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Screening of Stripe Rust Resistance in Bread Wheat (*Triticum aestivum* L.) Genotypes

Heena Attri* and Tuhina Dey

Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, India

**Corresponding author*

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A B S T R A C T

Durable resistance based on partial resistance is an important and effective way to combat yellow rust (*Puccinia striiformis*). The present study was carried out during *Rabi* 2016-17 and 2017-18 to reveal variability for field-based partial resistance to yellow rust among different genotypes, F_1, $F_2$and three-way crosses grown at University Research Farm, SKUAST-Jammu. Partial resistance screening was screened 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). IC 535352 genotype was found to be resistant than other genotypes with 4 % Coefficient of Infection (CI). Strong association was found between Area Under Disease Progress Curve (AUDPC) and Coefficient of Infection (CI) while too weaker association reported between Coefficient of Infection (CI) and Infection Rate (r). The present study revealed enough diversity regarding slow rusting behavior and yellow rust resistance ranging from resistant to susceptible lines. Thus, FRS, AUDPC, CI and r are suggested to be useful for screening partial resistance to stripe rust.

Introduction

Stripe rust (*Puccinia striiformis* f. sp. tritici, Pst) is a devastating fungal disease that attacks much of global wheat production. The rapid emergence of virulent Pst races has overcome most of the known stripe rust resistance genes in wheat. Stripe rust of wheat caused by *Puccinia striiformis* west. 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).Epidemics of the disease can rapidly destroy leaf tissue and significantly reduce grain yield and quality. In most wheat-producing areas, yield losses caused by stripe rust range from 10 to 70% depending on the degree of susceptibility of the cultivar, timing of the initial infection, rate of disease development and duration of disease.

Accordingly, stripe rust has been a threat to global food security (Strange and Scott 2005). Till recently, 80 yellow rust resistance (*Yr*) genes have been permanently named in wheat, including the recently mapped *Yr79* (Feng *et al.,* 2018) and *Yr80* (Nsabiyera *et al.,* 2018). Resistance is the most economical and environmentally friendly approach to control this disease (Chen, 2007).

Resistance to stripe rust is broadly categorized as: all stage resistance (also called seedling resistance), which can be detected at the seedling stage, but is also expressed at all stages of plant growth; and adult plant resistance (APR), which is expressed at later stages of plant growth. Development and use of resistance genes in wheat breeding is the most effective, economic and environmental friendly approach for controlling stripe rust of wheat (Chen, 2005).

The cultivation of resistant varieties remains the most economic and environmentally preferable method to manage this disease. Up-to-date, 80 genes and alleles of leaf rust resistance genes in wheat have been mapped to chromosome location and given gene designations McIntosh *et al.,* (2012). Some of the resistance genes are effective at seedling stage and they are race specific. Several of these genes may become ineffective due to the emergence of new virulent races and also because of rapid evolution and adaptation of pathogen Kolmer *et al.,* (2008).

In contrast, others are effective through the adult plant stage and are referred to as slow rusting genes and they are race non-specific provide durable resistance or a broad spectrum of races. Therefore, a cultivar that only has slow rusting resistance to leaf rust will display susceptible infection type response throughout the entire lifecycle of the plant (Fahmi *et al.,* 2005).

Slow rusting resistance can be measured in the field by recording disease severity at weekly intervals and then calculating the area under disease progress curve (AUDPC) Wilcoxson, (1981).

Materials and Methods

Plant materials

Wheat varieties (Table 1) were evaluated under field conditions at University Farm of Division Plant Breeding and Genetics, Faculty of Agriculture, SKUAST-Jammu, Chatha for two successive seasons (2016-17 and 2017-18).

Disease scoring

The disease was recorded in five plants in each row after the disease initiated (10 Feb, 2016) at 10 days interval till the leaves were green. Disease severity was recorded using Modified Cobb's Scale (Paterson *et al.,* 1948) at different intervals, whereas the disease response (type of infection) was recorded as under:

Observations

Final rust severity (FRS)

Final rust severity (FRS) was used to classify wheat germplasm into different group such as 1-35 per cent as moderately resistant, 36-65 per cent as moderately susceptible and 66-90 per cent as susceptible.

