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PREDICTING STRIPE RUST DISEASE SEVERITY IN WHEAT USING METEOROLOGICAL DATA WITH ENVIRONMENTAL RESPONSE MODELING

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ABSTRACT: Eleven wheat cultivars were evaluated against yellow rust disease at two different locations in Egypt i.e. Shibin El-Kom, Minufiya governorate and Itay El-Baroud Agricultural Research Station, Behira governorate, Egypt during three successive growing seasons i.e. 2018/2019, 2019/2020 and 2020/2021. Correlation between weekly eight environmental factors; solar radiation, total precipitation, average wind speed, maximum wind speed, minimum air temperature, maximum air temperature, minimum relative humidity and maximum relative humidity to yellow rust severity (%) was determined using step wise regression analysis. Predictive models for each tested variety to final yellow rust severity disease (%) using environmental data were determined. In general, maximum relative humidity was positively correlated with final yellow rust severity (%). Significant correlation between two environmental factors maximum relative humidity and final yellow rust severity (%) was found in this study. Meanwhile, negative correlation was found between final yellow rust severity (%) and the two environmental factors i.e. solar radiation and minimum relative humidity. High values of R^2 for all regression models under study referred to the validation of these models to predict yellow rust severity (%) and facilitate the use of each as a warning forecast to wheat farmers.

Key words: Wheat, yellow rust, environmental factors, prediction models.

INTRODUCTION

Wheat (*Triticum aestivum* L.*)* is considered one of the most important cereal crops in Egypt and all over the world. The importance of wheat as staple food is well known as it is the most popular, widely grown cereal crop allover the world. Due to fast growing population of the world especially in the developing countries the demand of wheat is keep on increasing (Rajaram, 2000 and Nagarajan, 2005).

This target can be achieved horizontally through expanding wheat area and/or vertically by growing the promising high yielding cultivars with high level of disease resistance.

In Egypt, wheat is liable to be attacked by the three rust diseases i.e. stripe, leaf and stem rusts. Nevertheless, disease infections with all rust diseases usually occur only at the late growth stages starting from the flowering stage. No disease infection was recorded on seedling plants under field conditions. Therefore, breeding for adult plant resistance is the most important method to control all rust diseases under the Egyptian conditions (Esmail *et al*., 2023).

Stripe rust (yellow rust) (*Puccinia striiformis* f. sp. *tritici*) began to be cosmopolitan disease due to the dynamic nature of it's causal agent, since it converted from a disease of cool weather to a disease of variable weather.

In Egypt, grain yield loss due to artificial yellow rust has reached 69.33% in the susceptible wheat cultivars that are cultivated under experimental field conditions favorable to disease incidence and development (El-Orabey *et al*., 2020; Shahin *et al*., 2020 and Elshafei *et al*., 2022).

Using wheat cultivars with sustainable resistance to yellow rust is the most effective approach to reduce yield losses and avoid severe epidemics (Todorovska *et al*., 2009). But, the

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emergence of new virulent races, lead to shortage of an effective host-genetic resistance and support the need for forecasting models (Moschini and Pérez, 1999). These models are needed to reduce using of recommended fungicides. Especially, if the fungicides are less effective or ineffective and not economical in reducing crop losses due to the sudden appearance of new races of the pathogen (Eversmeyer & Kramer, 1992). Therefore, Khan (1997) get a model for yield loss in soft red winter wheats that predicted a 1% yield loss for each 1% increase in rust severity at the milky-ripe stage of grain development.

Low temperature and high relative humidity are factors suitable to the wide distribution of wheat yellow rust (Stubbs, 1988). In Egypt, yellow rust is a sporadic disease because it appears in same year in Near and Middle East regions. However, starting from 1990s, it became common due to its continuous appearance (Abu El-Naga *et al.*, 2001).

The disease was epidemic on several wheat cultivars including Giza 144 (at Manzala district in 1967/68), Sakha 69, Giza 163, Gemmeiza 1 and most of the commercial cultivars especially the long spiked ones at the Northern governorates in 1995/96 and 1997/98 growing seasons (Abu El-Naga, *et al*., 1999).

Crop-weather models may be the maximum useful tools for forecasting the occurrence of a particular disease (Hatfield, 1990). Most of wheat rust epidemics have been successfully predicted using mechanistic and empirical approaches (Coakley and Line, 1988). The empirical models were based on either meteorological factors alone (Coakley and Line, 1988) or both biological and meteorological factors (Eversmeyer and Kramer, 1992). Most of the previous studies developed leaf rust-prediction models by evaluating few selected wheat cultivars in Argentina and Europe (Daamen *et al*., 1992). The main objective of this study was to determine a suitable relationship between yellow rust severity (%) and some environmental factors.

MATERIALS AND METHODS

Experimental wheat plots were established at the Egyptian field conditions in the two locations; Shibin El-Kom, Minufiya governorate and Itay El-Baroud Agricultural Research Station, Behira governorate, Egypt during three growing seasons i.e. 2018/2019, 2019/2020 and 2020/2021. Moreover, another experiment was conducted in the farm, Faculty of Agriculture, Minufiya University, Minufiya governorate, Egypt during 2021/2022 to validate the prediction models to yellow rust severity (%). Eleven wheat varieties i.e. Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95 and the highly susceptible variety Morocco were sown in plots (3 X 3.5 m) in a randomized complete block (RCB) design with three replicates. Each plot contained 10 rows with 3 m long and 30 cm between rows. In order to maintain crop stand normal agronomic practices including recommended fertilization dose and irrigation schedule were applied. All plots were surrounded by spreader area planted with a mixture of the highly susceptible wheat varieties to yellow rust i.e. Morocco and Thatcher.

Inoculation and disease assessment

For field inoculation the spreader plants were mist with water and dusted with a mixture of urediniospores of the most prevalent and aggressive races and talcum powder at a rate of 1 (spore):20 (talcum powder gram) (v:v). The spores of yellow rust pathotypes were obtained from Wheat Diseases Research Department, Plant Pathology Research Institute, ARC, Giza, Egypt. Dusting was carried out in the early evening (at sunset) before dew formation. The inoculation of all plants was carried out at booting stage according to the method of Tervet and Cassell (1951). To keep protected plots free from yellow rust infection, the recommended fungicide Sumi-eight 5 EC was applied as 35 cm^3/100 L water on three times, the mid-February and 15 days intervals.

Yellow rust severity (%) and infection type (IT) were recorded at adult plant stage of wheat plants in each plot every seven days intervals in 7, 14, 21 and 28 March, using the modified Cobb's scale (Peterson *et al*., 1948). Disease reaction was expressed in four infection types i.e.

resistance = (R), moderately resistance = (MR), moderately susceptible = (MS) and susceptible = (S) (Roelfs *et al*., 1992). Also, final rust severity (FRS %) was assessed as a percentage of disease severity for each of the tested wheat variety when the highly susceptible (check) cultivar i.e. Morocco was severely rusted and its disease severity reached to maximum and final level (Das *et al*., 1993).

