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Evaluation of Wheat Genotypes for Slow Rusting Resistance to Stripe Rust (*Puccinia Striiformis*) in Afghanistan

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ABSTRACT

Stripe rust (*Puccinia striiformis*) is the most common wheat rust disease in wheat-producing areas of Afghanistan. Durable resistance based on partial resistance is an important, eco-friendly, and effective way to manage stripe rust (*Puccinia striiformis*). The present study was conducted during 2019-20 and 2020-21 to reveal variability for field-based partial resistance to stripe rust among different varieties/genotypes at (ARIA) Research Farm, Bin-Hisar, Kabul. Partial resistance genotypes were evaluated through Final Rust Severity (FRS), Area under Disease Progress Curve (AUDPC), Infection Rate (r), Coefficient of Infection (CI), and Relative Area under Disease Progress Curve (rAUDPC). Genotypes 22, 26, 27, 32, and 43, consistently resistant to stripe rust in both crop seasons, were the most promising. Likewise, the genotypes that showed MS type of reaction and their severity was not beyond the 40MS during both the crop seasons indicated slow rusting behavior were genotypes no 14, 16, 20, 21, 23, 34, and 39. The average infection rate and CDL values of stripe rust development in two crop seasons indicated promising highly resistant and slow rusting behavior of varieties/genotypes.

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Introduction

Stripe rust (*Puccinia striiformis* f. sp. *tritici*, Pst) is a devastating fungal disease that attacks global wheat production. The rapid emergence of virulent Pst races has overcome wheat's known stripe rust resistance genes. Stripe rust of wheat caused by *Puccinia striiformis* f. sp. *tritici* presents a serious problem for wheat production worldwide and has reportedly caused significant yield losses in more than 60 countries (Chen, 2005). The disease can spread quickly, destroying leaf tissue and drastically lowering grain production and quality during epidemics. Stripe rust causes yield losses ranging from 10% to 70% in most wheat-producing locations, depending on the genotype or variety susceptibility, initial infection period, disease development rate, and disease duration. Consequently, the world food supply has been threatened by stripe rust (Strange and Scott, 2005). Until recently, 80 genes related to yellow rust resistance (*Yr*) in wheat were permanently designated. *Yr79* (Feng *et al.,* 2018) and *Yr80* (Nsabiyera *et al.,* 2018) were recently mapped. The most cost-effective and environmentally friendly way to manage the disease is through resistance (Chen, 2007). There are two main types of resistance to stripe rust: adult plant resistance (APR), which is expressed at later stages of plant growth, and all-stage resistance (also known as seedling resistance), which is expressed at all stages of plant growth and may be identified at the seedling stage. The most efficient, cost-effective, and environmentally responsible method of preventing wheat stripe rust is developing and using resistance genes in wheat breeding (Chen, 2005). The best practical and eco-friendly way to control the disease is still to cultivate resistant cultivars. The area under the disease progress curve (AUDPC), which can be computed by recording disease severity at weekly intervals, can be used to assess slow-rust resistance Wilcoxson, (1981).

The aim of the present study is:

- To find wheat genotype for adult plant resistance (APR) to stripe rust (Puccinia striiformis).

Materials and Methods

Plant materials

Wheat varieties/genotypes (Table 1) were evaluated under field conditions at Bin-Hisar Research Farm of Agricultural Research Institute of Afghanistan (ARIA), Bin-Hisar, Kabul, for two successive seasons (2019-20 and 2020-21).

Disease scoring

After the disease started, plants in each row had their disease records made every seven days until the leaves were green. The Modified Cobb's Scale (Paterson *et al.*, 1948) was utilized to record the severity of the disease at various intervals, while the disease response, or the type of infection, was recorded in the following manner:

Final rust severity (FRS)

Wheat genotypes were categorized using final rust severity (FRS) into three groups: 1-35% as moderately resistant, 36–65% as moderately susceptible, and 66–90% as susceptible.

