	0-5	1	Tr-5	5
Raya-Azebo	11	18	0-50	20	Tr-30	20
Raya-Alamata	6	17	0-5	1	Tr-10	10
Total/mean	52	12	0-100	5	Tr-80	20

Tr: Trace

Table 3: Prevalence and intensity of leaf rust in tigray in 2012 main cropping season

			Incidence (%)		Severity (%)	
District	Total field	Prevalence (%)	Range	Mean	Range	Mean
2012						
Raya-Alamata	9	44	0-100	19	5-40	17
Emba-Alaje	10	40	0-15	4	5-25	18
Enda-Mekoni	10	0	0	0	0	0
Ofla	22	5	0-5	1	Tr-15	Tr
Raya-Azebo	10	30	0-100	11	5-50	20
Total/mean	61	20	0-100	7	Tr-50	15
2013						
Ofla	30	10	0-50	3	Tr-20	12
Emba-Alaje	23	17	0-50	5	5-50	24
Enda-Mekoni	7	0	0	0	0	0
Raya-Azebo	4	50	0-100	28	10-100	55
Raya-Alamata	6	33	0-100	30	10-30	20
Total/mean	70	17	0-50	13	Tr-50	27

Tr: Trace

mean incidence (57%) was recorded in Raya-Azebo district followed by the Raya-Alamata district (52%). The mean severity of the disease was 25, 26 and 14% in Raya-Azebo, Raya-Alamata and Emba-Alaje districts, in that order. Emba-Alaje district sustained maximum incidence (100%) and severity (80%) which was consistent with 2010 season. The mean percent severity of the disease varied from 10% in Raya-Alamata and Enda-Mekoni districts to 50% in Emba-Alaje district during the second year, respectively (Table 2).

Of the 61 and 70 wheat fields inspected, 20 and 17% were infected with leaf rust in 2012-2013 seasons, respectively (Table 3). This indicated that the distribution and intensity of leaf rust was present in four districts in both years except one district. Leaf rust was more widely distributed in Raya-Alamata, Emba-Alaje and Raya-Azebo districts with prevalence of 44, 40 and 30%, in 2012, respectively. The prevalence of leaf rust in the former districts was 33, 50 and 17% during 2013, in that order. The prevalence of the disease in Ofla district varied from 5% during 2012 to 10% in 2013 cropping season. The peak incidence range truncated by the maximum possible value (100%) was noted in two districts (Raya-Alamata and Raya-Azebo) at many fields. This indicated the importance of the disease where wheat is grown in these districts. The incidence ranged from 5-50% in Ofla and from 15-50% in Emba-Alaje district for the two consecutive years, respectively. Similarly, the mean incidence of leaf rust was greater than 10% in Raya-Azebo and Raya-Alamata districts. Likewise, the disease severity showed similar trend as the incidence in all the districts. Districts with 30% and more severity range include Raya-Alamata and Raya Azebo in both seasons and Emba-Alaje district in 2013. The mean severity of leaf rust ranged from trace in Ofla district as high as 20% in Raya-Azebo district in 2012. Similarly, Ofla district was with lower mean severity (12%), while, the highest was noted in Raya-Azebo (55%) followed by Emba-Alaje (24%) and Raya-Azebo (20%) districts during 2013 cropping season (Table 3).

Reaction of wheat cultivars to leaf rust populations: The four year surveys showed that the region was mainly composed of improved bread wheat varieties and local cultivars. About 73% of the area was covered by different improved bread wheat varieties and the remaining 27% was

Table 4: Response of wheat varieties to the leaf rust in Tigray from 2010-2013

				Incidence (%)		Severity (%)	
Variety	Altitude range (m)	Total field	Prevalence (%)	Range	Mean	Range	Mean
Kubsa/HAR 1685	2256-2715	33	33	0-100	16	0-100	10 RS
Local	1517-2728	46	80	0-100	39	0-100	22 MSS
Dashen	1585-2557	26	12	0-10	1	0-5	15 MR
Shinna/HAR 1868	2110-2966	12	8	0-10	1	0-15	15 MR
Hawi (HAR 2501)	1522-2577	14	29	0-100	13	0-20	8 MRMS
Digelu	2277-2952	26	4	0-15	1	0-25	10 MRMS
Kakaba	1494-2492	31	16	0-100	7	0-10	5 R
Unknown bread wheat	2125-2952	19	16	0-100	4	0-25	5 MRS
Mekelle 4	2407	1	0	0	0	0	0
Danda'a	2125-2590	20	0	0	0	0	0
Shorima	2531	1	0	0	0	0	0

