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Evaluation of Bread Wheat (*Triticum aestivum* L.) Genotypes for Yellow Rust Resistance in Relation to Meteorological Parameters

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ABSTRACT

Three bread wheat varieties (*Triticum aestivum* L.), i.e., HD 2967, WH 711 and PBW 343, were grown in randomised block design with four replications under field conditions over two years in winter season at wheat and Barley Research farm, at CCS Haryana Agricultural University Hisar to evaluate the stripe rust severity in relation to meteorological factors like minimum and maximum temperature (°C) and relative humidity (%), rainfall (mm), soil temperature (°C), canopy temperature (°C), cloud cover (Okta), wind speed (km/h), sunshine hours (h/day) and morning and evening vapour pressure (mm Hg). Observations were recorded on five randomly selected plants in each replication on stripe rust severity as percent leaf area covered using Modified Cobb's scale. Results revealed that low temperature (10-12°C) and high relative humidity (90%) along with intermittent rainfall were found conducive for the onset of stripe rust. Low temperature and moderate humidity favored the disease initiation and development. At the initiation of disease, the severity was more in PBW 343 (0.68%) followed by WH711 (0.59%) during first SMW whereas HD 2967, exhibited disease initiation during 2^{nd} SMW with 2.19% severity. Disease progression was also different in different wheat varieties. Disease gradually advanced with the crop age, and increased sharply from 15.00 to 38.00% in HD 2967, 27.50 to 46.00% in WH711 and 35.00 to 43.6% in PBW 343 during 6-8^{th} Standard Meteorological Week, when the crop was at stem elongation to jointing stage, i.e., GS 36-47 (64-78 DAS). Yield loss due to disease severity was estimated to be 356 kg/ha, 690 kg/ha and 400 kg/ha in wheat varieties HD2967, WH711 PBW343, respectively. Step-wise multiple regression showed high R^2 value of 0.885, 0.919 and 0.952 for the predictive model of stripe rust in HD 2967, WH 711 and PBW 343, respectively

Keywords**:** Stripe rust, bread wheat, *Triticum aestivum* L., temperature, rainfall, relative humidity

Introduction

Bread wheat is one of the most important cereal crops meeting daily calorie need of about 35% population worldwide. Although bread wheat has a wide range of climatic adaptability, but it is usually affected by many fungal diseases, the most devastating of which is the rust. Stripe (yellow) rust is widespread disease across the major bread wheat growing regions with diverse cropping systems, growing seasons and germplasm characteristics (Wellings, 2011). The worldwide loss in bread wheat production due to stripe rust has been estimated to be at least 5.5 million tonnes per year. (Beddow et al. 2015). Globally, the epidemics of stripe rust was reported in United States (Line, 2002), Australia (Wellings et al. 2000), Middle East (Akar et al. 2007), New Zealand and China, (Chen et al. 2009) while in South Asia (India, Pakistan and Nepal), the yield loss was reported moderate to high over the years (Singh et al. 2004). The yield loss was usually due to the result of poor root growth, reduced dry matter, low test weight, reduced kernel number size and quality (Wellings, 2011).

Stripe rust caused by the obligate biotroph *Puccinia striiformis*, is a serious fungal disease of bread wheat, especially under the cool and moist conditions (Chen et al. 2014). The minimum temperature for the occurrence of stripe rust infection is 0°C, optimum 11°C and maximum 23°C (Curtis et al. 2002), however, due to the changed climate conditions occasionally, yellow rust predominated over leaf rust (Jevtić et al. 2017).

To avoid epidemics and yield loss, breeding for disease resistance is the main strategy for the management of diseases (Chen et al. 2014). Bread wheat cultivars become susceptible to rusts due to their narrow genetic base and the rapid evolution of new pathogen races, making it necessary for the search of new resistance sources. An effective and economical approach to reduce yield loss caused by the diseases is the development of disease resistant varieties. The disease severity is determined by the congeniality of pre-disposing meteorological factors and/or abiotic stresses such as drought and salinity affecting plant, water relationships, besides genetic factors in wheat varieties. (Pandey et al. 2017). To develop an effective management strategy for the management of stripe rust, it is essential to evaluate key factors involved in initiation and progress of diseases. Understanding of meteorological parameters is prerequisite for providing baseline information to develop simple and reliable disease prediction system. Keeping this fact in view, it is imperative to develop a location specific reliable prediction system for stripe rust in bread wheat. The present paper deals with stripe rust severity in three wheat varieties in relation to prevailing meterological conditions and to develop a model for prediction of disease severity in semi-arid conditions.

