RESEARCH Egyptian Journal of Agricultural Research Plant Pathology

Role of Environmental Conditions on the Epidemic of Wheat Yellow Rust in Gharbia Governorate of Egypt

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Received: 27-01-2022; **Accepted**: 01-05-2022; **Published:** 17-05-2022 doi: 10.21608/ejar.2022.118682.1201

ABSTRACT

This work aimed to evaluate one hundred and fifty-five commercial wheat fields including six varieties of yellow rust (stripe rust) epidemics caused by *Puccinia striiformis* f. sp. *tritici,* in Gharbia governorate during the 2019 to 2021 seasons. Also, study the weather variables associated with yellow rust outbreaks in wheat. Temperature, relative humidity, and rain variables were obtained from the regional climate model imeto2 (http//meto.at/farmview/) as well as the World Climate Research Programme (WCRP) Global Energy and Water Cycle Experiment's (GEWEX) Surface Radiation Budget (NASA/GEWEX SRB) during the infection period from January to March. Results revealed that the high disease epidemic linked to rain precipitation and number of precipitation days combined with the minimum temperatures (5−10°C) and relative humidity (RH) of at least 60%. Levels of yellow rust severity varied according to the studied year, and wheat variety. Gemmeiza-11, Sids-12, Misr-1, and Misr-2 were the most susceptible varieties, while both Gemmeiza12 and Sakha95 were resistant to yellow rust disease during the studied period. In the 2021 season, all the wheat varieties showed a resistance response. The loss % ranged between 36.00, 40.00 %(Gemmeiza-11); 36.00, 37.25% (Sids-12); 25.00, 33.33% (Misr-1) and 21.21, 24.84% (Misr-2) in 2019 and 2020 growing seasons, respectively compared to the grain yield in 2021 season. Low disease severities were detected ranging from zero to trace infection (2.00%) in the 2021 season. A high and positive correlation coefficient (R^2) was found between disease severity % and loss in grain yield of the tested wheat varieties.

Keywords: Yellow rust, *Puccinia striiformis*, disease severity, rain precipitation, relative humidity, temperature.

INTRODUCTION

Wheat (*Triticum aestivum*) is produced in almost all the governorates of Egypt, which is considered the first field crop followed by maize. Stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici* (Pst), is one of the most important diseases of wheat that incurred great yield losses around the world (Hovmøller *et al.,* 2011; de Vallavieille-Pope *et al.,* 2012; Chen *et al.,* 2014). In the last decade, epidemics of yellow rust destroyed most of the wheat area grown with Giza 144 variety in the Northern Egyptian provinces, particularly in Manzala district in 1967 (Abdel-Hak *et al.,* 1972). Also, in 1995, the disease attacked most of the commercial wheat varieties including Gemmeiza-1, Giza-163, Sakha-69, Giza-157, Sakha-92, Giza-166, and Giza-164, causing severe infection, particularly in the north and south Delta region. The national average loss in grain yield ranged from 14.00 –20.50% in the Nile delta region (El-Daoudi *et al.,* 1996; El-Shamy and Hamada, 1997; Abu El-Naga *et al.,* 1998). Then, yellow rust epidemics occurred regularly in all the governorates of Egypt including Gharbia governorate until the 2020 season. During this period, the recent wheat varieties i.e. Gemmeiza-11, Sids-12, Misr-1, Misr-2, Giza-171 showed susceptible responses to stripe rust under field conditions and new virulent stripe rust races were appeared (Abou-Zeid and Omara, 2018; Omar, 2020; Shahin, 2020; Shahin *et al.,* 2020). Favorable climatic conditions include different variables i.e. temperature, relative humidity(RH), and rain precipitation, which leads to an increasing threat of the disease (El Jarroudi *et al.,* 2017; Bita and Farhad, 2019; Draz and Abd El-Kreem, 2021). The duration of the favorable temperature and moisture during wheat growth plays an important role in increasing yellow rust epidemics (van den Berg and van den Bosch, 2007). On the role of temperature, severe epidemics of stripe rust were linked to optimal temperatures from 7 to 12°C (Grabow *et al.,* 2016). This work aims to study the relationship between weather factors and occurrence yellow rust disease epidemics. In addition to investigate the reaction of six wheat varieties to the disease and its effect on grain yield in Gharbia governorate during the 2019 -2021 growing seasons.