Environmental data

Environmental data of the two locations; Shibin El-Kom and Itay El-Baroud were obtained from Central Laboratory for Agricultural Climate, ARC. The following environmental variables were calculated and then evaluated for their utility in predicting yellow rust severity (%). These environmental parameters were (X1) solar radiation (mJ/m^2) (which, mJ=Mega joules), (X2) total accumulated precipitation in millimeters (mm), (X3) average wind velocity (m/sec.), (X4) maximum wind velocity (m/sec.), (X5) minimum air temperature (ºC), (X6) maximum air temperature (ºC), (X7) minimum relative humidity (RH%) and (X8) maximum relative humidity (RH%). All of the environmental variables data used in this study are converted in mean weekly data during March which rust response was recorded.

Statistical parameters and development of predicted equations

Correlation coefficients were calculated between yellow rust severity (%) and environmental data using SPSS. Correlation coefficients were calculated between actual and predicted yellow rust severity (%) and using Microsoft Excel 2010. Stepwise regression identified environmental variables that explained the maximum variation in yellow rust severity (%). Also, stepwise regression was used to select the environmental variables for different wheat cultivars under study using all yellow rust severity (%) data at the two locations Shibin El-Kom and Itay El-Baroud, during the three seasons of the study to produce linear regression model in order to predict yellow rust severity (%) (Coakley and Line, 1988).

Significance of difference among the studied cultivars was tested by the analysis of variance (ANOVA) test as outlined by Snedecor and Cochran (1967). Mean comparisons for variables were made among genotypes using least significant differences (LSD at 5%) tests.

Model validation

Model validation and accuracy of prediction models for yellow rust severity (%) was done by comparing the values of actual (observed) and predicted yellow rust severity (%) of the 11 cultivars under study. The actual yellow rust severity (%) was calculated using the mean of three replicates data of disease severity (%) at Shibin El-Kom location during 2021/2022 growing season. These data did not use in stepwise analysis to produce linear regression models for yellow rust severity (%). The predicted values of yellow rust severity (%) was calculated from the regression models for each variety using the environmental parameters (predictors) that were present at Shibin El-Kom location during 2021/2022 growing season when the actual data were scored. The values of environmental factors at Shibin El-Kom location during 2021/2022 were, solar radiation (X1) = 16.3, precipitation (X2) = 0.1, average wind speed (X3) = 0.73, maximum wind speed (X4) = 1.7, minimum air temperature (X5) = 11.6, maximum air temperature (X6) = 26.2, minimum relative humidity (X7) = 49.5 and maximum relative humidity (X8) = 83.1. Correlation coefficients between actual and predicted yellow rust severity (%) for each cultivar were calculated using Microsoft Excel 2010.

Results

1. Evaluation of 11 wheat cultivars against stripe rust under field conditions

Eleven commercial wheat cultivars including Morocco, as a highly susceptible (check) variety were evaluated for their adult plant reaction to stripe rust infection under field conditions at the two locations; Shibin El-Kom and Itay El-Baroud. The fungicide-protected plots remained almost free from disease during the three growing seasons of this study (2018/2019 - 2020/2021).

a. Response of the tested wheat varieties at Shibin El-Kom location

2018/2019 growing season

Data in Table (1) indicated that the wheat verities; Misr 3, Sakha 95, Giza 171, Gemmeiza 12, Sids 14 and Giza 168 showed the lowest levels of final yellow rust severity (FRS%) i.e. 0, 0, 2.67, 8.33, 8.33 and 13.33 %, respectively. While, the wheat varieties; Misr 2, Misr 1, Shandweel 1, Gemmeiza 11 and Morocco showed the highest percentage of FRS (%) i.e. 30.00, 43.33, 76.67, 80.00 compared to control cultivar morocco 96.67% .

2019/2020 growing season

During the second season, data presented in Table (1) revealed that, the seven wheat cultivars Misr 3, Sakha 95, Giza 171, Gemmeiza 12, Sids 14, Giza 168 and Misr 2 showed the lowest levels of final yellow rust severity (FRS%) i.e. 0, 0, 4.33, 4.33, 6.67, 26.67and 26.67%, respectively. While, the wheat cultivars ; Misr 1, Shandweel 1, Gemmeiza 11 and Morocco showed the highest percentage of FRS (%) i.e. 66.67, 83.33, 86.67 compared to morocco cultivar 100%.

2020/2021 growing season

Similar to the results obtained in the two previous growing seasons, the wheat varieties; Misr 3, Sakha 95, Giza 171, Gemmeiza 12, Giza 168, Sids 14, Misr 2 and Misr 1 showed the lowest levels of final yellow rust severity (FRS%) i.e. 0, 0, 0, 2.67, 3.67, 4.33, 8.33 and 26.67%, respectively. While, the wheat varieties; Shandweel 1, Gemmeiza 11 and Morocco showed the highest percentage of FRS (%) i.e. 53.33, 76.67 and 86.67 %, respectively.

Table (1): Mean final yellow rust severity (%) of 11 wheat varieties under field conditions at Shibin El-Kom and Itay El-Baroud locations during 2018/2019, 2019/2020 and 2020/2021 growing seasons.

No.	Variety	Season / Location / Mean final rust severity (%) (FRS)					
		2018/2019		2019/2020		2020/2021	
		Shibin El-Kom	Itay El-Baroud	Shibin El-Kom	Itay El-Baroud	Shibin El-Kom	Itay El-Baroud
1	Shandweel 1	76.67	90.00	83.33	86.67	53.33	66.67
2	Giza 168	13.33	26.67	26.67	23.33	3.67	13.33
3	Giza 171	2.67	4.33	4.33	8.33	0.00	6.67
4	Gemmeiza 11	80.00	86.67	86.67	83.33	76.67	76.67
5	Gemmeiza 12	8.33	8.33	4.33	8.33	2.67	6.67
6	Sids 14	8.33	20.00	6.67	8.33	4.33	3.67
7	Misr 1	43.33	60.00	66.67	80.00	26.67	23.33
8	Misr 2	30.00	56.67	26.67	46.67	8.33	5.00
9	Misr 3	0.00	0.00	0.00	0.00	0.00	0.00
10	Sakha 95	0.00	0.00	0.00	0.00	0.00	0.00
11	Morocco (check)	96.67	96.67	100.00	100.00	86.67	93.33
L.S.D. at 5%		11.598	8.787	6.849	7.583	7.825	7.583

b. Response of the tested wheat varieties at Itay El-Baroud location

2018/2019 growing season

Data in Table (2) indicated that the wheat cultivars; Misr 3, Sakha 95, Giza 171, Gemmeiza 12, Sids 14 and Giza 168 showed the lowest levels of final yellow rust severity (FRS%) i.e. 0, 0, 4.33, 8.33, 20.00 and 26.67 %, respectively. The wheat varieties; Misr 2, Misr 1, Gemmeiza 11, Shandweel 1, and Morocco showed the highest percentage of FRS (%) i.e. 56.67, 60.00, 86.67, 90.00 respectively

2019/2020 growing season

Data in Table (2) indicated that the wheat verities; Misr 3, Sakha 95, Giza 171, Gemmeiza 12, Sids 14 and Giza 168 showed the lowest levels of final yellow rust severity (FRS%) i.e. 0, 0, 8.33, 8.33, 8.33 and 23.33 %, respectively. While, the wheat varieties; Misr 2, Misr 1, Gemmeiza 11, Shandweel 1, and Morocco showed the highest percentage of FRS (%) i.e. 46.67, 80.00, 83.33, 86.67 respectively.