Materials and Methods

Three bread wheat (*Triticum aestivum* L.) varieties, i.e., HD 2967, WH711 and PBW 343, were grown in randomized block design with four replications under field conditions over two years in winter season at Wheat and Barley Research farm, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University Hisar to evaluate the effect of different meterological factors and stripe rust severity. These selected varieties were sown under late sown conditions in first week of December in plots of 8 m^2 size at a row spacing of 22.5 cm with 12 lines in each plot. The infector rows were placed after the interval of 10 lines as border rows of the experiment to ensure uniform infection. Inoculums were sprayed at tillering stage with urediniospores of *Puccinia striformis* (concentration 10^{-6} spore/ml). Plants were screened under epiphytotic conditions and data in terms of per cent leaf area infected were recorded by using Modified Cobb's Scale (Peterson et al. 1948) on five randomly selected plants until crop maturity (14^{th} Standard Meteorological Week). Disease severity was recorded in terms of per cent leaf area infection, and pustule type was recorded as response.

The effect of different meteorological factors *viz*., minimum and maximum temperature (°C), minimum and maximum relative humidity (%), rainfall (mm), soil temperature (°C), canopy temperature (°C), cloud cover (Okta), wind speed (km/h), sunshine hours (h/day) and morning and evening vapour pressure (mm Hg) were studied on the development of stripe rust in bread wheat. The Meteorological data of one week prior to the date of observation were collected from the meteorology department of CCS Haryana Agricultural University Hisar. The canopy temperature was recorded with infrared thermometer (Ramson make) and soil temperature with soil thermometer (Japson make) at the depth of 5, 10 and 20 cm. During both the seasons, from the last week of December onward, the selected varieties in the experimental plots were monitored regularly for the initial foci of *Puccinia striiformis.*

Statistical analysis

To determine the cumulative effect of meteorological parameters and prediction of stripe rust severity, multiple stepwise regression was computed to generate models through SPSS 16.0 (Cornell and Berger 1987), having coefficient of determination (R^2) and F_{cal} value e< 0.0001. The correlation coefficients (r) were determined to find the effect of single as well as combined meteorological parameters on the severity of stripe rust in bread wheat as proposed by Madden, 1986). Further, the graphs of recorded and predicted values were determined by the stepwise regression model to evaluate the accuracy of equations in predicting the disease.

Results and Discussion

Effect of meterological factors on stripe (yellow) rust of bread wheat

The disease severity *vis-a-vis* meteorological parameters in all the selected bread wheat varieties exhibited that under late sown conditions appeared in 1^{st} Standard Meteorological Week, when the crop was at tillering stage GS 21, i.e., 28 days after sowing (Table 1). The minimum and maximum temperature was 7°C and 18°C, minimum and maximum relative humidity 49 and 92%, sunshine 2.9 h/day, morning and evening cloud cover 3.8 and 6.5 okta, mean wind velocity1.5 km/h, morning and evening vapour pressure 7.2 and 9.0 mmHg, soil temperature 11.4°C and canopy temperature 13.4°C. Singh et al. (2002) reported that minimum, optimum and maximum temperature for urediniospores penetration, growth and sporulation in host were 2, 12-15 and 23, 3, 12-15 and 20 and 5, 12-15 and 20°C, respectively. deVallavielle-Pope et al. (2002) documented that urediniospores infection by *Puccinia striiformis* was higher under the conditions of long light hours and prolonged clear sky. It was reported that yellow rust would predominate over leaf rust if requirement for high winter temperature was met (Hovmøller et al. 2016).