MATERIAL AND METHODS

Selected locations:

This study was carried out in five districts in Gharbia governorate during 2019 – 2021 growing seasons. The surveys for yellow rust were carried out across the wheat-growing areas of El-Santa, El-Mahalla El-Kubra, Samnnoud, Zifta, and Tanta districts during the National Campaign of wheat .The district's extension engineers shared in selecting the wheat fields. Six commercial bread wheat varieties i.e. Gemmeiza-11, Gemmeiza-12, Sids-12, Sakha-94, Misr-1, and Misr-2 were observed from January–March during the 2019 – 2021 growing seasons. Three to six fields per site were surveyed depending on the year. The number of observed fields ranged from 47 to 54 each year and the total number was 155 fields during the period of study Fig.1 and Table(1). Bread wheat is usually sown from mid-November to first December.

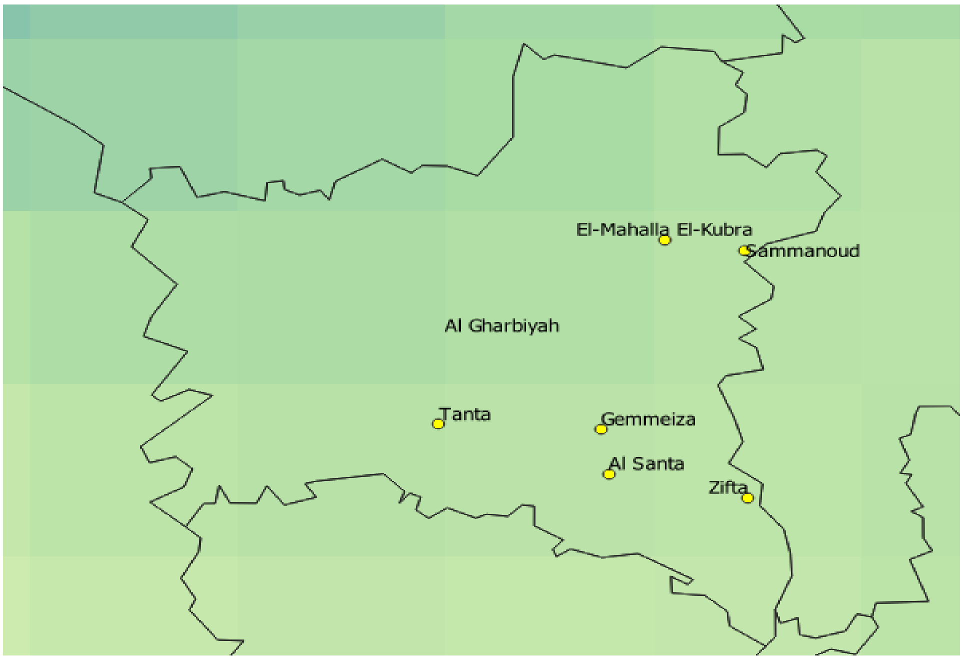

Fig. 1. Selected five districts for the observed wheat fields during the 2019 – 2021 cropping seasons in Gharbia governorate

Table 1. Distribution of 155 bread wheat fields selected in Gharbia governorate during 2019 - 2021 growing seasons.

District	Location	No. of fields in		
		2019	2020	2021
ElSanta	El-Gemmeiza	4	4	6
	Shinraq	5	4	5
	Shubra Qas	3	4	4
El-Mahalla El-Kubra	Saft Turab	4	5	4
	Shubra Malakan	3	5	4
	EL Hyatem	4	4	5
Sammanoud	Sammanoud	4	4	4
	Aziziyyah	4	5	5
Zifta	Sunbat	3	6	5
	Hanout	4	4	4
Tanta	Ragdia	4	5	4
	Shabsheir	5	4	4
Total no. of fields 155		47	54	54

Meteorological data.