2020/2021 growing season

Data in Table (2) indicated that the wheat verities; Misr 3, Sakha 95, Sids 14, Misr 2, Giza 171, Gemmeiza 12, Giza 168 and Misr 1 showed the lowest levels of final yellow rust severity (FRS%) i.e. 0, 0, 3.67, 5.00, 6.67, 6.67, 13.33 and 23.33 %, respectively. While, the wheat varieties; Shandweel 1, Gemmeiza 11 and Morocco showed the highest percentage of FRS (%) i.e. 66.67, 76.67 respectively.

2. Correlation between environmental factors and yellow rust severity (%)

Data in Table (2) showed the correlation of environmental conditions with yellow rust severity (%).

a. Solar radiation

The relationship of solar radiation with yellow rust severity was negative in all of the 11 tested varieties (r = -0.015 to -0.245) and the contribution (r^2) of solar radiation in prediction of rust severity was ranged from 0.02 % to 6.00%. These indicate that a higher solar radiation is associated with less rust severity caused by yellow rust disease.

b. Precipitation of rain

The relationship of precipitation with yellow rust severity (%) was positive in all of the 11 tested varieties. The wheat varieties Sakha 95, Morocco, Misr 2, Sids 14, Sids 14 and Misr 1 showed significant response with increase in precipitation (r = 0.619, 0.743, 0.753, 0.779, 0.779 and 0.892, respectively). While, the wheat varieties Misr 3, Giza 168 and Shandweel 1 showed the lowest values of correlation coefficient i.e. r = 0.576, 0.663 and 0.668, respectively. The contribution of precipitation in prediction of rust severity ranged from 38.32 % - 79.57 %.

c. Average wind speed

The relationship of average wind speed with yellow rust severity was positive in all of the six tested varieties. The wheat variety Morocco showed significant response with increase in average wind speed (r = 0.709). While, the wheat variety Misr 2 showed the lowest values of correlation coefficient (r = 0.231). The contribution of average wind speed in prediction of rust severity ranged from 5.34 % - 50.27 %.

d. Maximum wind speed

The relationship of maximum wind speed with yellow rust severity was positive in all of the 11 tested varieties. The wheat variety Morocco showed significant response with increase in maximum wind speed (r = 0.720). While, the wheat varieties Shandweel 1 and Misr 2 showed the lowest values of correlation coefficient (r = 0.253 and 0.030, respectively). The contribution of maximum wind speed in prediction of rust severity ranged from 0.09 % - 51.84 %.

e. Minimum air temperature

The relationship of minimum air temperature with yellow rust severity was positive in all of the 11 tested varieties. The wheat varieties Gemmeiza 12, Giza 171, Giza 168 and Sids 14 showed significant response with increase in minimum air temperature (r = 0.851, 0.859,

Table (2): Correlation between weekly environmental factors and their contribution on yellow rust severity of 11 wheat varieties.

Variety	Solar radiation [mJ/m²] (X1)		Precipitation [mm] (X2)		Wind speed (m/sec.)				Air temperature (°C)				Relative humidity (%)			
					Average (X3)		Maximum (X4)		Minimum (X5)		Maximum (X6)		Minimum (X7)		Maximum (X8)	
	R	R^2	R	R^2	R	R^2	R	R^2	R	R^2	R	R^2	R	R^2	R	R^2
Shandweel 1	-0.123	1.51	0.668	44.62	0.510	26.01	0.030	0.09	0.784	61.47	0.499	24.90	-0.322	10.37	0.959	91.97
Giza 168	-0.107	1.14	0.663	43.96	0.532	28.30	0.628	39.44	0.887	78.68	0.569	32.38	-0.346	11.97	0.882	77.79
Giza 171	-0.136	1.85	0.697	48.58	0.315	9.92	0.425	18.06	0.859	73.79	0.537	28.84	-0.383	14.67	0.890	79.21
Gemmeiza 11	-0.076	0.58	0.699	48.86	0.688	47.33	0.710	50.41	0.771	59.44	0.332	11.02	-0.542	29.38	0.903	81.54
Gemmeiza 12	-0.015	0.02	0.719	51.70	0.382	14.59	0.500	25.00	0.851	72.42	0.593	35.16	-0.602	36.24	0.867	75.17
Sids 14	-0.144	2.07	0.779	60.68	0.383	14.67	0.487	23.72	0.899	80.82	0.247	6.10	-0.302	9.12	0.866	75.00
Misr 1	-0.245	6.00	0.892	79.57	0.445	19.80	0.410	16.81	0.724	52.42	0.498	24.80	-0.203	4.12	0.930	86.49
Misr 2	-0.239	5.71	0.753	56.70	0.231	5.34	0.253	6.40	0.815	66.42	0.236	5.57	-0.272	7.40	0.935	87.42
Misr 3	-0.112	1.25	0.619	38.32	0.358	12.82	0.366	13.40	0.746	55.65	0.138	1.90	-0.132	1.74	0.837	70.06
Sakha 95	-0.169	2.86	0.722	52.13	0.440	19.36	0.377	14.21	0.650	42.25	0.247	6.10	-0.148	2.19	0.915	83.72
Morocco (check)	-0.047	0.22	0.743	55.20	0.709	50.27	0.720	51.84	0.766	58.68	0.586	34.34	-0.610	37.21	0.950	90.25

0.887 and 0.899, respectively). While, the wheat variety Sakha 95 showed the lowest value of correlation coefficient (r = 0.650). The contribution of minimum air temperature in prediction of rust severity ranged from 42.25 % - 80.82 %.

f. Maximum air temperature

The relationship of maximum air temperature with yellow rust severity was positive in all of the 11 tested varieties. The wheat varieties Gemmeiza 12 and Morocco showed significant response with increase in maximum air temperature (r = 0.593 and 0.586, respectively). While, the wheat variety Misr 3 showed the lowest value of correlation coefficient (r = 0.138). The contribution of maximum air temperature in prediction of rust severity ranged from 1.90 % - 35.16 %.

g. Minimum relative humidity

The relationship of minimum relative humidity with yellow rust severity was negative in all of the 11 tested varieties. The wheat varieties Gemmeiza 12 and Morocco showed significant response with increase in minimum relative humidity (r = -0.602 and -0.610, respectively). While, the wheat varieties Misr 2 and Misr 3 showed the lowest value of correlation coefficient (r = -0.132 and -0.148, respectively). The contribution of minimum relative humidity in prediction of rust severity ranged from 1.74 % - 37.21 %.

h. Maximum relative humidity

The relationship of maximum relative humidity with yellow rust severity was positive in all of the 11 tested varieties. Most of the tested wheat varieties i.e. Shandweel 1, Morocco, Misr 2, Misr 1, Sakha 95 and Gemmeiza 11 showed significant response with increase in maximum relative humidity (r = 0.959, 0.950, 0.935, 0.930, 0.915 and 0.903, respectively). While, the wheat variety Misr 3 showed the lowest value of correlation coefficient (r = 0.837). The contribution of maximum relative humidity in prediction of rust severity ranged from 70.06 % - 91.97%.