At the initiation of disease, the severity was more in PBW 343 (0.68%) followed by WH711 (0.59%). In HD 2967, the disease appeared in 2nd SMW with 2.19% severity, when crop was at late tillering stage GS 36 (36 DAS). Thereafter, disease gradually advanced with the crop age, but increased sharply from 15.00 to 38.00% in HD 2967, 27.50 to 46.00% in WH711 and 35.00 to 43.6% in PBW 343 during 6-8th Standard Meterological Week, when the crop was at stem elongation to jointing stage, i.e., GS 36-47 (64-78 DAS). This coincided with minimum and maximum temperature of 8.2-10.6 and 19.5-23°C, minimum and maximum relative humidity of 51-62 and 81-97%, mean wind velocity of 3.0-1.2 km/h, morning and evening vapour pressure of 11.0-13.5 and 12.5-16.0 mmHg, sunshine of 3.6-6.8 h/day, morning and evening cloud cover of 6.8-4.0 and 3.0-1.5 okta, soil and canopy temperature of 13.8-15.9 and 17.0-18.6°C.

At the milk development stage, i.e., GS 75 (120 DAS) in 14th Standard Meteorological Week, maximum disease severity was recorded in WH711 (74.0%) followed by PBW 343 (73.2%) and HD 2967 (61.5%), during which, the minimum and maximum temperature was 11.1 and 28.0°C, minimum and maximum relative humidity 46.5 and 81.0%, mean wind velocity 5.3 km/h, morning and evening vapour pressure 8.5 and 14.0 mmHg, sunshine 9.4 h/day, rainfall 18.3 mm, morning cloud cover 1.0 okta and soil and canopy temperature 20.6 and 24.8°C, respectively. Chen et al. (2014) also reported that cool and moist conditions with low temperature (7-12°C) were favourable for stripe rust epidemic. The minimum temperature of 11.7°C coupled with 8.2 h of bright sunshine per day was found favourable for faster development of stripe rust of bread wheat (Singh and Tewari, 2001).

Correlation of meterological factors with the severity of stripe rust

Correlation coefficient between various meteorological factors and stripe rust were computed, which revealed that in HD 2967, the minimum and maximum temperature, morning and evening vapour pressure, canopy temperature, soil temperature and age had significantly positive correlation with the disease severity (0.836, 0.848, 0.685, 0.836, 0.812, 0.936 and 0.978), respectively (Table 2). In WH711 and PBW 343, the 'r' value was 0.843, 0.844, 0.700, 0.856, 0.830, 0.926 and 0.992, and 0.859, 0.846, 0.705, 0.844, 0.850, 0.922 and 0.990, respectively. The maximum relative humidity had significantly negative correlation with the disease severity in the tested varieties, wherein the correlation coefficients were -0.636, -0.651 and -0.650 respectively. Likewise, correlation coefficients for the three varieties between disease severity and rainfall were 0.550, 0.546 and 0.513, respectively indicating positive association. Ahmed et al. (2010) recorded strong correlation of minimum and maximum temperature and sunshine radiation with stripe rust. Christensen et al. (1993) found that temperature in January and February was significantly correlated with the severity of stripe rust in bread wheat. Chen., (2005) recorded that moisture enhanced spores' germination and infection, but the availability of free water inhibited infection by reducing the viability and survival of the pathogen. Yield reduction was observed in tested bread wheat varieties due to stripe rust (Table.4). In general, a variable yield loss was observed in tested varieties due to different levels of stripe rust severity at anthesis (Fig. 2).

Development of predictive model

Results of this study have been used to develop a predictive model for predicting the possible incidents and severity of the yellow rust in different varieties of wheat cultivated in north west plain zone of India. The model is based on analysis of variance, correlation and regression coefficients among, meteorological parameters and disease severity. In WH711, the model was highly significant, having F_{cal} (3, 10)= 38 at $p \leq 0.01$ in predicting severity of stripe rust with R^2 value of 0.919. This indicated that cumulative effect of minimum temperature, maximum temperature including rainfall explained 91.90% variation. The results revealed an increase or decrease in disease severity by 0.90% per week by per unit increase or decrease in rainfall, if all the other parameters remained congenial (95% CI from 0.03 to 1.80%), whereas, 2.77 and 3.82% increase or decrease in disease severity was predicted per week by per unit increase or decrease in maximum and minimum temperature, if all the other parameters remained favourable (95% CI from 1.20 to 4.33 and 1.83 to 5.82%), respectively. The contribution of minimum and maximum temperature and rainfall in the prediction model was 51, 37 and 12%, respectively. Plotting of observed versus predicted value of disease severity (Fig. 1a) showed good association (R^2= 91.90%).