Temperature (°C), relative humidity (RH %), and precipitation (mm), and precipitation days were computed using the regional climate model imeto2 (http//meto.at/farmview/). This weather station is located in Gemmeiza Agricultural Research Station which is based on its location relative to wheat-producing areas in Gharbia governorate, the station covers about 25 km in all directions and is away from 7 and 25 km from the selected sites. Obtained data are present in (Table 2).

Table 2. Mean of Metrological data obtained by the regional climate model imeto2 (http//meto.at/farmview/) in Gharbia governorate during 2019 up to 2021 seasons.

Variable	2019			2020			2021		
	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.
Precipitation(mm)	1.13	0.37	0.65	2.03	0.77	3.05	0.77	0.79	0.12
Precipitation days	19	10	7	11	22	15	9	4	6
RH%	55.34	58.79	58.3	67.24	66.94	57.9	58.56	57.77	52.28
TMAX	18	20.41	21.36	17.23	20.29	25.68	20.56	25.06	21.62
TMIN	6.5	7.37	7.87	7.82	8.5	10.92	9.4	11.68	9.78

Rain: Precipitation (mm day-1) RH: Relative Humidity at (%) TMAX: Maximum Temperature(C) TMIN: Minimum Temperature

To confirm the meteorological data, we obtained the weather data per each district from the World Climate Research Programme (WCRP) Global Energy and Water Cycle Experiment's (GEWEX) Surface Radiation Budget (NASA/GEWEX SRB), Table (3).

Table 3. Mean of Metrological data obtained by the World Climate Research Programme (WCRP) Global Energy and Water Cycle Experiment's (GEWEX) Surface Radiation Budget (NASA/GEWEX SRB) in Gharbia governorate during 2019 up to 2021 seasons

Variable	2019			2020			2021		
	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.	Jan.	Feb.	Mar.
Precipitation(mm)	1.23	0.43	0.82	2.10	0.60	2.74	0.27	1.16	0.23
RH%	55.29	58.54	56.2	69.07	65.91	59.81	62.02	62.75	60.40
TMAX	19.72	21.39	23.84	18.36	20.80	24.65	22.08	19.81	30.78
TMIN	7.25	8.17	9.70	8.47	8.72	10.35	9.67	9.52	10.09

Assessment of wheat yellow rust severity:

Visual disease severity estimates were done using the 0 -100 scale proposed by (Peterson *et al.,* 1948) and infection type adopted by (Johnston, 1961). Yellow rust severity was detected as percent leaf area affected by the disease, while Infection types were classified into five categories, 0 (immune), R (resistance), MR (moderate resistance), MS (moderately susceptible), and S (susceptible). The first record started with appearance of yellow rust symptoms in any variety and location. Assessment of the disease was carried out at least on ten sites of each field. Four assessments were carried out along the season to detect the final disease severity.

Grain yield affected by yellow rust epidemics:

Estimation of the grain yield for each variety/ site and season was carried out in cooperation with farmers as a ton per acre. The loss % of grain yield/acre was estimated by comparing the yield in 2019 and 2020 and 2021seasons , which relatively no yellow rust infection was detected, using the equation adopted by (Calpouzos *et al.,* 1976)

Loss% = (1-Yd /Yh) x100

Yd =Yield of diseased field   Yh= yield of healthy field

Least significant differences (L.S.D. at 0.05%) were used to comparisons yield components parameters under study according to Snedicor (1957). The correlation coefficient was used to expos the relation disease severity %and grain yield loss

RESULTS

Yellow rust mean disease severity:

Mean disease severity of yellow rust of 6 bread wheat varieties evaluated in 155 fields in Gharbia governorate from the 2019 - 2021 seasons Table (4). The first observation of yellow rust varied depending on the year, and wheat variety. First symptoms were generally observed between the 1st January and 5th February 2019 and 2020 in most of the sites. The varieties Gemmeiza-11, Sids-12, Misr-1, and Misr-2 showed high mean disease severity percentages ranging from 46 to 94 S in 2019 and 2020 seasons at all the tested sites, while the Gemmeiza-12 variety showed low mean disease severity % (4S) in 2019 and high (55S) in 2020. Slight disease severities were detected on the evaluated varieties ranging from zero to trace infection in the 2021 season.

