Early Warning of Wheat Leaf Rust Disease and Prediction Disease Status Based on the Modeling Weather

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Abstract: Wheat leaf rust (WLR), caused by *Puccinia triticina* (Pt) is an epidemic disease. The present study was concerned with the epidemiology of WLR disease in Egypt during the 2014/16 growing seasons, in Egypt. To study the effect of climatic factors on WLR incidence; four wheat genotypes were screened against WLR, under field conditions at Kafer El-Sheikh and Beni-Suef governorates. The average daily temperature during the four months of the study was closely related to the development and final rust severity %. The weather data indicated that most of January and February nights of 2014/2015 were relatively cool (min temperature <10°C) at wheat growing areas. There was a big contrast in this regard with January and February of 2015/2016 at Kafr El-Sheikh and Beni Suef, which had relatively warm nights. An epidemic of WLR disease started 10 to 16 days earlier during 2015/2016 rather than 2014/2015. It depends on the favorability of weather conditions such as early warm seasons. Disease infection in wheat crop highly influenced meteorometeorids' highly influenced logicall factors. The weather-based modeling for early warring disease infestation may provide appropriate tool for investigating and predicting disease status.

Keywords: Wheat, *Puccinia triticina,* Epidemiology and Climatic factors

INTRODUCTION

The widespread occurrence of the wheat leaf rust (WLR) is pathogen mainly attributed to its broad climatic adaptation to the wide range of diverse environmental conditions such as rainfall, humidity, temperature, wind speed and direction. The evolution of new virulence through migration, mutation, recombination of existing virulence and their selection is more frequent in rust fungi (Brittain *et al.,* 2013).

The occurrence and development of WLR disease were, generally affected by the environmental conditions dominate through the growing seasons. Rust appears 30-40 days earlier in Lower Egypt than in the Middle and Upper Egypt. Also, disease severity is higher in the northern than in the southern Governorates (Nazim *et al.,* 1976; Kamel *et al*., 1976). The urediospores require at least 3h of continuous moisture (dew formation) on the plant surfaces for germination and development of infection structures (Obst and Paul, 1993; Singh *et al*., 2007).

In Egypt, the high levels of distribution of WLR at Sakha location compared with Giza location, in Egypt the clear variance in meteorological factor between the two locations gave a reasonable explanation where Sakha location reported higher relative humidity (RH%) values and greater amount of rainfall and wind (Diab, Hoda, 1994). However, the optimal conditions for WLR developing are day time temperatures of around 20–25°C (Prigge *et al*., 2005). There was a high positive correlation between rust severity (%) and minimum temperature. Meanwhile, a negative correlation was obtained with the maximum temperature degree (Bassiouni, 1971; El Jarroudi *et al*., 2014). The main goals of the present study were proposed to track and assess changes in WLR spore traps, as well as their geographical distribution. In addition, meteorological factors in relation to WLR development.

MATERIALS AND METHODS

1. Disease survey

The wheat leaf rust severity of each cultivar was recorded every 7 days post the initial infection occurred until the early dough stage (Large, 1954) using the modified Cobb's scale (Peterson *et al.,* 1948). The host response was evaluated using the scale described by Roelfs *et al.* (1992) and Singh *et al.* (2013).

The susceptibility and resistance reaction were assessed through host response, and the component of disease incidence that was estimated as follows; final rust severity (FRS) was assessed as a percentage of disease severity for each of the tested wheat cultivars, when the highly susceptible check variety, was severely rusted and the disease severity reached its maximum and final level (Das *et al.,* 1993).

2. Meteorological factors in relation to WLR development

Climatic data were collected in the two months of March and April during the 2014/2015 and 2015/2016 growing seasons in Beni-Suef and Kafr El-Sheikh Governorates. Which was (daily maximum and minimum temperature (C^0), relative humidity (RH%) and wind direction (^{0}).

2.1. Disease progress curves and statistical analysis

Statistical modeling of disease progress data for WLR represented as $y = f(x)$, where y is disease severity, x is time (days after planting)*;* $f(x)$ is function of time. The equations of disease progress curves for the growing area.

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3. Monitoring of host characters

3.1. Effect of wheat age

To study disease progress curves, statistical analysis the metrological data was used for fitting the best model to describe the relationships between time (days after planting) and developing disease severity. Statistical modeling of disease progress data for WLR represented as $y = f(x)$, where y is disease severity, x is time (days after planting); $f(x)$ is the function of time. The function of time as the liner model form as $y= b_0 + b_1x + b_2 x^2 + b_qx^q$, in which the *b's* are unknown parameters estimated from the data and x is days after wheat planting (Khan *et al.,* 2013).

3.2. Day-degree centigrade in relation to WLR **appearance (DDC)**

A calculated of day-degree (DDC = Max temperature – Mini temperature/basic temp (8°C). The DDC model described in this study has proven effective for timing initial control.

3.3. Empirical model for predicting disease severity

The disease severity has been predicted by regression estimated disease severity versus the accumulative day-degree at studied location. Prediction of disease severity has been formed as $y= b_0 + b_1x + b_2 x^2 + ... b_qx^q$, in which the *b's* are unknown parameters estimated of the data and x is accumulative day-degree value, which is estimated from wheat planting time.

4. Model to predict of wheat leaf rust epidemic under field conditions (Critical point)

A critical point model was selected and tested to describe the occurrence of the WLR epidemic by combination weather conditions factors. Model =If (and (Max tem. < 25, and (Min temp. > 8, Min temp. < 14), and (RH >70), (and (Wind speed >1.5))), 1, 0) (described by Moschini & Perez, 1999 and modified by Najeeb, Khadegah).