In HD 2967, the developed model for predicting severity of stripe rust was highly significant having F_{cal}(2,11)= 42 at $p \leq 0.01$, explaining 88.50% variation in the prediction model by minimum and maximum temperature. The contribution of minimum and maximum temperature was 43 and 57%, respectively. The observed versus predicted disease severity value (Fig.1b) showed good association (R^2= 88.50%). It further revealed that, in PBW 343, the prediction model was highly significant, having F_{cal} (3,10)= 73 at $p \leq 0.01$, with R^2 value of 0.952, which indicated that 95.20% variation was due to canopy temperature, morning vapour pressure and rainfall having contribution of 34, 52 and 24%, respectively. Plotting of observed versus predicted value of severity (Fig.1c) exhibited good association (95.20%). The prediction models developed through stepwise multiple regression analysis depicted that under late sown conditions the maximum and minimum temperature, vapour pressure and canopy temperature and rainfall variables were found to account for approximately 85-97% variation. In all the three developed prediction models, temperature was the key variable, which influenced the stripe rust severity and epidemics. Coakley et al. (1988) also developed model for the prediction of stripe rust based on temperature, total precipitation and frequency of precipitation for susceptible cultivar (Omar). The best model describing disease severity of *stripe* rust consisted of maximum temperature and rainfall with R^2 value of 86.40% (TeBeest et al. 2009). Jarroudi et al. (2017) reported that the prediction models are useful in predicting the yellow rust severity, so that the appropriate management strategies can be adopted.

Conclusions

Yellow rust resistance has assumed significance in recent years in North-West plain zone of India due to climate change and consequent combination of pre-disposing factors like low and high temperatures, relative humidity, vapour pressure deficit, sunshine etc. The importance of wheat breeding for yellow rust resistance has been realized in recent years to avoid yield losses to ensure higher wheat production for food security. In present study, three wheat varieties grown extensively in the region have been investigated for severity of the yellow rust *vis-a-vis* meteorological parameters. Attempts have been made to develop a prediction model based on stepwise multiple regression using data on meteorological parameters and yellow rust severity. All the three varieties established significance of different meteorological parameters being rainfall, temperature and vapour pressure deficit. Future attempts are needed to develop comprehensive prediction model by including more variables for meteorological parameters like radiation intensity, photoperiod, number of spores in ambient air monitored through spore trap, *Yr* genes, pustules number and size onset of disease infection and consequent disease progression. Such a model will be useful in developing a management strategy integrating genotypic variability for yellow rust resistant genes, yield attributes and grain yield *per se* as well as agronomic factors such as staggered sowing so that the disease severity could be kept controlled or bare minimum for sustainable production of wheat.

Table 1. Effect of different meteorological factors on the severity of stripe rust of bread wheat (pooled data).