Table 4. Mean disease severity of yellow rust of 6 bread wheat varieties evaluated in 156 fields in Gharbia governorate during 2019- 2021 growing seasons.

Variety	**2019**	**2020**	**2021**
Gemmeiza-11	76S	94S	1.8S
Gemmeiza-12	4S	5.5S	0
Sakha-94	2.33S	0	0
Sids-12	76S	77.5S	2.0S
Misr-1	48S	80S	2.2S
Misr-2	46S	55S	2.0S

Mean disease severity % was assessed according to the modified 0 -100 scale proposed by Peterson et al. (1948) and infection type (Johanston, 1961).

Metrological analysis:

Precipitation (mm/ day) and Precipitation days, humidity, and maximum and minimum temperature during the critical months of infection (January – March) in 2019 up to 2021 seasons were obtained from the regional climate model imeto2 (Table 2). Data clear that mean precipitation (mm) and precipitation days in 2019 and 2020 seasons (1.3, 0.37, 0.65mm and 2.03, 0.77, 3.05 mm/ day) were more than those in 2021(0.77, 0.79 and 0.12 mm/ day (Fig. 2). The associated degrees of minimum temperature in 2019 and 2020 were relatively less than those in 2021. The minimum temperatures (5−10°C) and humidity percentages(RH%) ranged from 52 up to 67% were relatively more in 2019, 2020 seasons than those in 2021 seasons Fig. (3). In general, slight differences in metrological data were observed between the regional climate model imeto2 and those obtained from NASA/GEWEX SRB Table (3).

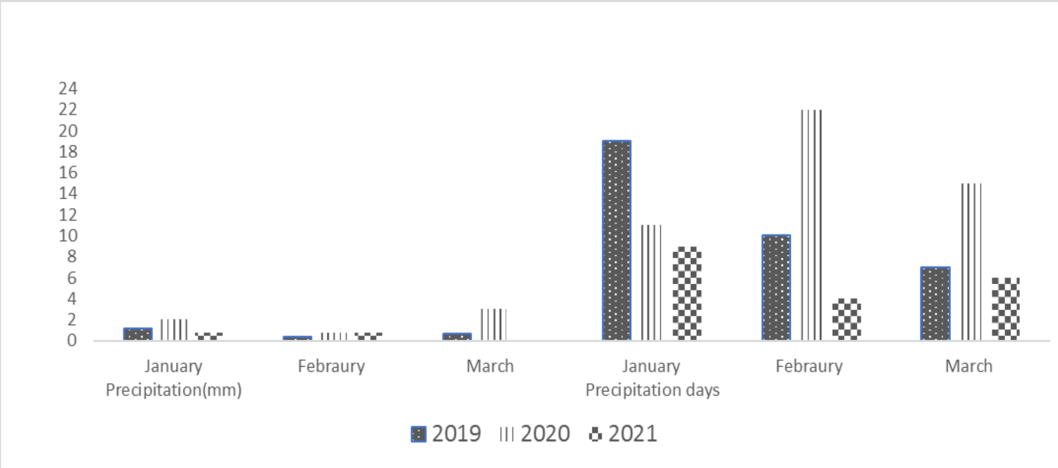

Fig. 2. Rain precipitation (mm/day) and precipitation days during the critical months in 2019 up to 2021 growing seasons.