3- Linear regression models

a- Prediction models for yellow rust severity (%):

The best simple equations for predicting yellow rust severity including meteorological factors are presented in Table (3). Coefficient of determination (R^2) values for each model was calculated and no value below 0.700 was observed which is a good indicator for forecast model. Eleven regression models were developed based on environmental conditions for forecasting yellow rust severity (%) and explained different amounts of variation in rust severity in the tested wheat varieties. The best models for forecasting rust severity were in the wheat varieties Sids 14 (R^2 = 90.60), Giza 171 (R^2 = 84.50), Shandweel 1 (R^2 = 84.20), Misr 1, (R^2 = 83.90), Misr 3 (R^2 = 81.90) and Gemmeiza 12 (R^2 = 81.70) , followed by model in the wheat varieties Giza 168 (R^2 = 77.50), Sakha 95 (R^2 = 77.40), Morocco (R^2 = 77.10), Gemmeiza 11 (R^2 = 76.70) and Misr 2 (R^2 = 72.20). Regression model in Sids 14 explained 90.60 % yellow rust severity variation. Moreover, Regression model in Shandweel 1 explained 84.50 % of yellow severity variation.

4- Validation of yellow rust severity (%) models

For validation of models, data of yellow rust severity (%) at Shibin El-Kom location during 2021/2022 growing season were used. These data did not use in stepwise analysis to produce linear regression models for yellow rust severity (%).

Data in Table (4) indicated that, the wheat varieties Sakha 95, Misr 3, Giza 171, Gemmeiza 12 and Giza 168 showed the lowest values of mean FRS (%) i.e. 0.00, 4.33 %, 6.67%, 11.67 % and 16.67 %, respectively. While, the wheat varieties Sids 14, Misr 2, Shandweel 1, Misr 1 and Morocco showed the highest value of mean FRS (%) i.e. 36.67 %, 46.67 %, 66.67%, 66.67% and 100.00 %, respectively.

Table (3): Prediction models for yellow rust severity (RS %) in 11 wheat varieties based on weekly environmental conditions using stepwise regression analysis.

Varietey	Model	R^2 (%)	F. alue	*P > F*
Shandweel 1	[a]RS %= -172.983 + 2.832 X1 - 107.631 X2 - 13.041 X3 + 0.947 X4 - 10.415 X5 + 6.643 X6 + 1.077 X7 + 1.676 X8	84.20	18.829	0.00
Giza 168	RS %= -60.872 + 0.941 X1 - 37.329 X2 - 20.251 X3 + 7.095 X4 - 1.984 X5 + 2.668 X6 - 0.245 X7 + 0.794 X8	77.50	17.481	0.00
Giza 171	RS %= -15.933 + 0.035 X1 - 11.278 X2 - 10.112 X3 + 2.023 X4 - 0.606 X5 + 0.927 X6 - 0.044 X7 + 0.209 X8	84.50	19.077	0.00
Gemmeiza 11	RS %= -104.203 + 1.271 X1 + 56.764 X2 + 6.597 X3 + 5.975 X4 - 2.819 X5 + 1.838 X6 + 1.056 X7 + 0.777 X8	76.70	15.733	0.00
Gemmeiza 12	RS %= -36.196 + 0.070 X1 + 3.866 X2 - 6.855 X3 + 2.502 X4 - 0.684 X5 + 0.541 X6 + 0.358 X7 + 0.062 X8	81.70	17.023	0.00
Sids 14	RS %= -40.026 + 0.399 X1 + 1.179 X2 - 2.634 X3 + 4.797 X4 - 0.827 X5 + 0.012 X6 + 0.354 X7 + 0.210 X8	90.60	35.310	0.00
Misr 1	RS %= -206.140 + 5.299 X1 - 409.078 X2 - 13.046 X3 - 9.465 X4 - 8.361 X5 + 11.428 X6 - 0.919 X7 + 2.650 X8	83.90	28.279	0.00
Misr 2	RS %= -221.835 + 3.637 X1 - 131.118 X2 - 46.435 X3 + 7.357 X4 - 7.807 X5 + 4.565 X6 + 1.280 X7 + 1.781 X8	72.20	23.479	0.00
Misr 3	RS %= -5.364 + 0.088 X1 + 24.063 X2 + 3.209 X3 + 0.904 X4 - 0.479 X5 - 0.244 X6 + 0.132 X7 + 0.045 X8	81.90	26.745	0.00
Sakha 95	RS %= -1.636 + 0.075 X1 + 26.519 X2 + 4.453 X3 - 0.641 X4 - 0.400 X5 - 0.133 X6 + 0.108 X7 - 0.016 X8	77.40	23.693	0.00
Morocco (check)	RS %= -113.312 + 1.153 X1 - 25.013 X2 + 3.098 X3 + 5.458 X4 - 2.623 X5 + 3.598 X6 + 0.960 X7 + 0.665 X8	77.10	25.251	0.00

[a] RS = Rust severity (%); [b] The predictors (X) included in the regression models were precipitation (X2), average wind speed (X3), maximum wind speed (X4), minimum air temperature (X5), maximum air temperature (X6), minimum relative humidity (X7) and maximum relative humidity (X8).

Table (4): Final yellow rust severity (%) and grain yield per plot (kg) of 11 wheat varieties under field conditions at Shibin El-Kom location during 2021/2022 growing season.

Variety	FRS (%)
Shandweel 1	66.67
Giza 168	16.67
Giza 171	6.67
Gemmeiza 11	93.33
Gemmeiza 12	11.67
Sids 14	36.67
Misr 1	66.67
Misr 2	46.67
Misr 3	4.33
Sakha 95	0.00
Morocco (check)	100.00

5. Validation of yellow rust severity (%) models

Eleven models for prediction of yellow rust severity (%) were also validated by comparing the values of actual yellow rust severity (%) at Shibin El-Kom location during 2021/2022 growing season and predicted yellow rust severity (%) (Table 5 and Fig. 1). All of predicted yellow rust severity (%) models were closest to the actual yellow rust severity (%) for each variety. So, these equations were considerably accurate in forecasting yellow rust severity (%). Coefficient of determination (R^2) value of the relation between predicted and actual yellow rust severity (%) for all models was high i.e. 0.890, these mean the accuracy of all of these prediction models are 89.00%.

DISCUSSION

Wheat (*Triticum aestivum* L.) is one of the most important food crops in Egypt and allover the world. The Egyptian government does it's best to minimize the gap between local production and consumption via planning strategies for increasing wheat productivity. Breeding for disease resistance and high production are useful tools in this regard.

Stripe rust of wheat (*Triticum aestivum* L.) caused by *Puccinia striiformis tritici* is considered one of the most serious diseases in Egypt. The disease became a very dangerous on most of the currently used varieties because of their susceptibility to the disease (El-Daoudi *et al.*, 1996, El-Orabey *et al.*, 2019, El-Orabey and Elkot, 2020 & Esmail *et al.*, 2021). It usually occurs at higher level of severity on the late sowings than the early ones when the environmental conditions became suitable for rust incidence and development (Mundt *et al.*, 1995).

Also, the amount of loss in grain yield depends on the aggressiveness of the prevailing physiologic race(s) as well as the suitable environmental conditions (Park *et al.*, 1988 and Hong and Singh 1996). In this case, the loss in grain yield may reach higher levels.

In 1967 the disease appeared on leaves and heads and destroyed a very large area of wheat plants in lower Egypt (Abd El-Hak *et al*., 1972). Also in 1985, 1996 and 1997 it appeared at very high levels of incidence and caused a highly significant loss in grain yield (El-Daoudi *et al.*, 1996).

The aim of study included evaluation of 11 wheat varieties i.e. Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95 and use the highly susceptible variety Morocco to compare.