Coefficient of disease level (CDL) determination

To quantify the rust observations, disease rating, disease incidence, and the coefficient of disease level were calculated. The average rate coefficient of disease level estimate shows the relative resistance variables and genotypes, and it involves both the reaction (response) and the proportion of infection. It is computed from the rust readings under conditions in the field. According to Loegering (1969), reaction (response) values range from 0 to 1 for each form of infection.

The coefficient of disease level (CDL), as per Gupta's (1979) explanation, is calculated for every genotype or variety.

CDL = MCIx UIV

CDL = Coefficient of disease level

UIV = Unit incidence value

MCI = Modified coefficient of infection

Where,

$$\text{Unit Incidence Value} = \frac{\%\ incidence}{100}$$

$$\text{Modified Coefficient of Infection} = \frac{\text{Loegering's coefficient of infection}}{100}$$

Where,

Loegering's Coefficient of Infection = Response value x Severity

The maximum CDL will be 1.0. The CDL values were used to analyze the infection rate (r).

Infection rate (r) determination

The infection rate for disease progression was calculated using a formula devised by Vander Plank (1963).

$$r = \frac{2.3}{t} \left(\log_{10} \frac{X_2}{1-X_2} - \log_{10} \frac{X_1}{1-X_1} \right)$$

Where,

r = Average infection rate of disease per day

t = Total days between the first and last date of observation of the disease.

X_1 = CDL value at the first date of disease observation

X_2 = CDL value at the last date of disease observation

Where,

X_1 and 1- X_2 are the correction factors, and one is considered the maximum disease.

The area under disease progress curve (A-values)

The area under disease progress curve computed for the varieties/genotypes using the formula Wilcoxson et al. mentioned in 1975

$$A = \sum \frac{K}{i=1} \, {}^{1}\!/_{2} \, (S_i - S_{i-1})$$

Where,

Si = Rust severity at the end of the week, and

K = Number of successive evaluations of rust.

Results

Screening of varieties and genotypes

Four wheat varieties (Kabul 13, Koshan, Mazzar99, Dehdadi), 49 genotypes, and Morocco were evaluated for stripe rust resistance. The first symptom of stripe rust was observed on 24^{th} April 2020 in the experimental plots. Thus, stripe rust severity and infection type data were recorded weekly from 24^{th} April to 10^{th} June 2020. In the 16^{th} SMW of disease observation on 24^{th} April 2020, stripe rust severity varied from 0.0 to 1.00 percent. Maximum stripe rust severity was recorded on the Morocco (1S) and genotype no 10 (1S), 37 (1S), and 47 (1S) (Table 3). At the end of the 21^{st} SMW on 3^{rd} June 2020, maximum stripe rust was contracted by the variety Morocco (100S) followed by genotype no 10, 28, 37, 38, and 47 with 60S disease severity. In contrast, minimum stripe rust severity was observed on genotype no 1 (5R), 2 (5R), 7 (5R), 12 (1R), 22 (5R), 27 (5R), 43 (5R), 44 (5R), 8 (10R), 9 (10R), 30(10R) and 31 (10R). Genotypes 26, 32, 45, 46, and 49 had no stripe rust infection. During next year's crop season, the first stripe rust was observed in the 17^{th} SMW (24^{th} April 2021), and the severity of stripe rust ranged from 0.0 to 1.00 percent. The maximum stripe rust severity was recorded in Morocco (1S) (Table 3). Final rust severity observed at the end of 23^{th} SMW (5^{th} June 2021), maximum stripe rust observed on variety Morocco (100S) followed by genotype no10 and 28 (60S), 38 (50S), and 29, 37, 47 and variety Koshan were having 40S disease severity whereas, minimum stripe rust severity found on the genotype no 22 (5R), 43 (5MR), 26 (10MR), 32 (10MR) and 43 (10MR). Only genotype no 27 was free from stripe rust infection. On the 24^{th} SMW (12^{th} June 2021), all the varieties and genotypes of stripe rust severity and infection type remained as of 5^{th} June 2021 (Table 3).