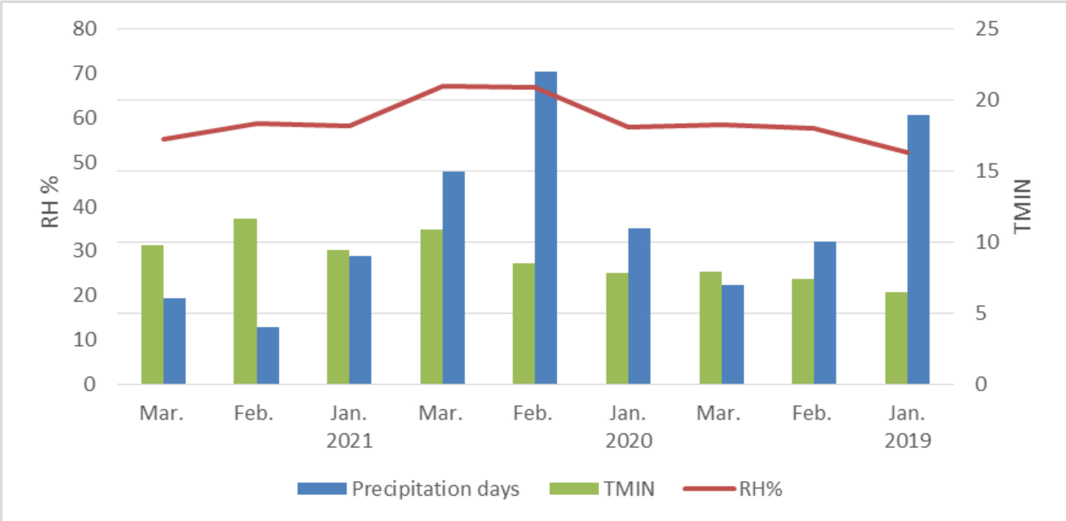

Fig. 3. Association between precipitation days (mm/day), minimum temperature (TMIN), and relative humidity (RH%) in the critical months during 2019 up to 2021 seasons.

Grain yield of the wheat varieties:

Data in the Table (5) revealed that the loss in grain yield was associated with yellow rust disease severity of each wheat variety / growing season. Significant differences were found between the tested wheat varieties. The wheat variety Gemmeiza-11 showed the lowest grain yield (1.725 and 1.600 ton /feddan) followed by Sids-12 variety (1.763 and 1.600 ton / feddan), Misr-1 (1.800 and 1.600 ton /acre) then Misr-2 variety (1.950 and 1.860 ton / feddan) in 2019 and 2020 seasons, respectively. While in 2021 season, all the wheat varieties gave high grain yields ranging from 2.400 ton / feddan (Misr-1) to 2,850ton/ feddan (Sakha-94). The loss % of grain yield/variety was assessed as compared between those in the 2019, 2020 seasons and the yield in the 2021 season. Gemmeiza-11, Sids-12, Misr-1 and Misr-2 gave the highest losses of grain yield, respectively. The loss % ranged between 36.00, 40.00 %(Gemmeiza-11), 36.00, 37.25% (Sids-12), 25.00, 33.33% (Misr-1) and 21.21, 24.84% (Misr-2) in 2019 and 2020 growing seasons, respectively compared to the obtained grain yield in 2021 season

Table 5. Mean grain yield (ton/feddan) and grain loss% of 6 bread wheat varieties evaluated in 155 fields in El-Gharbia governorate during 2019- 2021 growing seasons.

Wheat variety	**Grain yield/ ton/ feddan**			**Loss %**	
	2019	**2020**	**2021**	**2019**	**2020**
Gemmeiza-11	1.725	1.600b	2.700b	36.00	40.00
Gemmeiza-12	2.750a	2.700a	2.775ab	0.90	2.00
Sakha-94	2.840a	2.800a	2.850a	0.35	1.75
Sids-12	1.763b	1,600b	2.550c	30.86	37.25
Misr-1	1.800b	1.600b	2,400d	25.00	33.33
Misr-2	1.950b	1.860b	2.475cd	21.21	24.84
L.S.D. at 0.05	0.62	0.43	0.12		

Correlation between disease severity and grain yield loss.

A positive and high significant correlation coefficient (R2) was found between disease rust severity (%) and loss (%) in grain yield (0.988**) in 2019 season and (0.999) in 2020 season Table (6)

Table 6. Correlation coefficient (R^2) between disease severity% and grain yield loss in 2019 and 2021 seasons.