Table (5): Comparisons between predicted yellow rust severity (%) from the models for each variety and observed yellow rust severity (%) at Shibin El-Kom location during 2021/2022 growing season.

Varietey	Regression model	Yellow rust severity (%)	
		Observed[b]	Predicted[c]
Shandweel 1	[a]RS %= -172.983 + 2.832 bX1 - 107.631 X2 - 13.041 X3 + 0.947 X4 - 10.415 X5 + 6.643 X6 + 1.077 X7 + 1.676 X8	66.67	60.59
Giza 168	RS %= -60.872 + 0.941 X1 - 37.329 X2 - 20.251 X3 + 7.095 X4 - 1.984 X5 + 2.668 X6 - 0.245 X7 + 0.794 X8	16.67	20.26
Giza 171	RS %= -15.933 + 0.035 X1 - 11.278 X2 - 10.112 X3 + 2.023 X4 - 0.606 X5 + 0.927 X6 - 0.044 X7 + 0.209 X8	6.67	10.36
Gemmeiza 11	RS %= -104.203 + 1.271 X1 + 56.764 X2 + 6.597 X3 + 5.975 X4 - 2.819 X5 + 1.838 X6 + 1.056 X7 + 0.777 X8	93.33	95.27
Gemmeiza 12	RS %= -36.196 + 0.070 X1 + 3.866 X2 - 6.855 X3 + 2.502 X4 - 0.684 X5 + 0.541 X6 + 0.358 X7 + 0.062 X8	11.67	15.13
Sids 14	RS %= -40.026 + 0.399 X1 + 1.179 X2 - 2.634 X3 + 4.797 X4 - 0.827 X5 + 0.012 X6 + 0.354 X7 + 0.210 X8	36.67	30.79
Misr 1	RS %= -206.140 + 5.299 X1 - 409.078 X2 - 13.046 X3 - 9.465 X4 - 8.361 X5 + 11.428 X6 - 0.919 X7 + 2.650 X8	66.67	70.36
Misr 2	RS %= -221.835 + 3.637 X1 - 131.118 X2 - 46.435 X3 + 7.357 X4 - 7.807 X5 + 4.565 X6 + 1.280 X7 + 1.781 X8	46.67	40.58
Misr 3	RS %= -5.364 + 0.088 X1 + 24.063 X2 + 3.209 X3 + 0.904 X4 - 0.479 X5 - 0.244 X6 + 0.132 X7 + 0.045 X8	4.33	5.79
Sakha 95	RS %= -1.636 + 0.075 X1 + 26.519 X2 + 4.453 X3 - 0.641 X4 - 0.400 X5 - 0.133 X6 + 0.108 X7 - 0.016 X8	0.00	3.62
Morocco (check)	RS %= -113.312 + 1.153 X1 - 25.013 X2 + 3.098 X3 + 5.458 X4 - 2.623 X5 + 3.598 X6 + 0.960 X7 + 0.665 X8	100.00	97.95

[a] Rust severity (%); [b] Mean of three replicates; [c] Calculated by using the constant a and predictor X6 and X7 on the regression model; [d] Observed and predicted values of rust severity (%) for all models were positive and high significant ($r = 0.997$, $P \leq 0.01$); [e] The predictors (X) included in the regression models were precipitation (X2), average wind speed (X3), maximum wind speed (X4), minimum air temperature (X5), maximum air temperature (X6), minimum relative humidity (X7) and maximum relative humidity (X8).

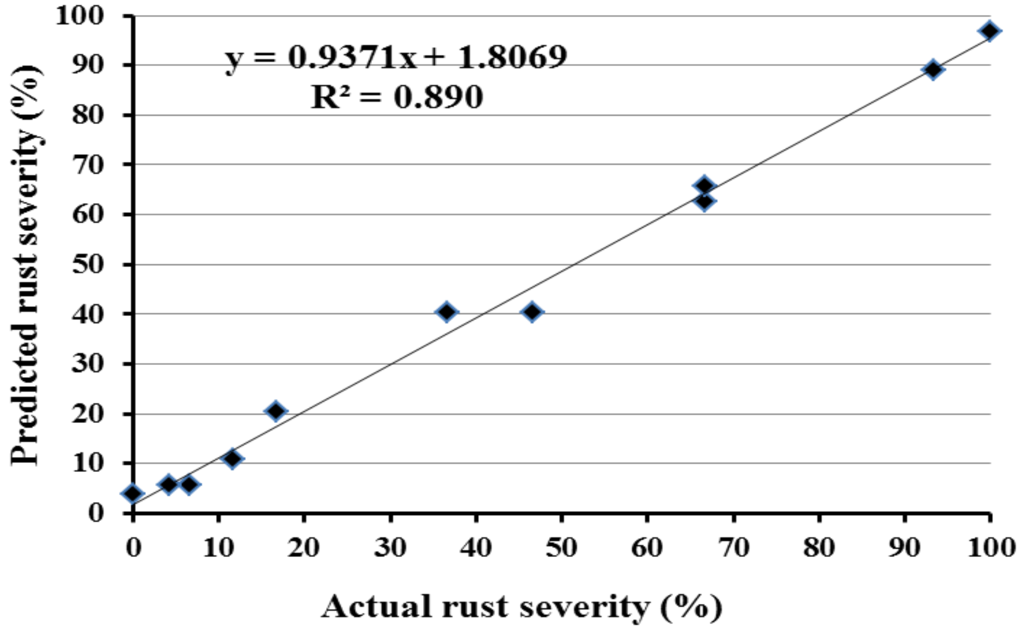

Fig. (1): Relationship between actual and predicted yellow rust severity (%) (shown as dots) as forecasted by regression models for 11 wheat varieties i.e. Shandweel 1, Giza 168, Giza 171, Gemmeiza 11, Gemmeiza 12, Sids 14, Misr 1, Misr 2, Misr 3, Sakha 95 and the highly susceptible variety Morocco.

Giza 162, Giza 163, Giza 164, Giza 165, Giza 167, Giza 168, Giza 170, Sids 1, Gemmeiza 9, Sakha 8, Sakha 69 and Sakha 93 against yellow rust under field conditions at Shibin El-Kom and Itay El-Baroud locations for three successive growing seasons (2018/2019 - 2020/2021).

In this work, rust incidence was recorded as final rust severity (FRS %). it was measured to compare the partially resistant and fast-rusting varieties under investigation.

It was noticed that over the three growing seasons, no rust infection appeared on the wheat plants before booting stage. At heading stage, disease appeared according to the location, the genotype and the dominant physiologic races. Moreover, obtained results indicated that yellow rust severity was relatively lower during 2020/2021 compared with those of to the situation during 2018/2019 and 2019/2020. The rust data also, revealed that disease severities that were recorded at Gemmeiza 11 and Morocco were higher than the other tested varieties at all locations during the three growing seasons of the study.

According to the final rust severity (%), the tested wheat varieties could be classified into three main groups depending on the response (rust severity (%) and infection type):

The first group is immune cultivars which included Sakha 95 and Misr 3 at both locations . The second group: Susceptible wheat varieties with partial resistance (slow rusting resistance) which included the wheat varieties with infection type susceptible (S) and rust severity up to 30%. This group included; Giza 171, Gemmeiza 12, Sids 14 and Giza 168 which were susceptible to stripe rust showing different degrees of rust severity ranged between 2.67 to 26.67 at both locations.