The experimental results of stripe rust revealed higher resistance and slow rusting varieties/ genotypes based on two crop seasons, 2019 and 2021. Most promising resistant wheat varieties/genotypes consistently expressed resistance to stripe rust in both crop seasons. Genotypes 22, 26, 27, 32, and 43 exhibited high resistance to stripe rust. Similarly, genotypes that showed MS infection-type reaction and their severity were not beyond the 40MS during both crop seasons indicated slow rusting behavior and included genotypes 14, 16, 20, 21, 23, 34, and 39.

Average area under disease progress curve (A-values)

Average AUDPC (A-values) significantly varied among different varieties/genotypes during the 2019-20 crop season. Morocco (395.50) showed the highest A-values followed by genotype no 10 (182), 37 (178.50), 38 (188.50) and 47 (204.50). Lowest A-values found in the genotype no1 (2.2), 2 (1.9), 7 (1.9), 12 (2.45), 22 (2.5), 27 (2.5), 43 (2.7) and 44 (3.1) and were statistically similar, while A-values shown in the genotype no 26, 32, 45, 46 and 49 were almost zero/nil(Table 3). During 2020-21, significantly different A-values were obtained among varieties and genotypes, ranging from 2.45 to 395.50. The highest A-values were found in Morocco (395.50), followed by genotype no 11 (172.5), 28 (159.8), and 38 (137.4), while the lowest A-values expressed in genotype no 22 (2.45) and 46 (5.7) and were statistically at par. Statistically equal, very low A-values were found in genotype no 26 (9.4), 32 (7.1), and 43 (9.4), whereas A-values in genotype no 27 were almost zero (Table 3). Genotypes 22, 26, 27, 32, 43, and 46 were identified as most promising based on lower A-values of stripe rust during both crop seasons.

Table 1 Wheat varieties/genotypes used in the experiment (Source: CIMMYT 39th ESWYT)

Sr. No.	Varieties/genotypes	Sr. No.	Varieties/genotypes
1	MXI17-18\MTES&BESTLBW\10	28	MXI17-18\M39ES26SA17H\139
2	MXI17-18\MTES&BESTLBW\44	29	MXI17-18\M39ES26SA17H\140
3	MXI17-18\MTES&BESTLBW\14	30	MXI17-18\M39ES26SA17H\150
4	MXI17-18\M39ES26SA17H\1	31	MXI17-18\M39ES26SA17H\153
5	MXI17-18\M39ES26SA17H\5	32	MXI17-18\M39ES26SA17H\167
6	MXI17-18\M39ES26SA17H\29	33	MXI17-18\M39ES26SA17H\173
7	MXI17-18\M39ES26SA17H\40	34	MXI17-18\M39ES26SA17H\177
8	MXI17-18\M39ES26SA17H\42	35	MXI17-18\M39ES26SA17H\188
9	MXI17-18\M39ES26SA17H\43	36	MXI17-18\M39ES26SA17H\203
10	MXI17-18\M39ES26SA17H\47	37	MXI17-18\M39ES26SA17H\211
11	MXI17-18\M39ES26SA17H\54	38	MXI17-18\M39ES26SA17H\214
12	MXI17-18\M39ES26SA17H\57	39	MXI17-18\M39ES26SA17H\218
13	MXI17-18\M39ES26SA17H\59	40	MXI17-18\M39ES26SA17H\223
14	MXI17-18\M39ES26SA17H\61	41	MXI17-18\M39ES26SA17H\229
15	MXI17-18\M39ES26SA17H\76	42	MXI17-18\M39ES26SA17H\233
16	MXI17-18\M39ES26SA17H\90	43	MXI17-18\M39ES26SA17H\240
17	MXI17-18\M39ES26SA17H\95	44	MXI17-18\M39ES26SA17H\249
18	MXI17-18\M39ES26SA17H\103	45	MXI17-18\M39ES26SA17H\250
19	MXI17-18\M39ES26SA17H\108	46	MXI17-18\M39ES26SA17H\254
20	MXI17-18\M39ES26SA17H\112	47	MXI17-18\M39ES26SA17H\258
21	MXI17-18\M39ES26SA17H\113	48	MXI17-18\M39ES26SA17H\270
22	MXI17-18\M39ES26SA17H\120	49	MXI17-18\M39ES26SA17H\273
23	MXI17-18\M39ES26SA17H\122	50	Morocco
24	MXI17-18\M39ES26SA17H\130	51	Kabul#13
25	MXI17-18\M39ES26SA17H\131	52	Koshan
26	MXI17-18\M39ES26SA17H\135	53	Mazzar#99
27	MXI17-18\M39ES26SA17H\137	54	Dehdadi