Combines between wind speed for at least 24-hours, maximum temperature < 25°C, minimum temperature not less than 8°C < 14°C and minimum RH 70%.

RESULTS AND DISCUSSION

1. Monitoring of the weather conditions

The weather data included the thresholds of temperature (min. 10°C & max. 25°C), relative humidity (85%) and wind speed (2 Km/s) were collected and plotted horizontally from January 1st to April 28th through 2014-2016 at Kafr El-Sheikh and Beni Suef. Most of the nights at wheat- growing fields in January and February of 2014/2015 were relatively cool (min. temperature <10°C). However, big contrast regards was observed January and February of 2015/2016 at Kafr El-Sheikh and Beni Suef, which had relatively warm nights.

2. Wheat leaf rust development

A survey of WLR incidence was carried out in two locations in Egypt, during two consecutive seasons 2014-2016. Various four wheat genotypes in each location were surveyed using the disease assessment keys. There were some differences between disease severities at these locations (Table 1). During the two consecutive growing seasons, from December to April 2014/2016, the three cultivars were evaluated in Kafr El-Sheikh and Beni-Suef. Observations for disease incidence were initiated 50-60 days post planting. During epidemic seasons, the disease progressed much more quickly in Gemmiza-7 and Morocco respectively. On the other hand, Sakha-94 showed a high level of resistance to *Puccinia triticina*. The obtained results indicated that the disease severity was very low in all surveyed locations at Kafr El-Sheikh, it ranged between 29.82 and 36.85%. On the other hand, the highest severity was recorded at Beni Suef, (33.74 and 35.56%) during 2014/2016 respectively. It was clearly shown that, the disease incidence varied between the two seasons and different locations in most surveyed areas. In Kafr El-Sheikh the highest severity indicated that these locations were grown under favorable weather conditions.

Table (1): Effect of wheat leaf rust infection expressed as final rust severity percentage (FRS %) of three wheat genotypes under Egyptian field conditions, during 2014 – 2016

NO.	Wheat genotypes	***Seasons / Areas / FRS%***					
		The first season 2014/2015			**The second season 2015/2016**		
		Area 1	**Area 2**	**Mean**	**Area 1**	**Area 2**	**Mean**
1	Gemmiza-7	63.33 [a]	66.66 [a]	**65.53**	80.0 [b]	66.66 [b]	**75.55**
2	Sakha-94	3.00 [f]	6.00 [d]	**4.76**	4.00 [f]	2.60 [e]	**3.43**
3	Morocco	60.00 [b]	60.00 [a]	**62.10**	90.00 [a]	80.00 [a]	**86.50**
	Mean	29.82	33.74	**32.74**	36.85	35.56	**38.23**

FRS%= Final rust severity%, Area1 = Kafr El-Sheikh, Area2 = Beni Suef

2.1. Monitoring and estimating of disease dynamics

Disease component; disease progress curves and final rust severity (FRS), were assessed. The epidemic of WLR disease began shortly after the warm season started and steadily progressed in most of the wheat growing locations. The first appearance of WLR infection was observed in non-epidemic season 2014/2015 between 1-March in Kafr El-Sheikh and 20-January in Beni Suef. However, through the epidemic season 2015/2016, it was observed between 24-February in Kafr El-Sheikh and 15-January in Beni Suef (Table 2). The progress of WLR disease in fields (x), the x increased from $0 \leq x\ 0 \leq 1.0$-10 % after 95 days in Kafr El-Sheikh during the non-epidemic year, while during the epidemic year, the x increased from $0 \leq x0 \leq 40$-45% after 50 days in Beni Suef from planting date. Severities values of WLR versus time (a disease progress curve) summarized the effect of host and environment on epidemic development (Figs. 1-3).

In the first location (Kafr El-Sheikh), the highly susceptible cultivars that showed high rust severity (%) were Gemmiza-7 and Morocco, in both two seasons, the second season (epidemic season) the most susceptible one. On the other hand, the wheat cultivar Sakha-94 showed high level of partial resistance in the first season (non-epidemic season). In the third location (Beni-Suef) the highly susceptible cultivars which obtained high rust severity % were Gemmiza-7 and Morocco in both two seasons. However, Sakha-94 showed high levels of partial resistance in the first season (non-epidemic season), while Sakha-94 cultivars in the second season (epidemic season) (Table 3). In general, the fast development of Kafr El-Sheikh severity was in Beni-Suef location followed by Kafr El-Sheikh parallel with a variable climatic condition of Egypt.

Table (2): Date of the first appearance of wheat leaf rust infection at different locations in Egypt, during 2014/15 & 2015/16 growing seasons

Location	Growing seasons	Wheat age (day)*	Date of the first appearance of leaf rust infection
KafrEl-Sheikh	2014/2015	95	1-Mar
	2015/2016	90	24-Feb
Beni Suef	2014/2015	55	20-Jan
	2015/2016	50	15-Jan

* The day post planting of wheat growing in Egypt

2.2. Disease progress curves and statistical analysis

Statistical analysis was used for fitting the best model to describe the relationships between time (days after planting) and developing disease severity. The model is based on the observed set of data about the mechanism of disease increase (Table 3). Statistical modeling of disease progress data for WLR is represented as $y = f(x)$, where y is disease severity, x is time (days after planting); $f(x)$ is a function of time. The equations of disease progress curves for the growing area have been shown in Tables (4 and 5).