SMW	Disease Severity in Bread Wheat Varieties			Age (days)	C_{Temp} (°C)	T_{max} (°C)	T_{min} (°C)	RH_{Max} (%)	RH_{Min} (%)	M_{WV} (km/h)	Vp_{Mor} (mmHg)	Vp_{Evn} (mmHg)	SS (h)	Rainfall (mm)	CC_{Morn} (okta)	CC_{Evn} (okta)	S_{Temp} (°C)
	HD2967	WH711	PBW343														
1st	0.00	0.59	0.68	28.0	13.4	18.0	7.0	92.0	49.0	1.5	7.2	9.0	2.9	0.0	3.8	6.5	11.4
2nd	2.19	3.17	3.17	36.0	14.0	14.7	5.8	94.0	68.5	2.0	8.3	9.3	0.8	0.6	6.5	5.0	11.8
3rd	3.83	5.50	7.50	43.0	15.0	15.7	4.3	95.0	71.0	4.8	7.3	10.1	7.2	0.0	0.5	0.5	11.6
4th	6.50	11.67	10.83	50.0	14.9	16.0	7.9	91.5	75.0	1.6	9.3	11.0	0.0	5.0	3.0	5.0	13.3
5th	10.00	17.50	24.17	57.0	17.5	20.6	4.6	91.5	50.5	2.0	9.4	12.1	4.7	0.0	2.0	1.5	13.2
6th	15.00	27.50	35.00	64.0	18.6	19.5	10.6	81.0	62.0	3.0	11.0	12.5	3.6	0.0	6.8	3.0	13.8
7th	25.00	38.33	40.00	71.0	20.3	22.6	6.1	93.0	48.5	2.1	10.7	12.8	6.2	0.0	2.5	2.5	14.9
8th	38.00	46.00	43.60	78.0	17.0	23.0	8.2	97.0	51.0	1.2	13.5	16.0	6.8	0.0	4.0	1.5	15.9
9th	40.00	50.00	50.00	85.0	18.0	17.5	11.7	88.5	77.0	1.9	13.3	14.8	0.5	0.0	5.0	5.0	14.8
10th	43.33	55.00	55.00	92.0	18.1	21.5	9.3	89.5	54.0	3.0	12.4	12.3	5.9	14.6	2.0	2.5	15.1
11th	48.33	60.00	60.00	99.0	17.2	22.7	9.4	81.0	52.0	2.2	11.8	13.7	4.7	9.8	4.0	4.0	16.8
12th	53.33	63.33	65.00	106.0	22.2	27.5	11.7	87.0	46.5	2.1	15.5	15.5	6.8	0.0	2.0	0.5	19.9
13th	56.67	66.67	70.00	113.0	23.4	24.0	14.7	83.0	72.0	5.8	14.5	14.1	2.2	3.7	5.5	5.0	20.9
14th	61.50	74.00	73.20	120.0	24.8	28.0	11.1	81.0	46.5	5.3	8.5	14.0	9.4	18.3	1.0	0.0	20.6

Note: SMW= Standard meteorological week, C_{Temp}= Canopy temperature, T_{Max}= Maximum temperature, T_{Min}= Minimum temperature, RH_{Max}= Maximum relative humidity, RH_{Min}= Minimum relative humidity, M_{WV}= Mean wind velocity, Vp_{Mor}= Morning vapour pressure, Vp_{Evn}= Evening vapour pressure, SS= Sunshine, CC_{Morn}= Morning cloud cover, CC_{Evn}= Evening cloud cover, S_{Temp}= Soil temperature

Table 2. Correlation of different abiotic factors with the severity of stripe rust of bread wheat (pooled data).

Epidemiological Factor	**Disease Severity (%) in Bread Wheat Varieties**		
	HD2967	**WH711**	**PBW343**
T_{max} (°C)	0.836	0.843	0.859
T_{min} (°C)	0.848	0.844	0.846
RH_{Max} (%)	-0.636	-0.651	-0.650
RH_{Min} (%)	-0.356	-0.385	-0.394
M_{WV} (km/h)	0.388	0.362	0.392
Vp_{Mor} (mmHg)	0.685	0.700	0.705
Vp_{Evn} (mmHg)	0.836	0.856	0.844
SS(h)	0.406	0.416	0.420
Rainfall (mm)	0.550	0.546	0.513
C_{Temp} (°C)	0.812	0.830	0.850
CC_{Morn} (okta)	-0.099	-0.084	-0.071
CC_{Evn} (okta)	-0.294	-0.310	-0.331
S_{Temp} (°C)	0.936	0.926	0.922
Age (days)	0.978	0.992	0.990

Note: Values in bold are highly significant at (p= 0.05). C_{Temp}= Canopy temperature, T_{Max}= Maximum temperature, T_{Min}= Minimum temperature, RH_{Max}= Maximum relative humidity, RH_{Min}= Minimum relative humidity, M_{WV}= Mean wind velocity, Vp_{Mor}= Morning vapour pressure, Vp_{Evn}= Evening vapour pressure, SS= Sunshine, CC_{Morn}= Morning cloud cover, CC_{Evn}= Evening cloud cover, S_{Temp}= Soil temperature

Table 3. Predictive Model for stripe rust of bread wheat.

