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Regional Monitoring of the Dynamic of Wheat Leaf Rust (*Puccinia triticina* Eriks) in Southwest of Iran, Khuzestan Province

M. Hasanzadeh[1], N. Safaie[1*], M. R. Eslahi[2], S. T. Dadrezaei[3], and S. N. Tabatabaei[3]

ABSTRACT

In this study, the first symptom appearance of wheat leaf rust disease was monitored in Khuzestan Province every ten days from early December 2014, for three years. Also, the climate changes and their influence on the development of the disease were studied. During 2014-2015, the first symptoms, with the severity of 5 MS (Moderately Susceptible), appeared in the south and west parts in early and mid-March, respectively. In northern areas, the symptoms appeared with 10 MS severity in early May. In 2015-2016, the first symptoms appeared with the severity of 5 MS in February in the southern areas. In the west, symptoms appeared and reached 20 S (susceptible) on March 10. In the north, the disease started in late February with the severity of 10 MS and developed to 30 S. In 2016-2017, the first symptoms appeared around the Karun River with the severity of 5 MS on March 10 and eventually reached 10 MS in late March. In the western areas, the disease started in early March with the severity of 5 MS and then stopped. Symptoms appeared one week later in the north, with the severity of 5 MS, and reached 15 MS until the end of March. Based on the previous studies, the first symptoms of wheat leaf rust usually start from the west. However, now, the regional pattern of the symptom has changed dramatically, and it appears in the south near Karun River and the Sugar Cane Crop Industry. This might be due to implementation of preventive measures and dryness of a big part of Hoveyzeh Marshland.

Keywords: Climate change, Epidemiology**,** Karun river, Winter wheat.

INTRODUCTION

According to the researchers' prediction, by 2050, wheat production in the world should be increased by 60%; meanwhile, 20-30% of wheat production will be reduced by environmental factors and pests (Prasad *et al.*, 2017). Biotic factors such as rusts, which are one of the most important yield-limiting diseases of cereals, influence the sustainable cultivation of wheat (Teferi, 2015). Severe epidemics of the Wheat Leaf Rust disease (WLR: Caused by *Puccinia triticina* Eriks) have resulted in significant yield losses and have become a serious economic problem in the world in recent years (El Jarroudi *et al*., 2014b; Ordonez and Kolmer, 2007). For example, a widespread leaf rust epidemic, which led to 14% yield loss, broke out in the Great Plains in North America in 2007 (Kolmer *et al*., 2009). In heavy epidemic years, losses due to leaf rust disease were 5% to 40% in plots of spring wheat cultivars, depending on the resistance of the cultivar (Kolmer *et al*., 2014). Even under suitable environmental conditions, yield

[1] Plant Pathology, Faculty of Agriculture, Tarbiat Modares University, Tehran, Islamic Republic of Iran.
[*] Corresponding author: e-mail: nsafaie@modares.ac.ir
[2] Plant Protection Research Department, Khuzestan Agricultural and Natural Resources Research Center, AREEO, Ahvaz, Islamic Republic of Iran.
[3] Seed and Plant Improvement Department, Agricultural and Natural Resources Research Center of Khuzestan, AREEO, Ahvaz, Islamic Republic of Iran.

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losses may reach up to 70% (Roelfs *et al*., 1992). The importance of rusts is still increasing due to the rapid emergence of new races and quick adaptation of pathogen populations to resistant cultivars. For example, new virulent types of stem rust (ug99) infected 80 to 90 % of the current cultivars (Hodson, 2011; Singh *et al*., 2011).

The fungal disease often appears in patches and causes aggregated damage to the plants (Ferrandino, 1989); nevertheless, WLR is borderless and is found throughout the world, and affects the wheat production (Buck *et al*., 2007). Due to the gradient of horizontal distribution and cultivation of susceptible plants, inocula is carried easily by the wind, causing a significant problem for local use of fungicides and considerable damage (Fitt *et al*., 1987). Therefore, for efficient spot control of leaf rust, reducing labor time, and improving the spraying time, understanding the regional pattern of the disease is essential (Pethybridge *et al*., 2005). The analysis of spatial patterns can result in compiling of ecological and biological hypotheses related to fundamental mechanisms, which can be studied about disease dispersion and the environment (Stevenson and Jeger, 2015). Madden (2006) showed that the epidemiology of plant disease could lead to the specific managerial suggestions as well as conceptual creativities in disease management. The dynamics of the plant disease are affected by biotic and abiotic factors (the pathogen type, soil's features, topography, the density of the host plant, plant's resistance, plant growth stage, the available rate of pathogen inoculum, temperature, humidity, etc.) (Tubajika *et al*., 2004) and represent the relationship among the host, microorganism, and environment.