Coefficient of infection (CI)

Coefficient of infection was calculated by using data on disease severity and host reaction by multiplying the severity value by a value of 0.10, 0.4,0.8 or 1.00 for host response rating of R, MR, MS or S, respectively (Pathan and Park, 2006).

AUDPC and rAUDPC value

AUDPC (Area under Disease Progress Curve) and rAUDPC (Relative Area under Disease Progress Curve) values were calculated as

(Milus and Line, 1986)

$$UDPC = N1\frac{(X_1 + X_2)}{2} + N_2\frac{(X_2 + X_3)}{2} + N_3\frac{(X_3 + X_4)}{2}$$

Where, X_1, X_2, X_3 and X_4 are rust intensities recorded on first, second, third and fourth recording date and N_1 is interval day between X_1 and X_2

N_2 is interval day between X_2 and X_3
N_3 is interval day between X_3 and X_4

$$rAUDPC = \frac{\text{line AUDPC}}{\text{Susceptible AUDPC}} \times 100$$

Infection Rate (r)

Infection rate (r) was calculated as (Broers, 1989)

$$r = \frac{2.303}{t_2 - t_1} \left(\log \frac{X_2}{X_1}\right)$$

Where,

X_1, X_2 are rust intensities recorded on first and second recording date

t_1 = interval day between X_1 and X_2
t_2 = interval day between X_3 and X_4

Results and Discussion

Screening of genotypes used as parents, F_1's and F_2's against stripe rust in wheat under field conditions

Eleven genotypes used in hybridization were screened against stripe rust at University Research Farm Chatha during *Rabi* 2016-17. The progress of disease was recorded at 10 day interval in all the selected germplasm from onset of the disease (10th February) till dough stage (1st April). The data is presented in Table 4.4 and 4.5 reveal that the disease severity gradually increased from (0) on 10th February, 2017 to 80 % at the end of cropping season with maximum disease severity of 80 per cent recorded in genotype EIGN 79. Based on Final Rust Severity, the parents, F_1's and F_2's were grouped into low (1-30%), moderate (31-50) and high level (51-80%) of resistance. The genotype IC 535352 and ten F_1's and F_2's exhibited low final rust severity (FRS) ranging from 1-30% while six other genotypes *viz*., EIGN 61, EIGN 76, EIGN 82, RSP 561, Raj 3765 and PNC 306 along with fifteen F_1's and F_2's exhibited moderate final rust severity (31-50%). Four genotypes namely EIGN 29, EIGN 79, WH 1080 and EIGN 31 and three F_1's and F_2's *viz.*, EIGN 29 x WH 1080, EIGN 79 x RSP 561 and EIGN 82 x WH 1080 showed high level of final rust severity (51-80%).

Evaluation of parents, F_1's and F_2's for slow rusting parameters against stripe rust (*Puccinia striiformis*) in wheat

All the parents, F_1's and F_2's used in the study were characterized for slow rusting resistance against *Puccinia striiformis* on the basis of parameters AUDPC (Area Under Disease Progress Curve), rAUDPC (Relative Area Under Disease Progress Curve and CI (Coefficient of Infection) during 2016-17. The data has been presented in Table 4.4 and 4.5.

AUDPC

The stripe rust resistant genetic stock *viz.*, IC 535352 had AUDPC of 75 and was classified as resistant. None of the F_1's or F_2's were grouped with AUDPC in the range of 1-100 to be classified as resistant. Eight genotypes *viz*., EIGN 31, Raj 3765, EIGN 79, EIGN 61, EIGN 29, RSP 561, PNC 306 and EIGN 76 were observed to be moderately resistant with AUDPC ranging from 101 to 500. All the F_1's except EIGN 79 x WH 1080 were moderately resistant with AUDPC (101-500). Two genotypes WH 1080 and EIGN 82 and one F_1 (EIGN 79 x WH 1080) showed high AUDPC (501-1000) which may be classified as susceptible. Relative AUDPC of IC535352 was 11.53 while EIGN 61, Raj 3765 and EIGN 31 ranged (31-50).Seven F_1's had rAUDPC value below 50 indicating moderate resistant possessed by them.