Bread Wheat Variety	**Model**	**R^2**	**F-Value**	**95% CI Lower-Upper**
HD2967	$Y= -61.127+3.75X_2+2.75X_1$	0.885	42.4	X_2= 1.81-5.68 X_1= 1.24-4.25
WH711	$Y= -61.52+3.81X_2+2.67X_1+0.90X_5$	0.919	37.6	X_2= 1.83-5.82 X_1= 1.20-4.33 X_5= 0.03-1.80
PBW343	$Y= -82.41+3.33X_4+4.99X_3+1.36X_5$	0.952	72.6	X_4= 2.00-4.66 X_3= 3.33-6.64 X_5= 0.65-2.08

Note: Y= Disease severity of HD2967, WH711 and PBW343, $T_{Max}= X_1$, $T_{Min}= X_2$, $Vp_{Morn}= X_3$, $C_{Tmp}= X_4$ and Rainfall= X_5.

Table 4. Yield reduction in different bread wheat varieties due to stripe rust (pooled data).

Variety	**Yield in Control (kg/ha)**	**Yield in Diseased Field (kg/ha)**	**Yield Loss (kg/ha)**	**Yield Loss (%)**	**Disease Severity (At Anthesis Stage)**
PBW343	4260	3820	440	10.32	40
WH711	4630	3940	690	14.90	40
HD2967	4336	3980	356	8.21	30