The best fitting of disease progress curves is around the infection point of the disease progress curves (Figs.1 and 2). When the highly significant (R^2= 0.9517-0.999). Statistical versions of theoretical and empirical models are used to handle the differences between predictions and observations.

Table (3): Disease severity (%) of *Puccinia triticina* at different wheat ages in Egypt locations, during 2014-2016 growing seasons

Growing seasons	Wheat cultivar	*Disease severity % / Days post planting / Locations					
		70-90		90-120		120 <	
		L1	L2	L1	L2	L1	L2
2014/ 2015	Gemmiza-7	5	25	70	70	75	70
	Sakha-94	2	2	2	2	4	2
	Morocco	10	40	90	70	100	70
2015/ 2016	Gemmiza-7	10	45	75	70	85	70
	Sakha-94	2	2	2.5	5	5	5
	Morocco	80	80	90	90	100	100

* Disease assessment keys, which are described by Coob's scale, after Peterson *et al.* (1948).

L1: location 1 (Kafr El-Sheikh) – L2: location 2 (Beni Suef)

Table (4): Linearized models form* for analysis the disease progress data for Kafr El-Sheikh location, during 2014-2016 growing seasons

Growing seasons	Cultivars	Linear model	R^2
2014/2015	Gemmiza-7	$y = 3E\text{-}05x^4 - 0.0049x^3 + 0.2128x^2 - 1.1462x$	$R^2 = 0.9892$
	Sakha-94	$y = -8E\text{-}07x^4 + 0.0001x^3 - 0.0058x^2 + 0.1727x$	$R^2 = 0.9877$
	Morocco	$y = 4E\text{-}05x^4 - 0.0058x^3 + 0.2619x^2 - 1.2152x$	$R^2 = 0.9836$
2015/2016	Gemmiza-7	$y = 2E\text{-}05x^4 - 0.0038x^3 + 0.2123x^2 - 2.2638x$	$R^2 = 0.9773$
	Sakha-94	$y = 2E\text{-}07x^4 - 4E\text{-}05x^3 + 0.0038x^2 - 0.0465x$	$R^2 = 0.9892$
	Morocco	$y = 2E\text{-}05x^4 - 0.0038x^3 + 0.2308x^2 - 2.5903x$	$R^2 = 0.9808$

* Statistical analysis by linear regression using a statistical program.
y is disease severity.
x is days after planting.
R^2 is the correlation coefficient between x and y variables.

Table (5): Linearized models form* for analysis of the disease progress data for Beni Suef location, during 2014-2016 growing seasons

Growing seasons	Cultivars	Linear model	R^2
2014/2015	Gemmiza-7	$y = 3E\text{-}05x^4 - 0.0044x^3 + 0.1964x^2 - 0.9805x$	$R^2 = 0.9873$
	Sakha-94	$y = 6E\text{-}07x^4 - 0.0002x^3 + 0.0114x^2 - 0.0871x$	$R^2 = 0.986$
	Morocco	$y = 3E\text{-}05x^4 - 0.0042x^3 + 0.1872x^2 - 0.8173x$	$R^2 = 0.9882$
2015/2016	Gemmiza-7	$y = -4E\text{-}07x^4 - 0.0005x^3 + 0.063x^2 - 0.6693x$	$R^2 = 0.9834$
	Sakha-94	$y = 5E\text{-}08x^4 - 4E\text{-}05x^3 + 0.004x^2 - 0.0632x$	$R^2 = 0.9729$
	Morocco	$y = 2E\text{-}05x^4 - 0.0032x^3 + 0.21x^2 - 2.5609x$	$R^2 = 0.9783$

* Statistical analysis by linear regression using a statistical program.
y is disease severity.
x is days after planting.
R^2 is the correlation coefficient between x and y variables.