covered by different local mixtures of durum wheat origin. The response of wheat varieties to leaf rust varied depending on the resistance or tolerance levels of the varieties and specific environmental grown conditions. Generally, about 73% of wheat cultivars were affected by the disease at varied levels of intensity except for three varieties (Mekelle 4, Shorima and Danda'a). The highest prevalence (80%) was noted for local mixtures followed by Kubsa/HAR 1685/(33%) and Hawi/HAR 2501) (29%). The maximum possible incidence 100% was registered for cultivars Kubsa (HAR 1685), local mixtures, Hawi (HAR 2501), Kakaba and unspecified improved bread mixtures (Table 4). In similar way, the severity of the disease was also important in considerable cultivars. The peak severity level (100%) was noted for Kubsa (HAR 1685) and local mixtures indicating their susceptibility to the disease. The reaction of the disease for Kubsa (HAR 1685), local mixture and unspecified bread wheat mixtures exhibited up to susceptible. On the other hand, three cultivars were free of infection from the disease. In addition, some cultivars sustained satisfactory level of resistance (Table 4).

Reaction of wheat differential hosts to leaf rust: In general, leaf rust epidemics were more sever in 2013 than 2014. The response of leaf rust wheat differentials showed that most of Lr genes (58%) were ineffective to the race populations of disease during 2013 (Table 5). Two differentials TC*6/EXCHANGE and TC*6/KENYA1483 were highly susceptible with severity level of 100S. The occurrence of the disease in 2014 was lower as most differentials ranged from resistant to moderately susceptible reaction and with severity level of 5-10% except for THATCHER and SELKIRK/6*TC exhibited susceptible reaction. Fifteen differentials were effective to the pathogen populations during in 2013 (Table 5). These differential hosts were also effective in 2014 cropping season. Therefore, these effective Lr genes could be used in resistant breeding programs against leaf rust populations.

DISCUSSION

The results showed that leaf rust was among the most widely distributed and important disease in many locations across years in Tigray region. About 21% out of 249 wheat fields were affected by the disease. In most fields the incidence and severity of leaf rust was reached 100% in considerable locations within the study areas. Correspondingly, Raya-Azebo, Raya-Alamata and

Table 5: Severity and response of wheat differential hosts to the leaf rust populations

Differentials	2013	2014	Differentials	2013	2014
THATCHER	10S	20S	TC*6/ RL5406 (RL6043)	0	0
TC*6/CENTENARIO	30S	0	TC*6/RL5404 (RL6044)	10S	0
TC*6/WEBSTER	40S	5R	LEE10/6*TC (RL6012)	10S	5R
TC*6/CARINA	30S	0	TC*6AGENT (RL6064)	10S	5R
TC*6/DEMOCRAT	30S	5R	TC*6/ST-1-25	0	5R
TC*6/ANIVERSARIO	40S	5R	GATCHER (W3201)	0	5R
BAGE/8*TC	20S	5R	CS2D-2M	0	5R
TRANSFER/6*TC	40S	0	TC*6/CS7AG#11	0	5R
TC*6/EXCHANGE	100S	5R	TCLR32 (RL5497)	0	0
KUSSAR	50S	5R	TC*6/PI58548	0	10MS
MANITUOU	10S	5R	TC*6/PI58548	0	5R
SELKIRK/6*TC	10S	20S	RL5711	0	5R
TC*6/MARIA	30S	10MS	E84018	0	5R
TC*6/KENYA1483	100S	5R	TC*6/VPM (RL6081)	0	5R
TC*6/EXCHANGE	50S	5R	TC*6/CARINA	0	0
KLEIN LUCERO/6*TC	50S	5R	WL711	0	0
TC*7/AFRICA43	10S	5R	GAZA (W277)	0	0
TC*7TR	5R	10MR	Morocco	80S	10S
THEW(W203)	20S	10MR	PBW343	50S	5R