Wheat variety	2019 season			2020 season		
	Disease severity	Loss %	R^2	Disease severity	Loss %	R^2
Gemmeiza-11	76S	36.00	0.988^{**}	94S	40.00	0.999**
Gemmeiza-12	4S	0.90		5.5S	2.00	
Sakha-94	2.33S	0.35		0	1.75	
Sids-12	76S	30.86		77.5S	37.25	
Misr-1	48S	25.00		80S	33.33	
Misr-2	46S	21.21		55S	24.84	

DISCUSSION

Yellow rust (*Puccinia striiformis* f. sp. *tritici*) is considered the most effective disease on wheat and causes a great reduction in grain yield worldwide. There is no prediction model for yellow rust epidemics now in Egypt. Only, the prediction depends on observations of the wheat trap nursery for yellow rust, which is cultivated in almost all the governorates of Egypt. These trap nurseries include all the resistance genes of yellow rust as well as the local wheat varieties. Evaluation of wheat varieties revealed that Gemmeiza-11, Sids-12, Misr-1, and Misr-2 varieties had high disease severities of yellow rust, respectively at all sites in 2019 and 2020 years Table (4). (Shahin, 2020) stated that recent commercial wheat varieties*,* Misr-1, Misr-2, Giza-171 became susceptible under field conditions. Also, infections of stripe rust were observed on some wheat lines carrying the *Yr* genes *Yr1, Yr17, Yr27, Yr32* and *YrSp* which previously known to be resistant in trap nurseries. In addition to prevalence of new virulent races of the fungus lead to breakdown rust resistance in wheat varieties. (Esmail *et al.*, 2021) reported that Six new aggressive races i.e. 151E80, 135E16**,** 160E173, 224E191, 238E143 and 72E8 during 2019 and 2020 seasons. There is no doubt that the cultivation of the highly susceptible variety, Gemmeiza-11 in about 60% of the wheat area of the governorate in the 2019 and 2020 seasons leads to an increase in yellow rust disease infection and considered as spreader of rust spores to the other varieties. (Solh *et al.,* 2012) stated that individual crop losses of up to 80% were reported in the widespread epidemic in the Middle East and North Africa in 2010 when initial infection occurred on susceptible wheat varieties at early growth stages. Also, the late discovery of the disease and the using the wrong machine for managing the disease leads to an increase in the disease severity. In contrast, in the 2021 year the same varieties were relatively resistant or showed very low disease severities to yellow rust due to the unsuitable weather conditions for the fungus.

Yellow rust epidemics are the outcome of interactions between susceptible host varieties, favorable environmental conditions, and sufficient quantities of virulent pathogen inoculum (Zadoks, 1985). Early field observations of yellow rust have been shown to have predictive value, so a forecast system combining weather and disease observations may be sufficiently accurate to be useful. (Young *et al.,* 2003).In our results, a low temperature (5 –10 ^{0}C) associated with great precipitation (mm) and more precipitation days and relative humidity ranging from 55 to more than 66% from January - March period were associated with subsequent higher disease severity. (Bita *et al.,* 2019) stated that occurrence of stripe rust epidemic was linked to the number of rainy days, the number of days with minimum temperatures within the range of 7−8°C and relative humidity (RH) above 60%.(El Jarroudi *et al.*, 2017) found that high humidity, precipitation, or dew is the requirement for the development of the yellow rust epidemic. (Papastamati and Van den Bosch, 2007) found that the temperature in January and February was the most influential variable for the progress of yellow rust disease. The temperature range from10 - 15°C was suitable for the development of yellow rust while temperatures higher than 23°C slow down the epidemic (Milus *et al.,* 2009). (In contrast, Te Beest *et al.,* 2008) found that the best model describing the disease epidemic of yellow rust consisted of maximum temperature and rain, with an RH of 86.4%. It could be stated that the regional climate model imeto2 presented relatively the same patterns of meteorological conditions obtained by NASA/GEWEX SRB.

The data revealed that the wheat varieties Gemmeiza-11, Sids-12, Misr-1, and Misr-2 highest disease severity consequently gave the highest percentage of grain loss in the 2019 and 2020 seasons. Sahin et al ,(2020) reported that the cultivars Gemmeiza 11 recorded 64.20% grain yield losses followed by Misr- 1 (62.38%), Misr-2 (57.66%) and Sids-12 (50.89%). The obtained results showed a positive and high significant correlation coefficient (R^2) between stripe rust disease severity and grain loss/ feddan releasing (988^{**} and 999**) in the two seasons, respectively. Many papers reflected the great relationship between final stripe rust severity and grain yield loss %(Ahmad *et al.,* 2010; Ashmawy *et al.,* 2013; Taye *et al.,* 2015).Yield loss was correlated with the proportion of leaf area affected by yellow rust development. In most wheat-producing areas, yield losses caused by yellow rust ranged from 10-70% depending upon the susceptibility of cultivar, earliness of the initial infection, rate of disease development, and duration of the disease (Chen, 2005).