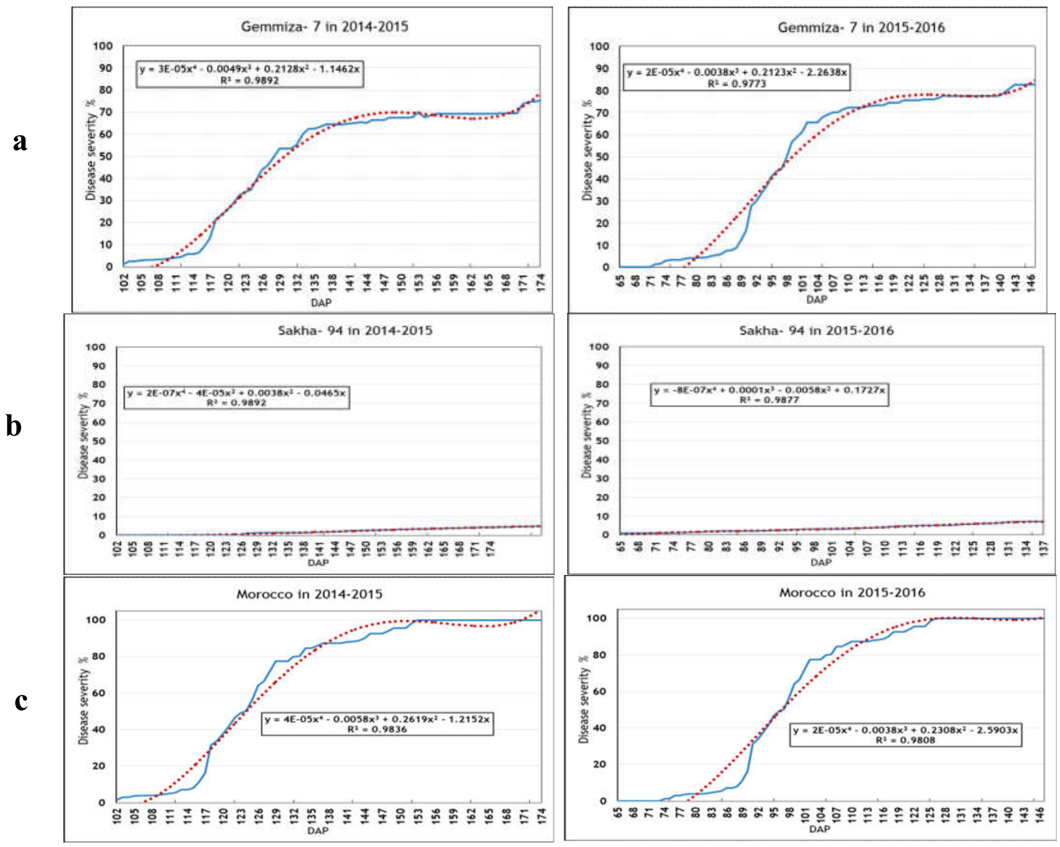

Fig (1): Predicted (**…**) and observed (**-**) progress curve of WLR on cultivars (a) Gemmiza-7, (b) Sakha-94 and (c) Morocco in Kafr El-Sheikh location during 2014-2016 seasons. The prediction was made by computing a polynomial curve based on an apparent infection rate

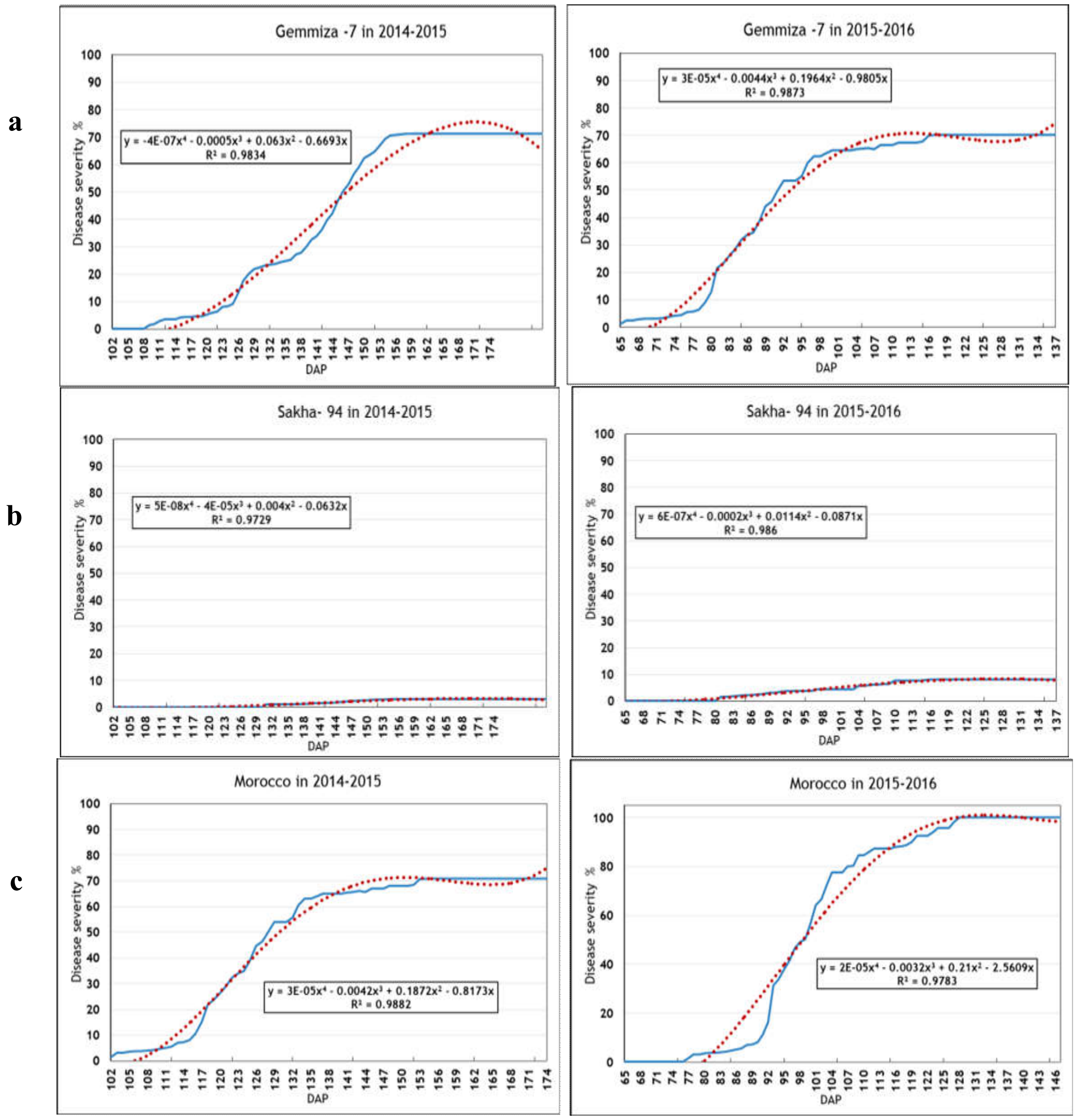

Fig (2): Predicted (**…**) and observed (**-**) progress curve of WLR on cultivars (a) Gemmiza-7,(b) Sakha-94 and (c) Morocco in Beni Suef location during 2014-2016 seasons. Prediction was made by computing a polynomial curve based on an apparent infection rate

3. Monitoring of host characters

3.1. Effect of wheat age

Data in Table (6) showed that the first appearance of WLR at 75-95 days in different locations during 2014/2015 (Non-epidemic season), while in the epidemic seasons 2015/2016, days before disease appearance ranged between 65-80 day. The epidemic of WLR disease started in season 2015/2016; from 10 to 16 days earlier than of season 2014/2015, it depends on the favorability of weather conditions such as early warm seasons. The time of the first WLR appearance of *Puccinia triticina* is closely related to plant maturity.