During last decades, many researchers have studied the relationship between climatic conditions and leaf rust disease in Europe and all over the world (El Jarroudi *et al*., 2014a; Huerta-Espino *et al*., 2010; Helfer, 2014). They showed that weather parameters including temperature, rainfall, and relative humidity are important factors in WLR development. With predictable climatic changes in the upcoming century (IPCC, 2014), the models of fungal disease prediction would also be influenced (Chen *et al*., 2011). Since finding the optimum time for conducting administrative provisions to the effectiveness of control measures is critical, many studies have focused on the first appearance of symptoms, temporal progress, and potential strategies to improve the best time for disease management (Shah *et al*., 2001). However, spatial components were neglected in most of these studies (Madden *et al*., 2007).

Iran is one of the key areas affected by WLR. About 71% of the cultivated crops in Iran are cereals, constituting 24% of the total crop products. Although awareness of the potential of the first appearance and the development of the WLR is necessary for planning and efficient use of fungicides, few studies have been done in this domain in Iran, thus monitoring its regional pattern is critical.

This study aimed to evaluate the potential of climate changes and their influence on the development of WLR disease in Khuzestan Province, which holds the fourth place in the wheat cultivation area while it is the first wheat producer in Iran. The climate of this province (warm and humid) is suitable for this disease.

MATERIALS AND METHODS

Regional Monitoring of Wheat Leaf Rust

Since the appearance of the disease symptoms, the intensity of disease was assessed visually ten times at 10-day intervals, based on the modified Cobb,s scale (Dadrezaei *et al*., 2103). During growing seasons of 2014-2015, 2015-2016, and 2016-2017, the appearance of disease symptoms was monitored on February 11th and continued until April 11. The epidemic assessment routes of the WLR on each date included counties from the center of Khuzestan Province (Ahvaz) to the west

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(Hoveyzeh, Susangerd, Bostan, Dasht-e Azadegan, and Shush) and south (Bandar-e Mahshahr, Khorramshahr, Abadan, Shadegan, and Hendijan). It also included Dezful and Andimeshk to the north, and Ramhormoz, Izeh, and Bagh-e Malek to the east. Moreover, in the center of the province , it covered Ahvaz, Bavi, and south of Shooshtar (Figure 1).

RESULTS

Meteorological Data Analysis

On February, March, and April, active growth stage of flag leaf and seed filling period, the rainfalls and average monthly temperatures in Khuzestan Province during 2014-2015 were 7, 32, and 36 mm and 11.5, 17, and 28°C, respectively. During 2015-2016 were the rainfalls in February, March, and April 41.7, 54, and 29.7 mm and the average monthly temperatures were 12.7, 18.3, and 27°C, respectively. During 2016-2017 were the rainfalls in February, March, and April 41.7, 20, 47 mm and the average monthly temperatures were 12, 16.9, 29.3°C.

2014-2015 Regional Monitoring

Leaf rust disease was monitored every ten days from early December based on wheat growth stage (tillering stage) during 2014-2015. The symptoms were not observed until early March. The first symptoms, with the severity of 5 MS, appeared on early March in the southern parts of the province i.e., South of Ahwaz and Ahvaz-Khorramshahr Road. The late appearance of symptoms is indicative of a delay in disease occurrence. In western parts of the province, from Ahvaz to Dasht-e Azadegan, Hoveyzeh, and Susangerd, symptoms were traceable with the severity of 5 MS on mid-March, but in the north and northeast of the Khuzestan where the weather is colder than the south region, symptoms did not appear. In the next monitoring, which continued until May 10, the disease progress rate was insignificant due to temperature increases and reduction of green wheat tissue. Based