Coefficient of infection

Disease severity and host reaction was combined to calculate coefficient of infection (CI). Data reveal nine genotypes and five F_1's had low coefficient of infection (below 10). Among F_2 populations from these five F_1's only two (EIGN 61 x Raj 3765 and EIGN 79 x WH 1080) observed low coefficient of infection.

Based on AUDPC and rAUDPC and CI values in the F_1 and F_2 two crosses EIGN 61 x Raj 3765 and EIGN 61 x WH 1080 are the potential crosses which generated transgressive segregants for stripe rust resistance.

Evaluation of three way crosses for slow rusting parameters under field conditions in chatha

Twenty seven three-way crosses were screened against stripe rust disease at University Research Farm Chatha during *Rabi* 2017-18. The progress of disease was recorded at 10 day interval in all the crosses from 13th February till the dough stage (4th April). Data presented in Table 4.7 revealed that the disease severity increased from 5% to 55% by the end of the cropping season. Based on FRS (Final Rust Severity), the three- way crosses were classified with low (1-30%), moderate (31-50%) and high (51-80%) low severity. Slow rusting resistance against *Puccinia striiformis* is determined based on AUDPC, rAUDPC and coefficient of infection. Seventeen three-way crosses exhibited low final rust severity (FRS) in the range of 1-30% with least disease severity recorded in EIGN 29 x WH 1080 x IC 535352. AUDPC, rAUDPC and CI of this cross is 75, 4 and 15, respectively, indicating low disease severity along with slow rusting trait.

Table.1 Description of F_1's and Genetic stocks

S. No.	**F_1's**	**S. No.**	**F_1's**
1.	EIGN 29× RSP 561	**8.**	EIGN 76 ×Raj 3765
2.	EIGN 29 ×Raj 3765	**9.**	EIGN 76 ×WH 1080
3.	EIGN 29 × WH 1080	**10.**	EIGN 79 ×RSP 561
4.	EIGN 61 × RSP 561	**11.**	EIGN 79 × Raj 3765
5.	EIGN 61 × Raj 3765	**12.**	EIGN 79 × WH 1080
6.	EIGN 61 ×WH 1080	**13.**	EIGN 82 × RSP 561
7.	EIGN 76 × RSP 561	**14.**	EIGN 82 × WH 1080
Genetic stocks		**Related traits**	**Genes postulated**
1.	IC 535352	Stripe rust resistance	*Yr 18, Yr 15 and Yr10*
Adapted commercial varieties			
1.	RSP 561		
2.	Raj 3765		
3.	WH 1080		

Table.2 Pedigree of the genotypes

S.No.	Genotypes	Source	Pedigree
1.	EIGN 29	25thHRWSN2105	ND643/2*WBLL1/4/CHIBIIA//PRLII/CM65531 /3/SKUAZ/BAV42/5/BECARD
2.	EIGN 61	13thHTWYT719	MUTUS*2/HARIL#1
3.	EIGN 76	22ndSAWYT316	MUTUS*2//ND643/2*WBLL1
4.	EIGN 79	22ndSAWYT323	KACHU//WHEAR/SOKOLL
5.	EIGN 82	22ndSAWYT333	PAURAQ//ND643/2*WBLL1/3/PAURAQUE#1
6.	RSP 561	SKUAST-Jammu	HD 2687/*Ae. crassa* //HD 2637
7.	WH 1080	SKUAST-Jammu	PARULA/2*PASTOR
8.	Raj 3765	SKUAST-Jammu	HD 2402/VL 639
9.	IC 535352	IIWBR, Karnal	Stripe rust resistance

Table.3 Stripe Rust (Cobb's scale)