3.2. Day-degree in relation to WLR appearance

A calculated of day-degree centigrade (DDC = Max temperature – Mini temperature / basic temp (8°C)). The DDC model described in this study has proven effective for timing initial control. Data for the wheat growing area in Table (6) showed that the accumulative day-degree required for the first appearance of WLR ranged from 100-200 day-degree centigrade (DDC) in Beni Suef (South Delta) and 200-250 in Kafr El-Sheikh (North Delta) during 2014-2016 growing seasons. An average DDC value of 200 for all growing areas was chosen as a threshold, which gave growers enough time to prepare for initial control application before the appearance of the first WLR (Figs. 3-4).

Table (6): The relationship of day-degree accumulation and wheat age at different locations in Egypt, during 2014-2016 seasons

Growing Seasons	Wheat cultivar	Kafr El-Sheikh		BeniSuef	
		wheat age (day)*	Day-degree Accumulation	wheat age (day)*	Day-degree Accumulation
2014/2015	Gemmiza-7	75	141.05	75	174.05
	Sakha-94	90	352.85	94	431.55
	Morocco	74	141.05	75	174.05
2015/2016	Gemmiza-7	65	125.03	65	146.25
	Sakha-94	75	349.43	81	450.30
	Morocco	67	125.03	77	254.40

*The day after planting of wheat growing in Egypt

a

b

c

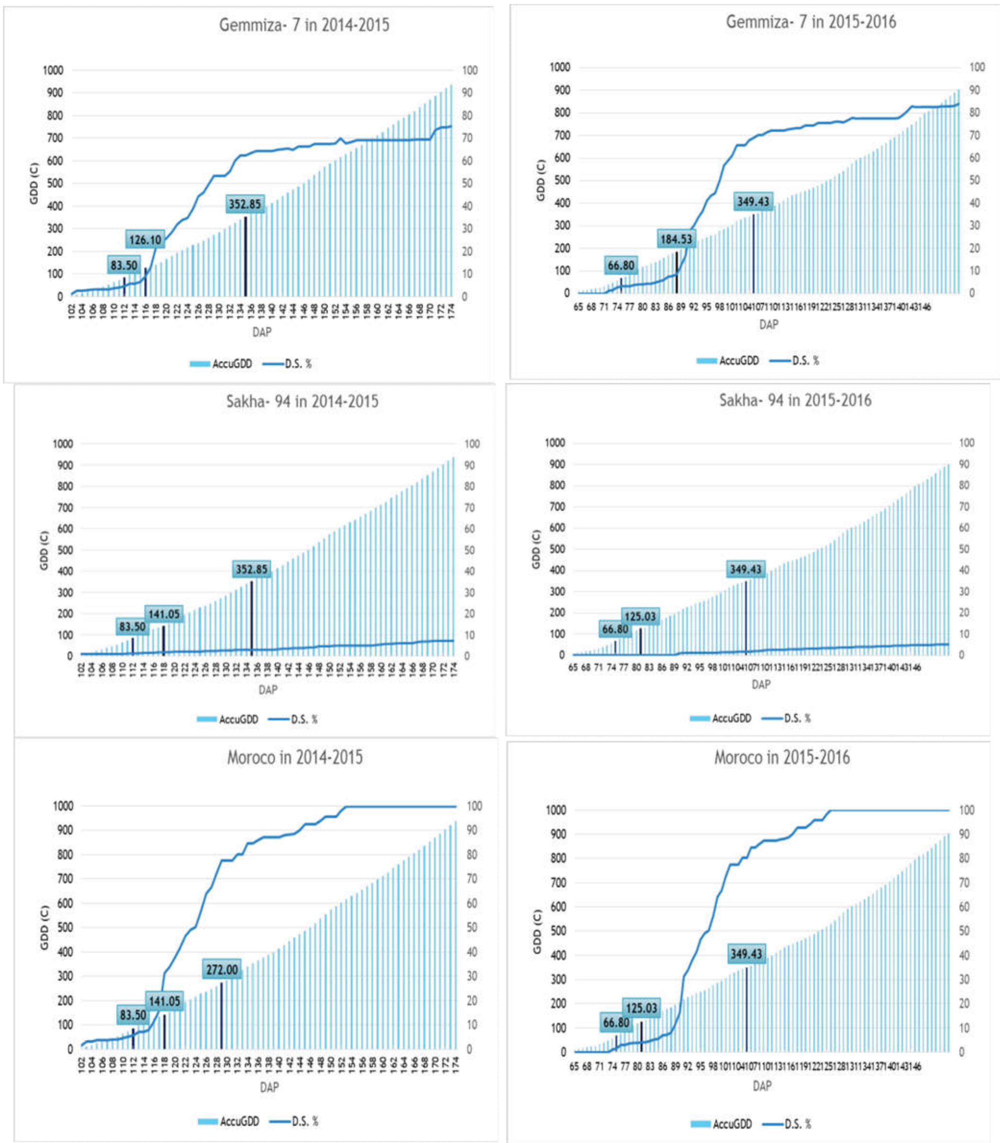

Fig (3): Environmental-physiological time scale (degree-day) relative to disease progress curve for determining the first appearance of the WLR on wheat cvs. (a) Gemmiza-7, (b) Sakha-94 and (c) Morocco in north Delta (Kafr El-Sheikh) growing area during 2014-2016