The last group is fast rusting varieties: This group included the wheat varieties Misr 2, Misr 1, Shandweel 1, Gemmeiza 11 and Morocco which were susceptible to stripe rust showing different degrees of rust severity ranged between 30.00 % to 100.00% at both location.

Partial resistance (PR) to wheat yellow rust has been previously identified by decreasing rate of an epidemic development in the field despite a susceptible infection type or a compatible host pathogen interaction (Parlevliet, 1988). Moreover, partial resistance results from a longer latent period, lower receptivity, smaller pustule size, and lower spore production and can be measured under field conditions by lower final disease severity compared to a susceptible check genotype (Das *et al*., 1993). Partial resistance was assessed through the infection type and final rust severity (%) (Parlevliet, 1988). Safavi and Afshari (2012) used FRS (%) as a parameter to assess slow rusting resistance of wheat lines.

Field-based assessment of partial resistance is crucial in developing countries for the breeders, dealing with hundreds of lines at a time. Partial resistance could be assessed through different measures. This may be final rust severity (FRS) (Parlevliet, 1988), area under rust progress curve (ARUPC) (Wilcoxson *et al*., 1975), infection rate (IR) (Broers *et al*., 1996) and coefficient of infection (CI) (Pathan and Park, 2006). Slow rusting, a mechanism of partial resistance has been assessed through AUDPC, infection rate and final disease severity by Ali *et al*. (2007). Thus the level of partial resistance in a given set of breeding lines may be assessed, in the form of slow rusting, which reduces the epidemic progress over the season, through AUDPC, FDS and infection rate (Broers *et al*., 1996; Ali, 2007). While on single scoring basis partial resistance, in general sense, may be determined through co-efficient of infection and average co-efficient of infection (Pathan and Park, 2006). Co-efficient of infection is the most commonly used parameter for assessment of yellow rust, used by different researchers (Shah *et al*., 2003). Thus The association between co-efficient of infection and other partial resistance parameters were studied.

Previously different researchers (Mirza *et al*., 2000) have evaluated different wheat lines for yellow rust resistance; however, their studies were based solely on vertical resistance. However, there is a need to search for diverse sources of breeding lines with partial resistance. Development of improved varieties based on partial resistance with diverse sources will help combat the rust problem.

Ali *et al*., (2008 and 2009) confirmed the above mentioned results and concluded that, partial yellow rust resistance can be measured according disease severity at the time when susceptible check variety was severely diseased. Similar results were also obtained by Das *et al*. (1993) who stated that, the effective selection for slow yellow rusting genotypes can be practiced in the field based on the final rust severity.

Immune and high resistant varieties could prolong the green state of leaves to the maximum extent. It was beneficial to the early accumulation of photosynthesis and photosynthetic substances, and the plumpness and grain weight of grain were generally affected when the leaf photosynthetic ability was damaged by *Pst* with grain dried, thousand-kernel weight significantly reduced, yield seriously reduced, population yellow abnormal, plant, stem, leaf sheath or panicle abnormal green dry or dead (Huang *et al*., 1981; Chen *et al*., 2002; Elbasyoni *et al*., 2019 and Erik *et al.*, 2002).

Environmental factors in general, play an important role for management most of plant disease epidemics, especially wheat yellow rust. However, study and analysis of the environmental factors in relation to yellow rust disease development, help us to predict the future yellow rust epidemics. So that preventive measures should be taken into consideration to minimize and/or decrease yield losses due to yellow rust.

The present study focus on determine the role of some environmental factors favoring to wheat yellow rust. Diseases response of all the tested varieties revealed a positive correlation between most of the environmental factors under study i.e. precipitation, average wind speed, maximum wind speed, minimum air temperature, maximum air temperature and maximum relative humidity. While, the environmental factors i.e. solar radiation and minimum relative humidity showed negative correlation with yellow rust severity(%).

As early study of Sharp (1965) stated that, the minimum, optimum and maximum temperatures for yellow rust urediniospores germination are 0 °C, 7–12 °C and 20–26 °C, respectively.

In Luxembourg, El Jarroudi *et al.* (2017) found that a combination of RH > 92%, R ≤ 0.1 mm, and 4 ◦C < T < 16 ◦C over a minimum of four consecutive hours were favorable to the development of WSR epidemics. De Vallavieille-Pope *et al*. (1995) reported that in controlled conditions (i.e., air-filtered chamber experiment inside a greenhouse) the optimal air temperatures favoring infections by *P. striiformis* under non-limiting wetness duration ranged from 5 ◦C to 12 ◦C. Air temperatures during the February–June period were the most influential factor for noticeable WSR severity and damaging epidemic (Beest *et al*., 2008). Khan *et al*. (2023) Evaluated seven wheat varieties included Sehar-06, Galaxy-13, Abdul Sattar-02, Faisalabad-08, Johar-16, TD-1 and Ujala-16 were planted at research farm of Muhammad Nawaz Shareef University of Agriculture, Multan, Pakistan during November 2019–20 and 2020–21 to determine their response toward *Puccinia striiformis*. They found that, minimum air temperature expressed a significant correlation with disease severity on varieties Sehar-2006, Galaxy-13 and Abdul Sattar-02 while non-significant correlation with disease severity on varieties Faisalabad-08, Johar-16, TD-1 and Ujala-16. Similarly, maximum air temperature, relative humidity, wind speed and solar radiation showed non-significant correlation with disease severity while rain fall was negatively non-significant.

During the three seasons of the study, at the two locations i.e. Shibin El-Kom and Itay El-Baroud, maximum relative humidity is the main environmental factor that plays a major role in creation of favorable environmental conditions for disease onset and it's development. The duration of yellow wetness period determines the amount and/or numbers of germinated spores, and in turn of the pathogen successful infection process (Rapilly, 1979). However, the second environmental factor under study, wind velocity did not affect directly on yellow rust development, but it plays a major role in the dispersal of spores both at short and long distance (El Jarroudi *et al*., 2020). It was stated from the previous studies that, the high wind velocity causes long distance dispersal (LDD) of urediniospores while low wind velocity agitates the leaves against each other, makes the canopy dry then releases and liberation of the spores from the uredinia (El Jarroudi *et al*., 2017).

Crop modeling has been used over a wide array of crop types and diseases. Models can be either mechanistic or empirical. Mechanistic models are generally more explanatory and often use results from controlled environment experiments, whereas empirical models generally use statistics to describe relationships between variables using data from field experiments. Once developed, disease prediction models must be validated regardless of strategy used to develop the model. This can be accomplished by dividing data into model development and model validation sets prior to development or by using data collected separately from the data used for model development. Bayesian decision theory may also be used to evaluate models. This method evaluates the likelihood of making the correct decision with the predictive model verses decisionsmade without any additional information (De Wolf and Isard, 2007).

Logistic regression is also often used in modeling to assess disease risk in cropping systems. Paul and Munkvold (2004) used pre-planting and hybrid genetics information to predict risk for gray leaf (caused by *Cercospora zeae-maydis*) spot on corn (Zea mays) using logistic regression. The model did not use any in-season data for disease risk prediction. Therefore, the predictive model can be used for decisions such as hybrid selection or fungicide application.

Moreover, crop-weather models may be the maximum useful tools for forecasting the occurrence of a particular disease (Hatfield, 1990). Most of wheat rust epidemics have been successfully predicted using mechanistic and empirical approaches (Coakley and Line, 1988).