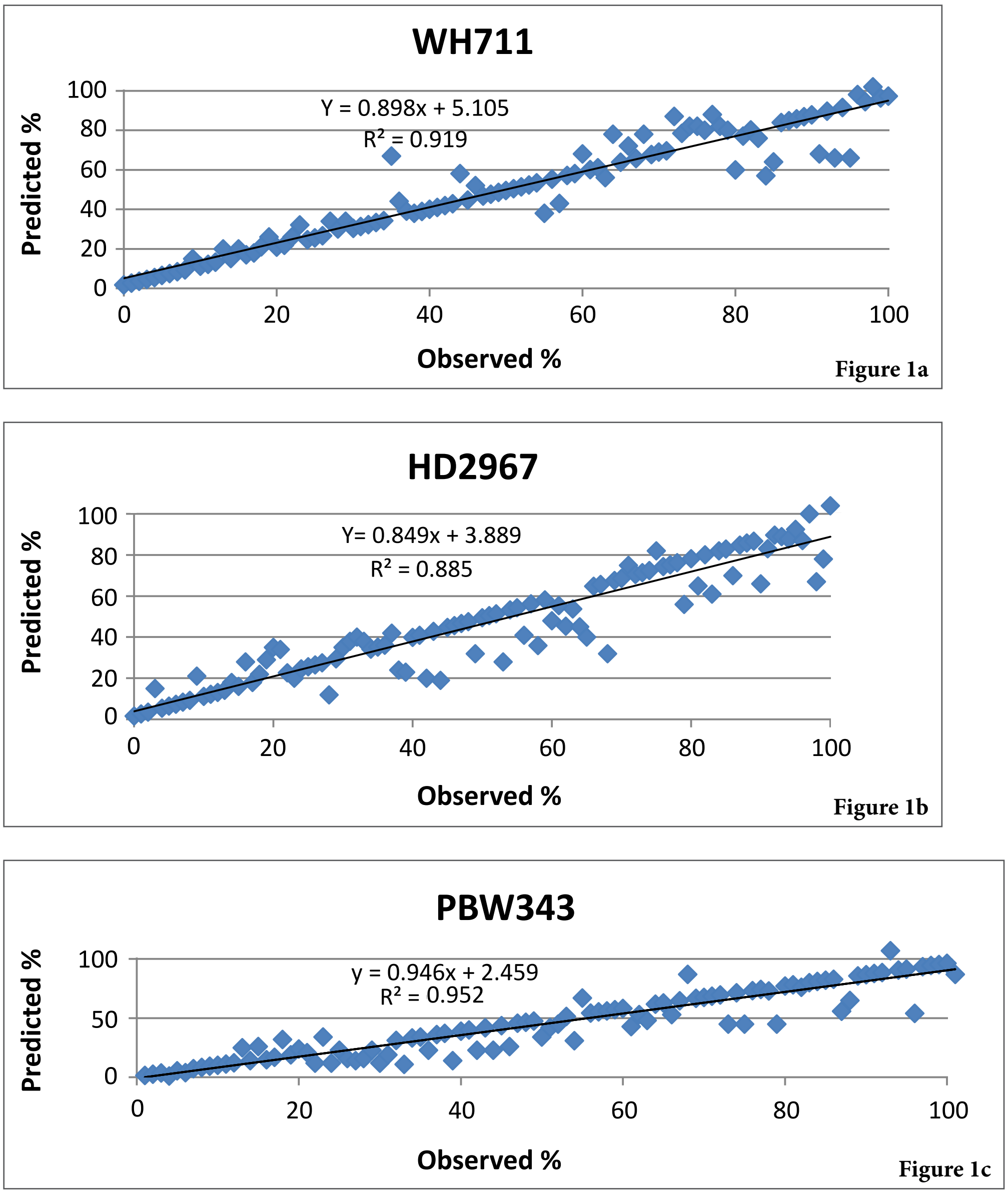

Figure 1a-c. Comparisions between observed and predicted values of the severity of bread wheat stripe rust in different bread wheat varieties.

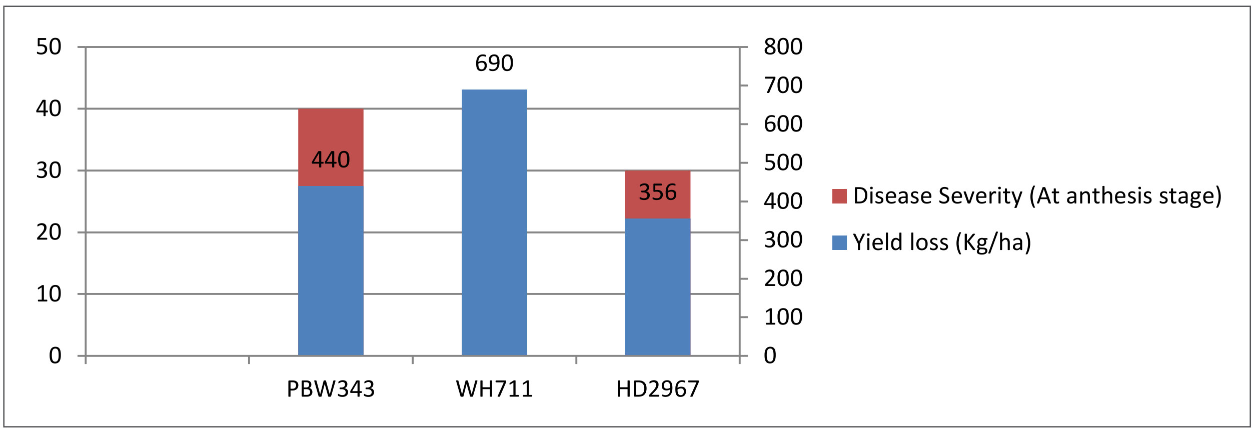

Figure 2. Estimated yield losses in response to different levels of stripe rust at anthesis.

References

Ahmed S, Afzal LRN, Iqbal Z, Akhtar N, Iftkar Y and Kamran M, (2010). Prediction of yield losses in bread wheat (*Triticum aestivum* L.) caused by yellow rust in relation to epidemiological factors in Faisalabad. Pak. J. Bot., 42: 401-407.

Akar T, Yazar S and Donmez E, (2007). Current status of national winter bread wheat breeding in Turkey. J. Agric. Res., 45: 1-9.

Beddow JM, Pardey PG, Chai Y, Hurley TM, Kriticos DJ and Braun JC, (2015). Research investment implications of shifts in the global geography of bread wheat stripe rust. Nat. Plant, 1: 132.

Chen W, Wellings C, Chen XM, Kang ZS and Liu TG, (2014). Bread wheat stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici*. Mol. Pl. Path., 15: 433-446.