Table2. Rust infection types at adult plant stage by Roelfs *et al.* (1992)

Reaction Types	Response value	Category	Visible Symptoms
0	(0.0)	Immune	No visible infection on the plant
R	(0.2)	Resistant	Necrotic areas with or without minute uredia present
MR	(0.4)	Moderately resistant	Small uredia present surrounded by necrotic areas
MS	(0.8)	Moderately susceptible	Medium uredia with no necrosis but possibly some distinct chlorosis
S	(1.0)	Susceptible	Large uredia with no necrosis and little or no chlorosis present
X	(0.6)	Intermediate	Variable-sized uredia, some with necrosis and/or chlorosis and some fully susceptible

Table3. Final rust severity, average area under disease progress curve (A-values), coefficient of disease level (CDL), and apparent infection rate "r" of stripe rust in different varieties and genotypes during 2019-20 and 2020-21 crop seasons at Kabul

		2019-20				2020-21			
Entry no	Genotype no	Final Rust Severity 10/06/2020	Average AUDPC (A-values)	Coefficient of Disease Level 10/06/2020	Infection rate "r"	Final Rust Severity 12/06/2021	Average AUDPC (A-values)	Coefficient of Disease Level 12/06/2021	Infection rate "r"
1	1	5 R	2.2	0.0005	0.043230261	20 MS	50	0.032	0.122798872
2	2	5 R	1.9	0.0005	0.043230261	20 MS	38.8	0.032	0.100396859
3	3	10 MS	15	0.006	0.035427274	20 MS	50.8	0.032	0.100396859
4	4	40 MS	54.4	0.088	0.156426827	30 MS	65.6	0.072	0.11778814
5	5	20 MS	25.2	0.024	0.084900082	30 MS	60	0.072	0.108449141
6	6	20 MS	24.4	0.024	0.129697582	20 MS	44.4	0.032	0.08288505
7	7	5 R	1.9	0.0005	0.043230261	20 MS	37.2	0.032	0.067568473
8	8	10 MR	6.3	0.003	0.101003391	20 MS	46.7	0.032	0.151060054
9	9	10R	4.1	0.002	0.061104265	30 MS	65.6	0.072	0.11778814
10	10	60 S	182	0.36	0.143190831	60 S	172.5	0.36	0.176024121
11	11	30S	79	0.09	0.085352098	20 S	47.5	0.04	0.122967638