Emba-Alaje districts was sustained 100% disease incidence at least in one year. Similarly, the severity of the disease was higher in these former districts, whereas, lower development of leaf rust was observed in Ofla and Enda-Mekoni districts. The high epidemics of leaf rust throughout the major wheat growing areas (Raya-Azebo, Raya-Alamata and Emba-Alaje districts) of Tigray in all years was most probably due to the environmental conditions (rainfall and temperature) suitable for development and survival of the disease. The temperature range of most districts was within the optimum requirement for the development of the disease (Table 1). According to Singh *et al.* (2002) and Roelfs *et al.* (1992) report the minimum, optimum and maximum temperature for leaf rust growth and sporulation is 2, 10, 25 and 35°C, respectively. Similarly, the altitude range of the districts could have a positive influence for the development of the disease. The highest level of leaf rust infection has been cited in literatures in the altitude ranges of 1800-2600 m (Kuzmichev *et al.*, 1985; Badebo *et al.*, 2008). According to this study, significant sites were included within this attitude range (Table 1).

The widespread use of resistant cultivars worldwide reduced the disease as a significant factor in production. Although changes in pathogen virulence have rendered some resistances ineffective, resistant cultivars have generally been developed ahead of significant damage. Hence, a number of rust in general and leaf rust specifically resistant varieties have been developed since the beginning of wheat research in Ethiopia (Temesgen *et al.*, 1995). The results of this study revealed that the local mixture cultivars (mainly durum wheat origin) were susceptible to leaf rust as compared to most known improved bread wheat varieties. The high intensity of the disease indicated that could be due to the cultivation of more susceptible cultivars (local mixtures). In addition, the wheat based mono-cropping system and the continuous and extensive cultivation of wheat genotypes with similar genetic background (commonality in parentage) could serve as reemergence for new races of leaf rust that can attack resistant cultivars. This survey result is inline with the findings of Badebo *et al.* (2008) who mentioned that the large proportion of Ethiopian durum wheat accessions/local mixtures were relatively more susceptible to leaf rust population of Ethiopia as compared to the improved bread wheat varieties.

Deploying and growing resistant cultivars is the most practical and economic method to control rust diseases because it is environmentally safe and does not require disease control inputs from the growers (Roelfs *et al.*, 1992; Kolmer, 2003; Herrera-Foessel *et al.*, 2008). This is very important, especially in areas where farmers do not have adequate resources especially for small scale farmers. Hence, enhanced knowledge of the presence and identity of leaf rust resistance genes in breeding materials and cultivars greatly improves the efficiency of developing and deploying resistant cultivars (Kolmer, 2003; Herrera-Foessel *et al.*, 2008). Accordingly, 36 leaf rust resistance genes were included in this study to identify the resistance level under the pathogen population and to utilize them efficiently. As a result, 15 out of 36 the Lr genes were found effective against the leaf rust populations in both seasons. The intensity of the disease is not as much higher than 2014 compared to the 2013 cropping season. This disparity mainly associated with prevailing specific environmental conditions especially rain fall amount and pattern and temperature (Roelfs *et al.*, 1992).

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REFERENCES

Abebe, T., G. Woldeab, W. Dawit, A. Mesele and Y. Nega, 2013. Distribution and seasonal variation in occurrence of wheat stripe rust in Tigray, Ethiopia. Direct Res. J. Agric. Food. Sci., 1: 11-17.

Admasu, B., W. Friedt and F. Ordon, 2013. Amplified fragment length polymorphism of *Puccinia graminis* f. sp. tritici population of Ethiopia. Ethiop. J. Agric. Sci., 23: 1-9.

Ayele, B., A. Alemtaye, G. Bedada and T. Payne, 2001. Double sources of resistance to *Puccinia striiformis* and *P. graminis* f.sp. *tritici*. Proceeding of the 9th Annual Conference CIMMYT Bread Wheat Lines, Volume 9, Jun 22-23, 2001, Addis Ababa, Ethiopia, pp: 11-19.

Badebo, A., B. Eshetu, B. Berhanu, H. Bekele and D. Melaku *et al.*, 2008. Review of two decades of research on diseases of small cereal crops. Proceedings of the 14th Annual Conference of the Plant Protection Society of Ethiopia (PPSE), December 19-22, 2006, Addis Ababa, Ethiopia, pp: 375-429.

CSA., 2013. Crop production forecast sample survey for the year 2013/2014. Central Statistics Agency (CSA), Report on Area and Crop Production Forecast for Major Crops, Addis Ababa, Ethiopia, pp: 7-10.