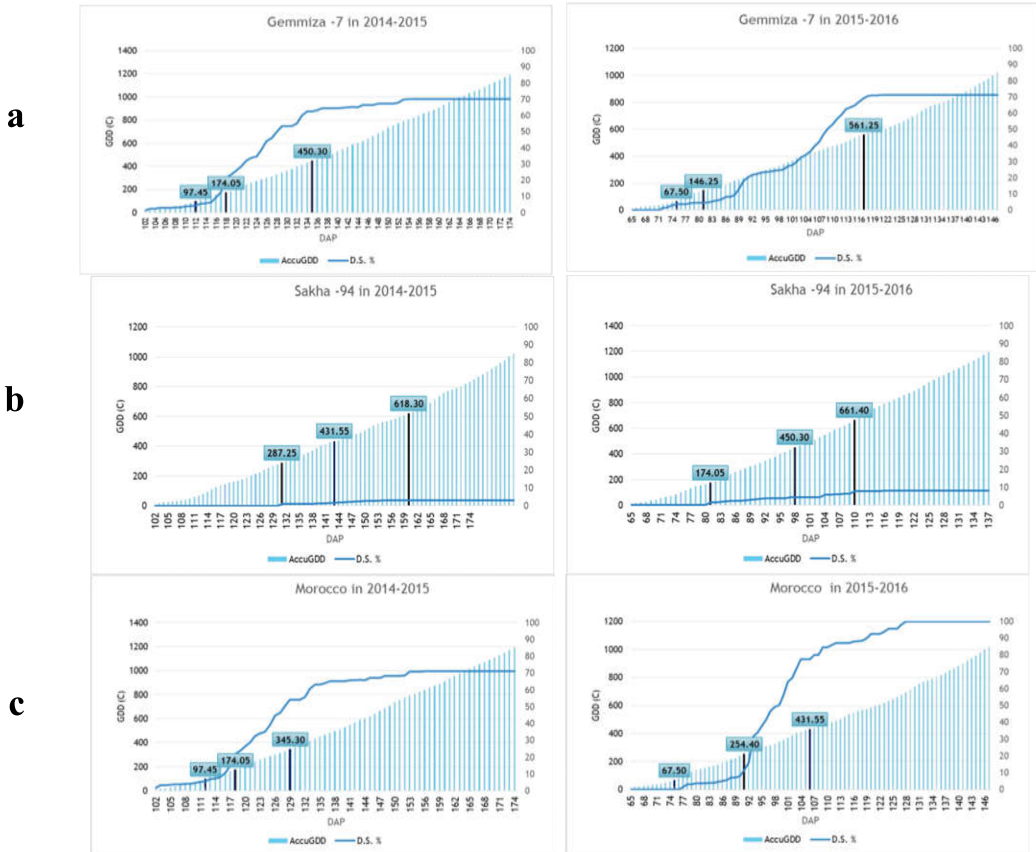

Fig (4): Environmental-physiological time scale (degree-day) relative to disease progress curve for determining the first appearance of the WLR on wheat cv.s (a) Gemmiza-7, (b) Sakha-94 and (c) Morocco in south Delta (Beni Suef) growing area during 2014-2016

4. Empirical model for predicting disease severity

The disease severity has been predicted by regression estimated disease severity versus the accumulative day-degree at studied location. Prediction of disease severity has been formed as $y= b_0 + b_1x + b_2 x^2 +..... b_qx^q$, in which was the *b's* are unknown parameters estimated of the data and *x* is accumulative day-degree value, which estimated from wheat planting time. A highly significant correlation between disease severity and accumulative day-degree, was found (Fig. 5).

5. Model to predict the wheat leaf rust epidemic under field conditions. (Critical point)

A critical point model was selected and tested to describe the occurrence of WLR epidemic by combination weather condition factors

Model =If (and (Max tem. < 25, and (Min tem.> 8, Min tem. < 14), and (RH >70), (and (Wind speed >1.5))), 1, 0) (described by Moschini& Perez, 1999 and modified by Najeeb, Khadegah).

Combines wind speed for at least 24-hours, maximum temperature < 25°C, minimum temperature not less than 8°C < 14°C and minimum RH 70%. The obtained results revealed that severity values during the non-epidemic season (2014/2015) reached 5, 7 and 3 values at the end of the season (Fig. 5), so, the WLR did not occur as an outbreak. While during epidemic season 2015/2016 WLR risk accumulated rapidly in mid-January at Beni Suef and mid-February at Kafr El-Sheikh (Fig. 5).