12	12	5 MR	2.45	0.0007 5	0.0726 9747	20 MS	38.8	0.032	0.1003 96859
13	13	20 MS	24	0.024	0.0640 60409	20 MS	50.8	0.032	0.1003 96859
14	14	40 MS	70	0.128	0.1367 80261	30 MS	62.8	0.072	0.1177 8814
15	15	40 S	113.75	0.16	0.1315 46022	30 S	81.7	0.09	0.1451 38279
16	16	40 MS	89.2	0.128	0.1531 87921	20 MS	40	0.032	0.1227 98872
17	17	20 MS	24.4	0.024	0.1296 97582	30 MS	64	0.072	0.1401 90153
18	18	10 MS	9.4	0.006	0.1010 64446	20 MS	38.8	0.032	0.1003 96859
19	19	50 S	140	0.25	0.1653 57576	30 S	83.5	0.09	0.1451 38279
20	20	40 MS	76	0.128	0.1531 87921	40 MS	78.8	0.128	0.1307 85908
21	21	40 MS	86.4	0.128	0.1602 53318	30 MS	62.2	0.072	0.1215 02362
22	22	5R	2.5	0.0005	0.0656 2738	5 MR	2.45	0.0007 5	0.0726 9747
23	23	40 MS	100	0.128	0.1531 87921	40 MS	100.4	0.128	0.1203 59535
24	24	40 S	112.5	0.16	0.1539 49668	30 S	77.8	0.09	0.1451 38279
25	25	40 S	96.5	0.16	0.1539 49668	30 S	81.7	0.09	0.1451 38279
26	26	TR	0	0	0	10 MR	9.4	0.004	0.0715 5969
27	27	5 R	2.5	0.0005	0.0656 2738	TR	0	0	0
28	28	60 S	171	0.36	0.1760 24121	60 S	159.8	0.36	0.1581 71353
29	29	20 MS	25.6	0.024	0.1296 97582	40 MS	98.8	0.128	0.1307 85908
30	30	10 MR	6.7	0.003	0.1010 03391	20 MS	38.8	0.032	0.1003 96859
31	31	10 MR	5.7	0.003	0.1010 03391	20 MS	31.6	0.032	0.1074 6552
32	32	TR	0	0	0	10 MR	7.1	0.004	0.0752 75137
33	33	40 MS	49.6	0.088	0.1564 26827	20 MS	74.8	0.032	0.1003 96859

34	34	30 MS	61.2	0.072	0.140190153	20 MS	34.6	0.032	0.107462256
35	35	40 MS	86	0.128	0.153187921	30 MS	66.8	0.072	0.11778814
36	36	40 S	112.5	0.16	0.153949668	30 S	83.2	0.09	0.126450488
37	37	60 S	178.5	0.36	0.176024121	40 S	97.7	0.16	0.158498913
38	38	60 S	188.5	0.36	0.176024121	50 S	137.4	0.25	0.137078435
39	39	20 MS	38	0.032	0.122798872	20 MS	31.4	0.032	0.114530917
40	40	40 S	117.5	0.16	0.153949668	20 S	46.2	0.04	0.127516883
41	41	50 S	156	0.25	0.165357576	40 S	92.2	0.16	0.158498913
42	42	20 MS	29.6	0.024	0.129697582	10 MS	18	0.008	0.094039658
43	43	5 MR	2.7	0.0015	0.086842757	10 MR	9.4	0.004	0.07155969
44	44	5 MR	3.1	0.0015	0.04204852	20 MS	24.4	0.024	0.129697582
45	45	0	0	0	0	20 MS	25.6	0.024	0.129697582
46	46	0	0	0	0	5 MS	5.7	0.0015	0.02791487
47	47	60 S	204.5	0.36	0.176024121	40 S	123.8	0.16	0.158498913
48	48	10 MS	12.6	0.006	0.101064446	30 MS	56.4	0.072	0.107361767
49	49	TR	0	0	0	20 MS	25.2	0.024	0.084900082
50	Morcco	100 S	395.5	0.99	0.281425736	100 S	395.5	0.995	0.281425736
51	Kabul #13	20 MS	26	0.024	0.115566787	40 MS	91.4	0.128	0.127434732
52	Koshan	40 S	115.4	0.16	0.113694886	40 S	117	0.16	0.121116377
53	Mazzar#99	30 S	110.3	0.09	0.145138279	30 S	81.8	0.09	0.122736266
54	Dehdadi	30 S	83.5	0.09	0.118185389	30 S	92.4	0.09	0.112309893
CD at 5%			**10.57**	**0.012586126**	**0.016860619**		**8.58**	**0.003186209**	**0.02353213**

Coefficient of disease level (CDL) and average infection rate 'r' per day

CDL values and the infection rate "r" per day were calculated from stripe rust severity data, as shown in Table 3. Stripe rust was first observed in the experimental plots on April 22, 2019, in Morocco and on genotypes nos. 10, 15, 37, and 47, where the disease was rated as 1S at that time. At the end of the 23rd SMW of stripe rust observation, i.e., June 10, 2020, statistically different CDL values were recorded in various varieties and genotypes. The highest CDL value (0.99) was recorded in Morocco, followed by genotype nos. 10 (0.36), 19 (0.25), 28 (0.36), 37 (0.36), 38 (0.36), 41 (0.36), and 47 (0.36). The lowest CDL values were obtained in genotype nos. 1, 2, 7, 12, 22, and 27.