Dadrezaie, S.T., S. Lababidi, K. Nazari, E.M. Goltapeh and F. Afshari *et al.*, 2013. Molecular genetic diversity in iranian populations of *Puccinia triticina*, the causal agent of wheat leaf rust. Am. J. Plant Sci., 4: 1375-1386.

Denbel, W., 2014. Epidemics of *Puccinia striiformis* f. sp. *tritici* in Arsi and West Arsi zones of Ethiopia in 2010 and identification of effective resistance genes. J. Nat. Sci., 4: 33-39.

Eshetu, B., 1985. A Review of Research on Diseases of Barley, Tef and Wheat in Ethiopia. In: A Review of Crop Protection Research in Ethiopia, Tsedeke, A. (Ed.). IAR, Addis Ababa, Ethiopia, Africa, pp: 79-108.

Herrera-Foessel, S.A., R.P. Singh, J. Huerta-Espino, H.M. William, V. Garcia, A. Djurle and J. Yuen, 2008. Identification and molecular characterization of leaf rust resistance gene Lr14a in durum wheat. Plant Dis., 92: 469-473.

Huerta-Espino, J., R.P. Singh, S. German, B.D. Mccallum and R.F. Park *et al.*, 2011. Global status of wheat leaf rust caused by *Puccinia triticina*. Euphytica, 179: 143-160.

Kolmer, J.A., 2003. Postulation of leaf rust resistance genes in selected soft red winter wheats. Crop Sci., 43: 1266-1274.

Kolmer, J.A., 2013. Leaf rust of wheat: Pathogen biology, variation and host resistance. Forests, 4: 70-84.

Kuzmichev, B., B.V. Anisimoff, A. Masresha and H. Temam, 1985. Influence of altitude on rust diseases of wheat in different agro-climatic zones. Proceeding of the 6th National Crop Improvement Conference, May 23-24, 1985, Addis Ababa, Ethiopia, pp: 816-833.

MoA., 2011. Animal and plant health regulation directorate. Ministry of Agriculture (MoA), Crop Variety Register Issue No. 14, Addis Ababa, Ethiopia, pp: 12-36.

Murray, G.M., P.J. Ellison, A. Watson and B.R. Cullis, 1994. The relationship between wheat yield and stripe rust as affected by length of epidemic and temperature at the grain development stage of crop growth. Plant Pathol., 43: 397-405.

Ordonez, M.E., S.E. German and J.A. Kolmer, 2010. Genetic differentiation within the *Puccinia triticina* population in South America and comparison with the North American population suggests common ancestry and intercontinental migration. Phytopathology, 100: 376-383.

Peterson, R.F., A.B. Campbell and A.E. Hannah, 1948. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res., 26c: 496-500.

Roelfs, A.P., R.P. Singh and E.E. Saari, 1992. Rust Diseases of Wheat: Concept and Methods of Disease Management. CIMMYT, Mexico, DF., Pages: 81.

Shimelis, H.A. and Z.A. Pretorius, 2005. Leaf and stripe rust resistance among Ethiopian grown wheat lines. Sinet: Ethiopian J. Sci., 28: 23-32.

Singh, A., R.E. Knox, R.M. DePauw, A.K. Singh and R.D. Cuthbert *et al.*, 2014. Stripe rust and leaf rust resistance QTL mapping, epistatic interactions and co-localization with stem rust resistance loci in spring wheat evaluated over three continents. Theor. Applied Genet., 127: 2465-2477.

Singh, R.P., J. Huerta-Espino and A.P. Roelfs, 2002. The Wheat Rusts. In: Bread Wheat: Improvement and Production, Curtis, B.C., S. Rajaram and H.G. Macpherson (Eds.). Food and Agriculture Organization, Rome, pp: 227-249.

Temesgen, K., G. Bekele, Y. Balcha and B. Ayele, 1995. Status of Wheat Rusts in the Major Wheat Producing Regions of Ethiopia. In: Breeding for Disease Resistance with Emphasis on Durability, Daniel, D.L. (Ed.). Central and Southern Africa, Njoro, Kenya, pp: 180-184.

Zadoks, J.C., T.T. Chang and C.F. Konzak, 1974. A decimal code for the growth stages of cereals. Weed Res., 14: 415-421.