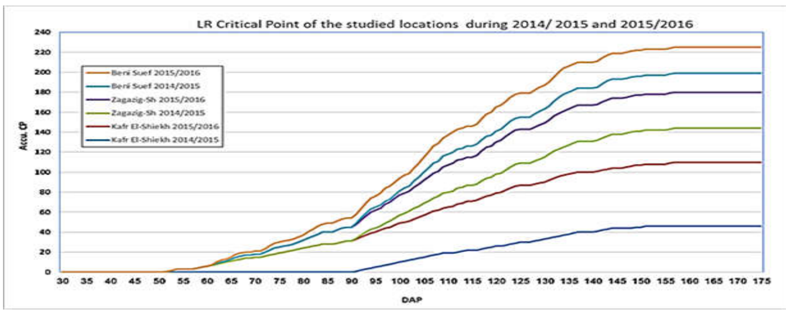

Fig. (5): Critical point of the WLR disease incidence in different locations in Egypt at 2014-2016

DISCUSSION

In Egypt, wheat (*Triticum aestivum* L.) is one of the most important cereal crops, as a nutritive source for humans and animals. Wheat plants are cultivated on large scale in Egypt and contribute approximately 2/3 of the local consumption. Wheat leaf rust (WLR)caused by *Puccinia triticina* is an epidemic disease in Egypt attacking wheat plant causing a great yield loss (EI-Daoudi *et al*., 1994; Bolton *et al*., 2008). In Egypt, WLR is more regular and more dominant as compared to the other rust diseases.

The combination of inoculum (urediospores), favorable environment and susceptible host plants are developing disease epidemics (Duveiller *et al*., 2007). The three important weather factors that are moisture, temperature and wind have the greatest effect on the severity and frequency of WLR epidemics (Shaw *et al.,* 2008; Chakvaborety *et al.,* 2010)

In addition, it was noticed that, over both two growing seasons, no rust infection appeared on the wheat plants before booting stage. While, the disease was appeared at the heading stage according to the location, wheat genotype and the dominant physiologic races (Rattu *et al*., 2010).

To study the effect of the usual climatic factors on WLR incidence, four wheat genotypes were screened against leaf rust disease. Plants were growing under field conditions at two different locations (Kafer El-Sheikh and Beni Suef) for two growing seasons (2014/2015 and 2015/2016). Rust incidence was recorded as rust severity % starting from the first appearance until the dough stage. The levels of susceptibility and the field resistance were determined for each wheat genotype tested by quantitative measurement, such as the epidemiological parameter, as final rust severity (FRS%).

The weather changes after the host-pathogen interaction play a vital role in WLR development. This study presents the impact of weather changes in wheat growing areas of Egypt (Kafr El-Sheikh and Beni Suef) on the development of WLR by taking into account the disease and weather data (between January 1st and 30 April) of 2014/2015and 2015/2016 growing seasons. For this aim, multiple regression analysis of the temperature, relative humidity and wind velocity with the disease severity on three wheat genotypes (Gemmiza-7, Sakha-94 and Moroco) was conducted.

The weather data included the thresholds of temperature (min. 10°C & max. 25°C), relative humidity (85%) and wind speed (2 Km/s) were collected and plotted horizontal lines between January 1st and April 28th through 2014-2016 for Kafr El-Sheikh and Beni Suef. Most of the nights at wheat growing area in January and February of 2014/2015 were relatively cool (min. temperature <10°C). There was a big contrast in this regard with January and February of 2015/2016 at Kafr El-Sheikh and Beni Suef, which had relatively warm nights. The results revealed that the fast development of leaf rust severity was in Kafr El-Sheikh location followed by Beni-Suef followed by Kafr El-Sheikh parallel with a variable climatic condition of Egypt. On the other hand, the epidemic started early from 10 to 16 days during 2015/2016 rather than that of 2014/2015. It depends on the favorability of weather conditions such as early warm seasons. The time of the first WLR appearance of *Puccinia triticina* is closely related to plant maturity (Diab, Hoda, 1994; Tohamy, Somaya 2004; Fahim *et al*., 2013)

To study the incidence of the WLR disease in different agro-climatic zones, as an early alarm for the disease epidemic airborne inoculum must be detected before the appearance of symptoms in the field and could be used as a model for predicting WLR epidemics (Dedeurwaerder *et al*., 2011).

REFERENCES

Bassiouni , A. A. (1971) . Epidemology of wheat rust in U.A.R. with special reference to black stem rust .M.Sc. Thesis, Fac. of Agric., AL–Azhar Univ.pp.70.

Bolton, M. D., J. A. Kolmer and D. F. Garvin (2008). Wheat leaf rust caused by *Puccinia triticina*. Mol. Plant Pathology, 9: 563–575.

Brittain, I., Katherine Selby, M. C. Taylor and R. Mumford (2013). Detection of plant pathogen spores of economic significance on pollen trap slides. J Phytopathology, 161: 855–858.

Chakvaborety, S., J. Luck, G. Hollaway, G. Fitzgerald and N. White (2010). Rust-proofing wheat for a changing climate. BGRI Technecal Workshop, 30-31 May 2010, St Petersburg, Russia.

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

Dedeurwaerder, G., M. Duvivier, S. M. Mvuyenkure, M. E. Renard, V. Van Hese, G. Marchal, J. M. Moreau and A. Legrève (2011). Spore traps network: a new tool for predicting epidemics of wheat yellow rust. Commun Agric. Appl. Biol. Sci., 76: 667-670.

Diab, Hoda, M. (1994). Epidemiology of Wheat Leaf Rust in Egypt in Relation to Ecological Conditions. Ph.D. Thesis, Institute Environment. Science Studies and Research. Ain Shams Univ. 114p.

Duveiller, E., R. P. Singh and J. M. Nicol (2007). The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. Euphytica, 157: 417–430.