Chen XM, (2005). Epidemiology and control of stripe rust (*Puccinia striiformis* f. sp. *tritici*) on bread wheat. Can. J. Pl. Path., 27: 314-337.

Chen WQ, Wu LR, Liu TG and Xu SC, (2009). Race dynamics, diversity and virulence evolution in *Puccinia striiformis* f. sp. *tritici*, the causal agent of bread wheat stripe rust in China from 2003 to 2007. Pl. Dis., 93: 1093-1101.

Christensen K, Jorgensen LN and Secher BJM, (1993). Development of a yellow rust model based on historical data. In: Proceeding of the 10th Danish Plant Protection Conference on Plantevaernscentret, Lyngby, Denmark, pp. 71-78.

Coakley SM, Line RF and McDaniel R, (1988). Predicting stripe rust on winter bread wheat using an improved method for analyzing meteorological and rust data. Phytopathol., 78: 543-550.

Cornell JA and Berger RD, (1987). Factors that influence the value of co-efficient of determination in simple linear and nonlinear regression models. Phytopathol., 77: 63-70.

Curtis BC, Rajaram S and Macpherson HG, (2002). Bread Wheat: Improvement and Production. Food and Agriculture Organization of the United Nations, Rome, Italy, Series Number 30, p.554.

DeVallavielle-Pope C, Huber L, Leconte M and Bethenod O, (2002). Pre-inoculation effects of light quantity on infection efficiency of *Puccinia striiformis* and *Puccinia triticina* on bread wheat seedlings. Phytopathol., 92: 1308-1314.

Hovmøller MS, (2016). Replacement of the European bread wheat yellow rust population by new races from the centre of diversity in the near-Himalayan region. Pl. Pathol., 65: 402-411.

Jevtić R, Župunski V, Lalošević M and Župunski LJ, (2017). Predicting potential winter bread wheat yield losses caused by multiple disease systems and climatic conditions. Crop Prot., 99: 17-25.

Jarroudi ME, (2017). A threshold-based weather model for predicting stripe rust infection in winter bread wheat. Pl. Dis., 101: 693-703.

Line RF, (2002). Stripe rust of bread wheat and barley in North America: a retrospective historical review. Ann. Rev. Phytopathol., 40: 75-118.

Madden LV, (1986). Statistical analysis and comparison of disease progress curve. In: Plant disease Epidemiology: Population Dynamic and Management (Eds. Loonard, K.J. and Fry, W.E.). Macmillan, New York (NY), pp. 55-83.

Pandey P, Irulappan V, Bagavathiannan MV and Senthil-Kumar M, (2017). Impact of combined abiotic and biotic stresses on plant growth and avenues for crop improvement by exploiting physio-morphological traits. Front. Pl. Sci., 8: 537.

Peterson RF, Campbell AB and Hannah AE, (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res., 26(5): 496-500.

Singh RP, William HM, Huerta-Espino J and Rosewarne G, (2004). Bread wheat rust in Asia: meeting the challenges with old and new technologies. In: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia.

Singh RP, Huerta-Espino J, Bhavani S, Herrera- Foessel SA, Singh D, Singh PK, Velu G, Mason RE and Crossa J, (2002). Race non-specific resistance to rust diseases in international maize and bread wheat improvement centre, Mexico spring bread wheat. Euphytica., 179: 175-186.

Singh TB and Tewari AN, (2001). The role of weather conditions in the development of foliar diseases of bread wheat under tarai conditions of north western India. Pl. Dis. Res., 16: 173-178.

TeBeest DE, Paveley ND, Shaw MW, Pietravalle S and Vanden BF, (2009). Disease weather relationship for powdery mildew and yellow rust on winter bread wheat. Phytopathol., 124: 413-425.

Wellings CR, (2011). Global status of stripe rust: a review of historical and current threats. Euphytica, 179: 129-141.

Wellings CR, Singh RP, McIntosh RA and Yayhaoui A, (2000). The assessment and significance of pathogenic variability in *Puccinia striiformis* in breeding for resistance to stripe (yellow) rust. In: Proceeding of 11th Regional Bread wheat Workshop for Eastern, Central and Southern Africa, Addis Ababa, Ethiopia, Africa, pp. 18-22.