Reaction	Observations	Response Value
No disease	O	0.0
Resistant	R	0.2
Resistant to Moderately resistant	RMR	0.3
Moderately resistant	MR	0.4
Moderately resistant to moderately susceptible	MRMS	0.6
Moderately susceptible	MS	0.8
Moderately susceptible to susceptible	MSS	0.9
Susceptible	S	1.0

Table.4 AUDPC based identification of stripe rust in bread wheat genotypes

S.No.	Genotypes	AUDPC	r	CI	rAUDPC
1	**EIGN 29**	450	0.069	24.00	69.2
2	**EIGN 61**	300	0.069	8.00	46.1
3	**EIGN 76**	500	0.0470	32.00	76.92
4	**EIGN 79**	350	0.069	10.00	53.84
5	**EIGN 82**	650	0.0405	45.00	100
6	**RSP 561**	400	0.0811	24.00	61.50
7	**Raj 3765**	325	0.069	12.00	50
8	**WH 1080**	600	0.0824	42.00	92.3
9	**C 306**	375	0.0470	24.00	57.62
10	**EIGN 31**	325	0.1178	12.00	50.00
11	**IC 535352**	75	0.069	4.00	11.53

Table.5 Various ranges of AUDPC in bread wheat genotypes

Range	Genotypes
0	Nil
1-100	IC 535352
101-500	EIGN 31, Raj 3765, EIGN 79, EIGN 61, EIGN 29, RSP 561, C 306 and EIGN 76
501-1000	WH 1080 and EIGN 82

Table.6 AUDPC based identification of stripe rust in F_1 and F_2 generation of bread wheat

Crosses	AUDPC		r		CI		rAUDPC	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
EIGN 29 x RSP 561	400	200	0.069	0.1098	24.00	4.80	66.66	33.33
EIGN 29 x Raj 3765	350	300	0.0336	0.0811	8.00	24.00	58.3	50
EIGN 29 x WH 1080	300	400	0.0356	0.0559	24.00	8.00	50	66.66
EIGN 61 x RSP 561	300	250	0.069	0.0847	24.00	6.00	50	41.66
EIGN 61 x Raj 3765	200	250	0.1098	0.0619	6.00	10.00	33.33	41.66
EIGN 61 x WH 1080	200	200	0.1386	0.0510	24.00	12.00	33.33	33.33
EIGN 76 x RSP 561	350	250	0.1098	0.0980	42.00	10.00	58.33	41.66
EIGN 76 x Raj 3765	200	225	0.069	0.0875	65.00	10.00	33.33	37.5
EIGN 76 x WH 1080	300	425	0.0470	0.0287	10.00	32.00	50	70.83
EIGN 79 x RSP 561	325	175	0.0847	0.0916	24.00	32.00	54.16	29.16
EIGN 79 x Raj 3765	250	175	0.069	0.0559	32.00	8.00	41.16	29.16
EIGN 79 x WH 1080	600	225	0.0916	0.069	8.00	4.80	100	37.5
EIGN 82 x RSP 561	175	225	0.058	0.055	65.00	24.80	29.16	37.5
EIGN 82 x WH 1080	400	200	0.082	0.069	8.00	24.00	66.66	33.33

Table.7 Various ranges of AUDPC in F_1 and F_2 generation in bread wheat

Range	F_1	F_2
0	Nil	Nil
0-100	Nil	Nil
101-500	EIGN 82 x RSP 561, EIGN 61 x Raj 3765, EIGN 61 x WH 1080, EIGN 29 x RSP 561, EIGN 29 x Raj 3765, EIGN 29 x WH 1080, EIGN 61 x RSP 561, EIGN 76 x RSP 561, EIGN 76 x Raj 3765, EIGN 76 x WH 1080, EIGN 76 x RSP 561. EIGN 79 x Raj3765 and EIGN 79 x WH 1080	EIGN 82 x RSP 561, EIGN 61 x Raj 3765, EIGN 61x WH 1080, EIGN 29 x RSP 561, EIGN 29 x Raj 3765, EIGN 29 x WH 1080, EIGN 61 x RSP 561, EIGN 76 x RSP 561, EIGN 76 x Raj 3765, EIGN 76 x WH 1080, EIGN 76 x RSP 561. EIGN 79 x Raj 3765, EIGN 79 x WH 1080 and EIGN 82 x WH 1080
501-1000	EIGN 82 x WH 1080	Nil