El-Daoudi, Y. H., O. F. Mamluk, E. Bekele, H. Enayat, M. B. Chanem and I. Shafik (1994). Preliminary results for leaf and stem rust of wheat, their prevalence and resistance in the Nile Valley Countries and Yemen. Fifth Arab Cong. Plant Prot., Morocco, Nov. 27-Des. 2 (Abstr).

El-Jarroudi, M., L. Kouadio, P. Delfosse and B. Tychon (2014). Brown rust disease control in winter wheat: I. Exploring an approach for disease progression based on night weather conditions. Environmental Science and Pollution Research Int., 2(7): 4797-4808.

Fahim, M. A., M. K. Hassanein, A. A. Khalil and A. F. Hadid (2013). Climate Change Adaptation Needs for Food Security in Egypt. Nature and Science, 11(12): 68-74.

Kamel, A. H., M. A. Nagieb and T. M. Abdel-Hak (1976). The Egyptian wheat disease surveillance program. 4th European and Mediterranean Cereal Rust Conference, Interlaken/Switzerland.

Khan, M. H., B. Asifa, A. D. Zahoor and M. R. Syed (2013). Status and strategies in breeding for rust resistance in wheat. Agricultural Sciences, 4(6): 292-301p.

Large, E. C. (1954). Growth Stages in Cereals: Illustration of Feekes scale. Plant Pathology, 3: 128-129.

Nazim, M., A. H. Kamel and S. Shafik, Ikhlas (1976). A country-wide survey for wheat leaf rust in Egypt during 1971-1975. Proc. 2nd Phytopathol. Conf., Cairo, 1-4 Nov., p. 643-651.

Obst, A. and V. H. Paul (1993). Krankheiten und Schädlinge des Getreides.1st ed. Th. Mann Verlag, Gelsenkirchen-Buer, Germany.

Peterson, R. F., A. B. Campbell and A. E. Hannah (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res., 60: 496-500.

Prigge, M. J., D. Otsuga, J. M. Alonso, J. R. Ecker, G. N. Drews and S. E. Clark (2005). Class III homeodomain-leucine zipper gene family members have overlapping, antagonistic, and distinct roles in *Arabidopsis* development. Plant Cell, 17: 61–76.

Rattu, A. R., I. Ahmad, R. P. Singh, M. Fayyaz, J. I. Mirza, K. A. Khanzada and M. I. Haque (2010). Resistance to *Puccinia triticina* in some Pakistani wheats. Pak. J. Bot., 42(4): 2719-2735.

Roelfs, A. P., R. P. Singh and E. E. Saari (1992). Rust diseases of wheat: concept and methods of disease management. CIMMYT, Mexico, D.F., 81p.

Shaw, M. W., S. J. Bearchell, B. D. L. Fit and B. A. Fraaije (2008). Long-term relationships between environment and abundance in wheat of *Phaeosphaeria nodorum* and *Mycosphaerella graminicola*. New Phytology, 177: 229-238.

Singh, D., V. Mohler and R. F. Park (2013). Discovery, characterization and mapping of wheat leaf rust resistance genes Lr 71. Euphytica, 190(10): 131-136.

Singh, R. P., J. Huerta-Espino, R. Sharma, A. K. Joshi and R. M. Trethowan (2007). High yielding spring bread wheat germplasm for global irrigated agro-ecosystems. Euphytica, 157: 351–363

Tohamey, Somaya M. M. (2004). Studies on the Dynamics of *Puccinia triticina* Races the Cause of Leaf Rust on Wheat under Dominant Environmental Conditions in Egypt. MSc. Thesis, Plant Pathology, Institute Environment. Science Studies and Research. Ain Shams Uni. 78 p.

الإنذار المبكر بمرض صدأ أوراق القمح والتنبؤ بحالة المرض بناءً على نمذجة الطقس.

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صدأ أوراق القمح (WLR) ، الذي تسببه *Puccinia triticina* (Pt) هو مرض وبائي. تناولت الدراسة الحالية وبائيات مرض WLR في مصر خلال مواسم النمو ٢٠١٦/٢٠١٤ في مصر ، لدراسة تأثير العوامل المناخية على حدوث WLR ؛ تم فحص أربعة طرز وراثية من القمح مقابل WLR تحت الظروف الحقلية بمحافظتي كفر الشيخ وبني سويف. ارتبط متوسط درجة الحرارة اليومية خلال الأشهر الأربعة للدراسة ارتباطًا وثيقًا بالتطور وشدة الصدأ النهائية ٪. أشارت بيانات الطقس إلى أن معظم ليالي يناير وفبراير لعام ٢٠١٥/٢٠١٤ كانت باردة نسبيًا (أدنى درجة حرارة أقل من ١٠ درجة مئوية) في مناطق زراعة القمح. وكان هناك تباين كبير في هذا الصدد مع شهري يناير وفبراير ٢٠١٦/٢٠١٥ في كفر الشيخ وبني سويف، حيث كانت الليالي دافئة نسبيًا. بدأ وباء مرض WLR قبل ١٠ إلى ١٦ يومًا خلال ٢٠١٦/٢٠١٥ بدلاً من ٢٠١٥/٢٠١٤. يعتمد ذلك على ملائمة الظروف الجوية مثل المواسم الدافئة المبكرة. قد توفر النمذجة القائمة على الطقس لانتشار المرض في وقت مبكر أداة مناسبة للتحقيق والتنبؤ بحالة المرض.

الكلمات المفتاحية: القمح ، *Puccinia triticina*، علم الأوبئة والعوامل المناخية