The empirical models were based on either meteorological factors alone (Coakley and Line, 1988) or both biological and meteorological factors (Eversmeyer and Kramer, 1992). Most of the previous studies developed yellow rust-prediction models by evaluating few selected wheat cultivars in Argentina and Europe (Daamen *et al*., 1992).

The relative humidity played an important role in the penetration of haustorium of fungus as it makes the leaf tender due to moisture content. The change in temperature due to rain certainly influences the disease progress. Similar results were reported by Naseri and Sharifi (2019).

REFERENCES

Abd El-Hak, T.M.; Stewart, D.M. and Kamel, A.H. (1972). The current rust situation in the near East countries. Regional Wheat Workshop. Beirut Lebanon, 1-29.11-15: 81-90.

Abou-El-Naga, I. F. (2001). Biomphalaria alexandrina in Egypt: Past, present and future. Journal of biosciences, 38: 665-672.

Abu El-Naga, S. A.; El-Habbaa, G. M.; Youssef, W. A. and Aly, A. M. (1999). Evaluation of certain wheat entries against leaf and stripe rust diseases in North Delta. Annals of Agricultural Science, Moshtohor., 37(2): 1125-1141.

Ali, S., Shah, S.J.A.; Khalil, I. H.; Raman, H.; Maqbool, K. and Ullah, W. (2009). Partial resistance to yellow rust in introduced winter wheat germplasm at the north of Pakistan. Australian Journal of Crop Science, 3(1): 37-43.

Ali, S.; Shah, S.J.A. and Maqbool, K. (2008). Field-Based Assessment of Partial Resistance to Yellow Rust in Wheat Germplasm. J Agric Rural Dev., 6(1&2): 99-106.

Ali, S.; Shah, S.J.A. and Ibrahim, M. (2007). Assessment of wheat breeding lines for slow yellow rusting (*Puccinia striiformis* west. *tritici*). Pak J Biol Sci 10: 3440-3444.

Beest, D.E.T.; Paveley, N.D.; Shaw, M.W and Bosch, F.V.D. (2008). Disease–Weather Relationships for Powdery Mildew and Yellow Rust on Winter Wheat. J. Ecology and Epidemiology. 98(5): 609-617.

Broers, L. H. M.; Cuesta Subias, X. and Lopez Atilano, R. M. (1996). Field assessment of quantitative resistance to yellow rust in ten spring bread wheat cultivars. Euphytica, 90: 9-16.

Chen, Q.; Sun, W.B.; Zhen, L.P. and Cha, Z.X. (2002). The determination and application of wheat stripe rust for different diseases. Plant Protection, 28 (2): 19-21

Coakley, S.M. and Line, R.F. (1988). Predicting stripe rust severity on winter wheat using an improved method for analyzing meteorological and rust data. Phytopathology, 78: 543-550.

Daamen, R.A.; Stubbs R.W. and Stol W. (1992). Surveys of cereal diseases and pests in The Netherlands. 4. Occurrence of powdery mildew and rusts in winter wheat. European Journal of Plant Pathology, 98: 301-312.

Das, M.K.; Rajaram, S.; Ktonstad, W.K.; Mundt, C.C. and Singh, R.P. (1993). Association and genetics of three components of slow rusting in leaf rust of wheat. Euphytica, 68 : 99 - 109.

De Vallavieille-Pope, C.; Huber, L.; Leconte, M. and Goyau, H. (1995). Comparative effects of temperature and interrupted wet periods on germination, penetration and infection of *Puccinia recondita* f. sp. *tritici* and *P. striiformis* on wheat seedlings. Phytopathology, 85: 409-415.

De Wolf, E. D. and Isard, S. A. (2007). Disease cycle approach to plant disease prediction. *Annu. Rev. Phytopathol.*, 45: 203-220.

El Jarroudi, M.; Kouadio, L.; Bock, C.H.; El Jarroudi, M.; Junk, J.; Pasquali, M.; Maraite, H. and Delfosse, P. A. (2017). Threshold-based weather model for predicting stripe rust infection in winter wheat. Plant Dis., 101: 693-703.

Elbasyoni, I.S.; El-Orabey, W.M.; Morsy, S.; Baenziger, P.S.; Al Ajlouni, Z. and Dowikat, I. (2019). Evaluation of a global spring wheat panel for stripe rust: Resistance loci validation and novel resources identification. PLoS ONE, 14(11): e0222755. Doi.org/10.1371/journal.pone.0222755.

El-Daoudi, Y.H.; Ikhlas Shafik, E.H.; Abu El-Naga, S.A.; Sherif, S.O.; Khalifa, M.M.O.; Mitkees, R.A. and Bassiouni, A.A. (1996). Stripe rust occurrence in Egypt and assessment of grain yield loss in 1995. Proc. Du Symposium Regional Sur les Maladies des Cerales et des Legumineuses Alimentaries 11-14 November, 1996, Rabat, Maroc.

El-Jarroudi, M.; Lahlali, R.; Kouadio, L.; Denis, A.; Belleflamme, A.; El-Jarroudi, M.; Mahyou, H. and Tychon, B. (2020). Weather-based predictive modelling of wheat stripe rust infection in Morocco. Agronomy, 10(1): 1-18.

El-Orabey, W.M.; Elbasyoni, I.S.; El-Moghazy, S.M. and Ashmawy, M.A. (2019). Effective and ineffective of some resistance genes to wheat leaf, stem and yellow rust diseases in Egypt. J. Plant Production, Mansoura Univ., 10 (4): 361 - 371.

El-Orabey, W.M.; Ashmawy, M.A.; Shahin, A.A. and Ahmed, M.I. (2020). Screening of CIMMYT wheat genotypes against yellow rust in Egypt . J. Phytophathol., 9(01): 51-70.

El-Orabey, W.M. and Elkot, A.F. (2020). Prediction of leaf rust severity and yield loss in wheat based on environmental factors. J. Plant Dis. Prot. 27 (3): Doi: org/10.1007/s41348-020-00304-2.

Elshafei, A.A.; El-Orabey, W.M.; Fathallah, F.B.; Esmail, R. and Abou-Zeid, M.A. (2022). Phenotyping and validation of molecular markers associated with rust resistance genes in wheat cultivars in Egypt. Mol Biol Rep 49, 1903-1915. https://doi.org/10.1007/s11033-021-07002-8.

Erik, H.; Murchie, L.; Yang, J.C.; Hubbart, S.; Horton, P. and Peng, S.B. (2002). Are there associations between grain flling rate and photosynthesis in the flag leaves of field-grown rice. Journal of Experimental Botany, 53(378): 2217–2224.

Esmail, S.M.; Draz I.S.; Ashmawy M.A. and El-Orabey W.M. (2021). Emergence of new aggressive races of Puccinia striiformis f. sp. tritici causing yellow rust epiphytotic in Egypt. Physiological and Molecular Plant Pathology, 114: 1-15.

Esmail, S.M.; Omar, G.E.; El-Orabey, W.M.; Börner, A. and Mourad, A.M. (2023). Exploring the genetic variation of stripe rust foliar and head infection in Egyptian wheat as an effect of climate change. Agronomy, 13, 1509. https://doi.org/ 10.3390 / agronomy13061509.