The average infection rate was highest (0.28143) in Morocco and in genotypes nos. 28, 37, 35, and 38. At the same time, it was lowest in genotype no. 3. Statistically similar, lower infection rates were observed in genotypes nos. 1, 2, 7, and 44. CDL values and average infection rates were zero in genotypes nos. 26, 32, 45, 46, and 49 (Table 3). Terminal CDL values and the average infection rate "r" were lower in genotype nos. 1, 2, 3, 7, 12, 27, 43, and 44.

Stripe rust was first observed in the experimental plots on April 24, 2021, in Morocco, rated 1S. By the end of the 24th SMW, stripe rust was observed on June 12, 2021, and statistically different CDL values were recorded in different varieties and genotypes. Morocco retained the highest CDL values of 0.995, followed by genotypes nos. 10 (0.36), 28 (0.36), and 38 (0.36). The lowest CDL value was in genotype no. 22. The average infection rate "r" was highest (0.28143) in Morocco, followed by genotypes nos. 8, 10, 28, 37, and 47, while it was lowest in genotype no. 46 (0.02791). Similar lower infection rates were observed in genotypes 6, 7, 22, 26, 32, and 43. CDL values and average infection rates "r" were zero in genotype no. 27. Terminal CDL values and the average infection rate "r" were lower in genotype nos. 22, 26, 32, 43, and 44. The CDL values and average rate of infection "r" over two crop seasons, 2019-20 and 2020-21, differentiated the highly resistant and slow rusting varieties/genotypes. Wheat varieties/genotypes that consistently had lower CDL values and average infection rates "r" during both crop seasons were the most promising rust-resistant genotypes, including genotypes nos. 26, 27, 32, 43, and 43.

Discussions

Stripe rust (*Puccinia striiformis f. sp. tritici*, Pst) is a devastating fungal disease that affects much of global wheat production. The rapid emergence of virulent Pst races has overcome most known stripe rust resistance genes in wheat. Stripe rust caused by *Puccinia striiformis f. sp. tritici* presents a serious problem for wheat production worldwide, reportedly causing significant yield losses in more than 60 countries (Chen, 2005). The disease can spread quickly, destroying leaf tissue and drastically reducing grain production and quality during epidemics. Stripe rust causes yield losses ranging from 10% to 70% in most wheat-producing regions, depending on genotype or variety susceptibility, initial infection period, disease development rate, and duration. The most cost-effective and environmentally friendly way to manage the disease is through resistance (Chen, 2007).

There are two main types of resistance to stripe rust: adult plant resistance (APR), which is expressed at later stages of plant growth, and all-stage resistance (also known as seedling resistance), which is expressed at all stages of plant growth and may be identified at the seedling stage. The most efficient, cost-effective, and environmentally responsible method of preventing wheat stripe rust is developing and using resistance genes in wheat breeding (Chen, 2005). The best practical and eco-friendly way to control the disease remains to cultivate resistant cultivars.

Experimental trial results on stripe rust indicate high resistance and slow rusting behavior of varieties/genotypes during the 2019 and 2021 crop seasons in Kabul. The most promising resistant wheat varieties/genotypes exhibiting high resistance to stripe rust were genotype nos. Both crop seasons are 22, 26, 27, 32, and 43. Similarly, genotypes nos. 14, 16, 20, 21, 23, 34, and 39 expressed slow rusting behavior and an MS infection-type reaction. Their disease severity did not exceed 40MS during both crop seasons.