Table.8 Per cent disease severity during the cropping season at different intervals in bread wheat genotypes

Genotypes	10th Feb	20th Feb	2nd March	12th March	22nd March	1st April (FRS)	Mean
EIGN 29	5	10	20	25	30	60	25.00
EIGN 61	5	10	15	20	30	50	20.83
EIGN 76	0	Tr	10	15	20	45	18.00
EIGN 79	5	10	20	30	40	80	30.83
EIGN 82	Tr	10	15	20	25	50	24.00
RSP 561	0	5	10	15	20	40	15.00
Raj 3765	0	Tr	5	10	15	35	13.00
WH 1080	5	15	20	30	35	60	27.50
IC 535352	0	0	Tr	Tr	5	10	3075
EIGN 31	0	5	10	15	20	65	19.16
C 306	5	10	15	20	25	40	19.16

Table.9 Per cent disease severity during the cropping season at different intervals of F_1 and F_2 generation in bread wheat

Crosses	10th Feb		20th Feb		2nd March		12th March		22nd March		1st April (FRS)		Mean	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
EIGN 29 x RSP 561	Tr	0	5	0	15	Tr	20	5	30	10	50	30	19.16	9.00
EIGN 29 x Raj 3765	0	0	5	Tr	5	5	10	15	20	20	50	40	13.33	17.00
EIGN 29 x WH 1080	Tr	0	5	0	10	5	15	10	20	20	40	60	18.00	17.00
EIGN 61 x RSP 561	Tr	0	5	Tr	10	5	15	10	20	15	40	35	15.00	13.00
EIGN 61 x Raj 3765	0	0	0	Tr	Tr	5	5	10	10	15	30	35	9.00	13.00
EIGN 61 x WH 1080	0	0	0	0	Tr	5	5	10	10	15	30	25	9.00	9.16
EIGN 76 x RSP 561	Tr	0	5	0	10	Tr	15	5	20	10	50	40	20.00	11.00
EIGN 76 x Raj 3765	5	0	10	Tr	15	5	25	10	30	15	50	25	22.5	11.00
EIGN 76 x WH 1080	0	0	0	Tr	Tr	5	5	10	10	15	30	40	9.00	12.00
EIGN 79 x RSP 561	0	Tr	0	5	5	10	15	20	20	25	40	60	11.66	24.00
EIGN 79 x Raj 3765	Tr	0	5	Tr	10	5	20	10	25	15	40	20	20.00	10.00
EIGN 79 x WH 1080	0	0	Tr	0	5	Tr	10	5	15	10	35	25	13.00	8.00
EIGN 82 x RSP 561	5	0	15	5	25	10	35	15	40	20	80	35	33.33	14.16
EIGN 82 x WH 1080	0	0	0	Tr	Tr	5	5	10	10	15	25	30	8.00	12.00