Eversmeyer, M. G. and Kramer, C. L. (1992). Models of multiple wheat disease epidemics in the Great Plains of the USA. *Vortraege fuer Pflanzenzuechtung (Germany)*, *24*.

Hatfield, J. L. (1990). Agroclimatology of semiarid lands. *Advances in Soil Science: Dryland Agriculture: Strategies for Sustainability* 13: 9-26.

Hong, M.A. and Singh, R.P. (1996). Contribution of adult plant resistance gene yr18 in protecting wheat from yellow rust. Plant Disease 1: 66-69.

Huang, Z.R.; Gong, J. and Feng, F.R. (1981). 1Studies of the influence of the early-senescence of wheat leaves on the grain yield with 14CO2 as a tracer. ACTA Agronomica Sinica, 7(1): 27–35.

Khan, M. A. (1997). Evaluation of multiple regression models based on epidemiological factors to predict leaf rust on wheat. Pak. J. Agric. Sci, 5(34): 1-7.

Khan, M. A.; Bashir, A. and Ayyub, M. U. (2023). Exploration of genetic diversity and drought tolerance potential of bread wheat genotypes at seedling stage using the multivariate analyses tools. *JPAA*, *8*(2): 1-10.

Mirza, J.I.; Singh, R.P. and Ahmed I. (2000). Resistance to leaf rust in Pakistani wheat lines. Pak. J. Biol Sci., (3): 1056-1061.

Moschini, R. C. and Pérez, B. A. (1999). Predicting wheat leaf rust severity using planting date, genetic resistance, and weather variables. *Plant disease*, 83(4): 381-384.

Mundt, C. C.; Brophy, L.S. and Schmitt, M.S. (1995). Disease severity and yield of pure-line wheat cultivars and mixture in the presence of eyespot, yellow rust, and their combination. Plant Pathology 44: 173 – 182 .

Nagarajan, S. (2005). Can India produce enough wheat even by 2020?. Current Science, 89(9): 1467-1471.

Naseri, B. and Marefat, A. (2019). Wheat stripe rust epidemics in interaction with climate, genotype and planting date. European Journal of Plant Pathology 2019. 154(4): 1077-1089.

Park, R.F.; Rees, R.G. and Platz, G.J. (1988). Some effects of stripe rust infection in wheat with adult plant resistance. Australian Journal of Agricultural Research 39(4): 555-562.

Parlevliet, J. E. (1988). Resistance of the non-race-specific type. In Diseases, distribution, epidemiology, and control (pp. 501-525). Academic Press.

Pathan, A.K. and Park, R.F. (2006). Evaluation of seedling and adult plant resistance to leaf rust in European wheat cultivars. Euphytica 149: 327–342.

Paul, P. and Munkvold, G. (2004). A model-based approach to preplanting risk assessment for gray leaf spot of maize. Phytopathology, 94: 1350-1357.

Peterson, R. F.; Campbell, A. B. and Hannah, A. E. (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Canadian journal of research, 26(5): 496-500.

Rajaram, S. (2000). Challenges in wheat research and development. The International Dimension of the American Society of Agronomy: Past and Future, 39-47.

Rapilly, F. (1979). Yellow rust epidemiology. Annual Review of Phytopathology, 17(1): 59-73.

Roelfs, A. P.; Singh, R. P. and Saari, E. E. (1992). Rust diseases of wheat: concepts and methods of disease management. CIMMYT, Mexico, 80.

Safavi, S. A. and Afshari, F. (2012) Identification of resistance to *Puccinia* striiformis f. sp. *triticiin* some elite wheat lines. J. Crop Prot. 1: 293–302.

Shah, S. J. A.; Khan, A. J.; Azam, F.; Mirza, J. I. and Rehman, A. U. (2003). Stability of rust resistance and yield potential of some ICARDA bread wheat lines In Pakistan. Pak J Sci Indus Res., 46: 443-446.

Shahin, A.; Ashmawy, M.; El-Orabey, W. and Esmail, S. (2020). Yield losses in wheat caused by stripe rust (*Puccinia striiformis*) in Egypt American Journal of life sciences, 8 (5): 127-134.

Sharp, E.L. (1965). Prepenetration and postpenetration environment and development of Puccinia striiformis. Phytopathology, 55: 198-203.

Snedecor, G. W. and Cochran, W. G. (1967). Shortcut and non-parametric methods. *Statistical methods*, *6*, 120.

Stubbs, R. W. (1988). Pathogenicity analysis of yellow (stripe) rust of wheat and its significance in a global context. Breeding strategies for resistance to the rusts of wheat, 8: 23-28.

Tervet, I. and Cassel, R. C. (1951). The use of cyclone in the race identification of microscopic particles. *Phytopathology*, 41: 282-285.

Todorovska, E.; Christov, N.; Slavov, S.; Christova, P. and Vassilev, D. (2009). Biotic stress resistance in wheat—breeding and genomic selection implications. Biotechnology & Biotechnological Equipment, 23(4): 1417-1426.

Wilcoxson, R. D.; Skovmand, B. and Atif, A. H. (1975). Evaluation of wheat cultivars for ability to retard development of stem rust. Annals of Applied Biology, 80(3):275-281.

التنبؤ بشدة الإصابة لمرض الصدأ الأصفر فى القمح بإستخدام بيانات الأرصاد الجوية مع نمذجة الاستجابة البيئية

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الملخص العربى

تم تقييم إحدى عشر صنفاً من القمح ضد مرض الصدأ الأصفر في موقعين مختلفين في مصر وهم شبين الكوم بمحافظة المنوفية ومحطة إيتاى البارود للبحوث الزراعية بمحافظة البحيرة، مصر خلال ثلاثة مواسم نمو متتالية هى ٢٠١٨/٢٠١٩ و٢٠١٩/٢٠٢٠ و٢٠٢٠. /٢٠٢١. تم تحديد الارتباط بين ثمانية عوامل بيئية أسبوعية وهى الإشعاع الشمسي ، إجمالي هطول الأمطار ، متوسط سرعة الرياح ، أقصى سرعة للرياح ، درجة حرارة الهواء الدنيا ، درجة حرارة الهواء العظمى ، الرطوبة النسبية الدنيا والحد الأقصى للرطوبة النسبية وشدة الإصابة بالصدأ الأصفر (٪) باستخدام تحليل الانحدار التدريجي. تم تحديد نماذج التنبؤ لكل صنف تم اختباره لشدة الإصابة للصدأ الأصفر النهائية (٪) باستخدام البيانات البيئية. بشكل عام، ارتبطت الرطوبة النسبية العظمى بشكل إيجابي مع شدة الصدأ الأصفر النهائية (٪). وجد فى هذه الدراسة ارتباط معنوى بين عاملين بيئيين هما الرطوبة النسبية القصوى وشدة الصدأ الأصفر النهائية (٪). ومن ناحية أخرى وجد ارتباط سلبي بين شدة الصدأ الأصفر النهائية (٪) والعاملين البيئين وهما الإشعاع الشمسي والرطوبة النسبية الدنيا. تشير القيم العالية لقيم معامل الارتباط (R^2) لجميع نماذج الانحدار تحت الدراسة إلى التحقق من صحة هذه النماذج للتنبؤ بشدة الصدأ الأصفر النهائية (٪) وتسهيل استخدام كل منها كنموذج تحذيري للتنبؤ لمزارعي القمح.