The area under the disease progress curve (AUDPC), which can be computed by recording disease severity at weekly intervals, can be used to assess slow-rust resistance (Wilcoxson, 1981). Average AUDPC (A-values) varied significantly among genotypes and varieties during Kabul's 2019-20 crop season. The highest A-values were observed in Morocco (395.50), followed by genotypes nos. 10 (182), 37 (178.50), 38 (188.50), and 47 (204.50). The lowest A-values were obtained in genotypes nos. 1 (2.2), 2 (1.9), 7 (1.9), 12 (2.45), 22 (2.5), 27 (2.5), 43 (2.7), and 44 (3.1), which were statistically similar, while A-values retained in genotypes nos. 26, 32, 45, 46, and 49 were almost zero/nil.

Significantly different A-values were expressed in the progression of stripe rust among varieties and genotypes, ranging from 2.45 to 395.50. Morocco (395.50) acquired the highest A-values, followed by genotypes nos. 11 (172.5), 28 (159.8), and 38 (137.4), while the lowest A-values were noted in genotype nos. 22 (2.45) and 46 (5.7), which were statistically at par. Statistically equal, very low A-values were recorded in genotype nos. 26 (9.4), 32 (7.1), and 43 (9.4), while the A-value in genotype no. 27 was almost zero.

Wheat varieties/genotypes that consistently had lower CDL values and average infection rates "r" during both crop seasons were the most promising rust-resistant genotypes, including genotypes nos. 26, 27, 32, 43, and 43. The CDL values and average infection rates "r" for stripe rust development over the two crop seasons, 2019-20 and 2020-21, differentiated the highly resistant and slow rusting varieties/genotypes.

The area under the disease progress curve (A-values), explained by Wilcoxson et al. (1975), measures slow rusting or partial resistance (Nayar et al., 2003) in various varieties/genotypes of wheat during the 2019-20 and 2020-21 crop seasons, clearly indicating resistance and slow rusting behavior. Varieties/genotypes that consistently obtained lower

A-values for stripe rust development in Kabul during both crop seasons—genotypes nos. The most promising genotypes were 22, 26, 27, 32, 43, and 46.

A low infection frequency and slow infection rate are important characteristics of slow rusting, as reported by Yang et al. (1987). Infection frequency has been used as a component of rust resistance in wheat varieties by Luo and Zeng (1988). Slow rusting can be confirmed by calculating the average infection rate or measuring the area under the disease progress curve (Nayar et al., 2003). They added that AUDPC is the best parameter for computing slow rusting, while slow-rust R-values are a less useful criterion (Rees et al., 1979).

Vander Plank (1984) documented that slow-rusting genotypes/varieties remained stable over the years and were free from boom-and-bust cycles. Sawhney and Mehta (1998) suggested that it would discourage the selection of virulent types and confer durability for rust resistance.

The CDL values and average infection rates for stripe rust progression addressed Kabul's highly resistant and slow-rust varieties/genotypes. Stripe rust-resistant wheat varieties/genotypes nos. 26, 27, 32, 43, and 43 consistently expressed lower CDL values and average infection rates during the 2019-20 and 2020-21 crop seasons, proving the most promising in Kabul.

Conclusion

The resistance responses of the wheat cultivars and genotypes varied, ranging from immunity to slow rusting resistance. When exposed to significant disease pressure, most of the assessed cultivars and genotypes performed better, as evidenced by the susceptibility check. Genotypes no. 22, 26, 27, 32, and 43 consistently showing resistance to stripe rust in both the crop seasons were most promising. Likewise, the genotypes that showed MS type of reaction and their severity was not beyond the 40MS during both the crop seasons indicated slow rusting behavior were genotypes no 14, 16, 20, 21, 23, 34, and 39. In Afghanistan, the wheat breeding program may use the slow-rusting cultivars/genotypes found in this study with higher levels of slow-rusting resistance for durable resistance. Such natural resistance is cost-effective, enduring, and environmentally safe to tackle the new races of *Pst. It* will be immensely important to safeguard future wheat varieties against the deadly pathogen (Ullah *et al*., 2016).

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