Fig.1 Association between Coefficient of infection and AUDPC

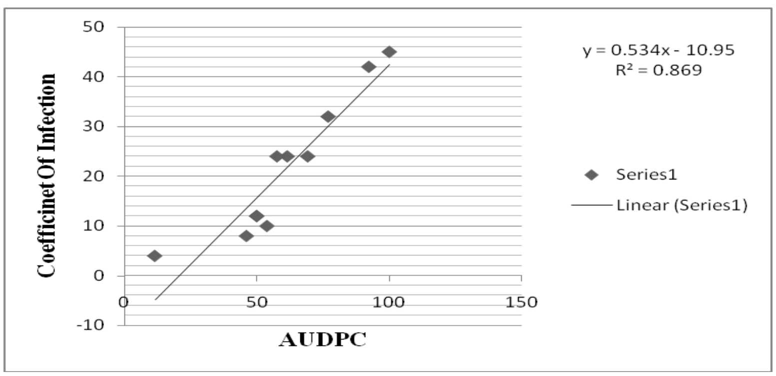
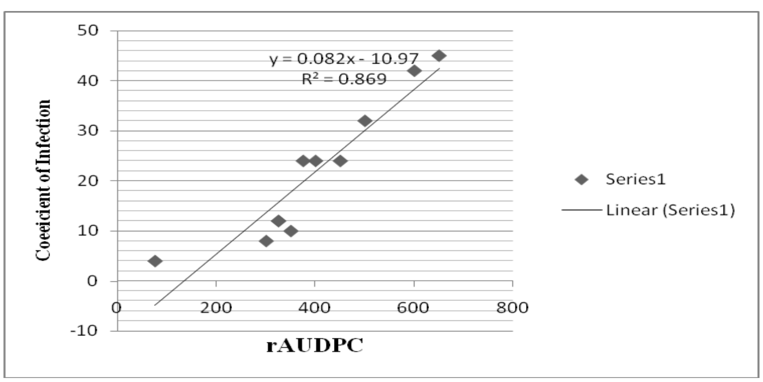


Fig.2 Association between Coefficient of infection and rAUDPC



AUDPC, rAUDPC and Coefficient of infection (CI)

Data presented in Table 4.8 indicate that based upon AUDPC, only one three- way cross namely EIGN 29 x WH 1080 x IC 535352 with AUDPC (75). The AUDPC value of all the other crosses were in the range of 101-500, being moderately resistant. Relative AUDPC of five three way crosses and CI of fourteen crosses indicated moderate resistance. The three other crosses with moderate level of slow rusting are EIGN 29 x Raj 3765 x PNC 306, EIGN 79 x Raj 3765 x IC 535352 and EIGN 79 x WH 1080 x IC 535352.

The genotype IC 535352 is one of genetic stock for stripe rust resistance. The F_1 desirable for stripe rust resistance is EIGN 61 x Raj 3765. The three-way $F_{1,}$ derived from this cross for stripe rust resistance shows moderate level of resistance and slow rusting. The mean final rust severity decreases from F_1 to F_2 in all crosses implying that selection has been effective in identifying resistant plants in F_2. Similar findings were reported by Ali *et al.*, (2008) and Shahin *et al.*, (2011). Parlevleit, (1988) recorded that breeding lines with low value of AUDPC, rAUDPC, CI and r were expected to possessed genes that conferred partial resistance. During the study positive relation of coefficient of infection (CI) with rAUDPC and AUDPC each having R^2 value of 70 per cent which was found to be in agreement with findings of Safavi *et al.*, (2010), who recorded strong association between Coefficients of infection (CI) as found with rAUDPC having R^2 value of 91 per cent.

The best combination imparting stripe rust resistance is EIGN 29 x WH 1080 x IC 535352 which is highly resistant based on AUDPC in line with the AUDPC of IC 535352 this cross further indicate the transfer of further gene from the genetic stock as the F_1 (EIGN 29 x WH 1080) does not show such level of resistance. Such results of transfer of resistance gene using genetic stock have also been reported by Niks *et al.*, (2011). The other crosses with moderate level of resistance along with high grain yield is shown by EIGN 29 x Raj 3765 x PNC 306, EIGN 79 x RSP 561 x IC 535352, EIGN 79 x WH 1080 x EIGN 31. None of the resistant F_1's could turn into resistant three-way F_1's when used in combination with IC 535352.

In conclusion the present study reveals that the genotypes were having enough diversity regarding partial resistance ranging from resistant to susceptible. The genotype IC 535352 and cross EIGN 82 x RSP 561 found to be more resistant. Thus, can be used as donor parent for developing disease resistant genotypes. The positive association of coefficient of infection (CI) with rAUDPC and AUDPC with R^2 value of 70 per cent in genotypes.

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