CONCLUSION

From our study, we found that low temperature (5-10^{0}C) associated with more precipitation quantities (mm/day), number of rainy days and humidity (RH %) more than 50% are the most suitable prediction for the occurrence of the yellow rust epidemics in Egypt. The increase in grain losses % may be related to cultivating the highly sensitive wheat variety Gemmeiza-11 on a large scale as well as the late discovery of the disease and emergence of new virulent stripe rust races. To reduce yellow rust epidemics, the following steps must be followed, 4-5 resistant wheat varieties should be cultivated, early discovery of the disease, use the appropriate fungicide and spray machine. High significance and positive correlation coefficient (R^2) were found between stripe rust severity % and loss % of grain yield.

ACKNOWLEDGEMENT
The Prediction of Worldwide Energy Resource (POWER) Project is funded through the National Aeronautics and Space Administration (NASA) Applied Sciences Program within the Earth Science Division of the Science Mission Directorate. The POWER team could not have completed this task without both technical and scientific inputs from the following Earth Science Division teams: The World Climate Research Programme (WCRP) Global Energy and Water Cycle Experiment's (GEWEX) Surface Radiation Budget (SRB) and the Clouds and the Earth's Radiant Energy System (CERES) projects at NASA LaRC and the Global Modeling and Assimilation Office at the NASA Goddard Space Flight Center. The data obtained through the POWER web services was made possible with collaboration from the NASA Langley Research Center (LaRC) Atmospheric Science Data Center (ASDC).

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دور الظروف الجوية فى تطور وبائية مرض الصدأ الأصفر على القمح فى محافظة الغربية بمصر

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الملخـــص

تهدف هذه الدراسه الى تقييم مائة وخمسه وخمسين حقلاً تجاريًا ممثله فى ستة أصناف من القمحً لوبائيات مرض الصدأ الأصفر الناجم عن *Puccinia striiformis* f. sp. *tritici* في محافظة الغربية خلال المواسم من 2019 إلى 2021. وأيضًا دراسة الظروف البيئية المناسبه لحدوث وبائيه بمرض الصدأ الأصفر. تم الحصول على درجات الحرارة والرطوبة النسبية والأمطار من محطة التنبؤ imeto2 بمحطة بحوث الجميزة وكذلك من برنامج أبحاث المناخ العالمي (NASA / GEWEX SRB) خلال الفترة من يناير إلى مارس خلال مدة الدراسه. أظهرت النتائج أن حدوث وبائيه شديده بالمرض كان مرتبط بكمية وعدد أيام الأمطار مع درجات حراره منخفضه (5-10 درجات مئوية) ورطوبة نسبية (RH) على الأقل 60٪ . وقد أظهرت نتائج الدراسة الى تفاوت شدة الاصابه بالصدأ الأصفر تبعًا للسنة وصنف القمح المنزرع. وكانت الأصناف جميزة11 – سدس12 – مصر1 و مصر2 على التوالى الأكثرشدة اصابه خلال موسمى الزراعه2019 و.2020 بينما أظهرت أصناف القمح جميزة12 و سخا94 أثار من الاصابه يالمرض . تراوحت نسبة الخسارة ما بين 36.00 ، 40.00٪ (جميزة 11)-.36,00 ، 37,25٪ (سدس 12) - 25,00 ,33,33%(مصر1) و 21,21 , 24.84٪ (مصر -2) في موسمي 2019 و 2020 على التوالي بالمقارنة بمحصول الحبوب لنفس الأصناف فى موسم 2021. والتى كانت تقريبا مقاومة للمرض. أظهرت الدراسه وجود معنويه عاليه موجبه لمعامل الارتباط بين شدة الاصابه والخساره فى محصول الحبوب للاصناف تحت الدراسه.

الكلمات المفتاحية : صدأ أصفر، بكسينيا ستريفورمز، شدة الاصابه، سقوط الامطار، الرطوبه النسبيه، درجة الحرارة