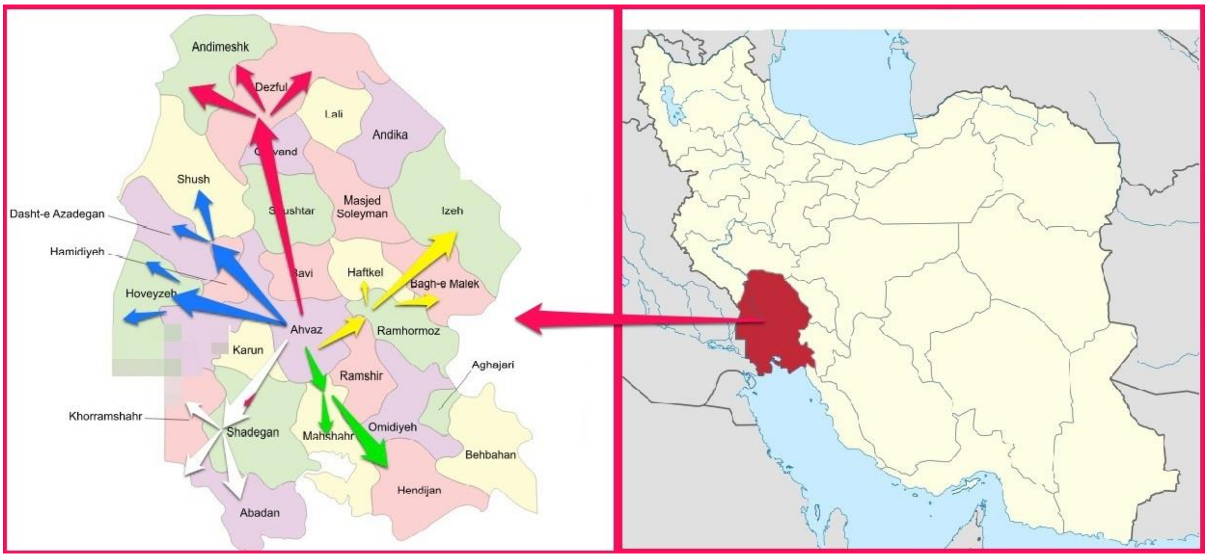

Figure 1. Map of Iran and Khuzestan Province and WLR monitoring routes. The yellow arrows indicate center to east direction. The red arrows indicate center to north direction. The blue arrows indicate center to northwest direction. The white arrows indicate center to southwest direction. The green arrows indicate the center direction to the southeast.

on the latest results, the highest disease severity was 10 MS in the Safhe region in the south of Ahvaz in late April, and then it stopped. In the west part of the region, near Susangerd and Hoveyzeh, the most severe intensity was between 10 MS to 15 MS. In the northern areas including Shush, Dezful, and Andimeshk, no symptom appeared until the end of April, but in early May subtle symptoms appeared with 5 MS and 10 MS severity. Symptoms did not appear until the end of monitoring in the eastern regions, i.e. Izeh and Bagh-e Malek (Table 1).

2015-2016 Regional Monitoring

During 2015-2016, environmental conditions for the development of leaf rust in this province were quite suitable. According to the results, symptoms appeared one month earlier in this year, and by considering the incubation period of the disease, the fields were infected in early January. The symptoms appeared in many susceptible cultivars of the region, and individually mixed cultivars in the experimental plot. In most of the monitored areas, the symptom of the disease was observed. The first symptom occurred with 5 MS severity in February in the southern areas (Ahvaz-Khorramshahr Road and Abadan). Symptoms appeared two weeks later in the west area (Susangerd, Hoveyzeh and Dasht-e Azadegan with 5 MS severity). In the northern regions, the disease started in late February, in counties such as Dezful and Andimeshk, with the severity of 10 MS. Eventually, the disease distributed over southern, western, and northern regions, while it did not appear in eastern parts of the province (i.e., Izeh, Bagh-e Malek, and Ramhormoz) until the end of the monitoring period. In the south, the disease developed until the end of February and reached 30 MS, then, it continued slowly due to high temperature, and on March 10, the growth stopped at the plants. Eventually, teliospores' sign appeared. In the west and north, plants grew until March 10, and disease severity was traceable to 20 S. Although symptoms appeared in different regions, the disease developed with less severity, due to cultivation of resistant cultivars. In northern regions that had favorable climatic conditions and susceptible cultivars, the disease developed to 30 S (Table 1).

2016-2017 Regional Monitoring

Leaf rust monitoring started in early December in 2016-2017, and was repeated every ten days and including monitored regions in the previous year. Similar to the previous years, the first symptoms appeared around Karun River, but because of the exceptional climatic conditions, leaf rust disease appeared partially in late February. Simultaneously with increasing temperature, disease progress rate decreased. In the south of Ahvaz (Safeh region) the disease continued in some spots trivially with the severity of 5 MS after March 10. Due to the weather conditions, the disease developed very slowly and eventually reached 10 MS in late March 2017 in the southern regions, and then stopped. In the western areas (Susangerd and Hoveyzeh) the disease started in early March with the severity of 5 MS and stopped in late March. In the northern parts of the province where the green areas remained until the end of March, the disease severity reached 15 MS, and then it stopped. Similar to previous year, no symptoms appeared in eastern parts of Khuzestan Province (Izeh, Bagh-e Malek, and Ramhormoz) (Table 1).

DISCUSSION

Khuzestan Province area is about 64,057 km^2. It is located in the southwest of Iran between 47 ° 41´ and 50° 39´ E longitudes and 29 ° 58´ and 33 ° 4´ N latitudes. Although it is influenced by special synoptic conditions in the major climate systems, influential variables have created a minor

Table 1. The first date of the disease symptom observation and severity of disease at the end of the growing season during 2014-2015, 2015-2016, and 2016-2017.

Site number	Location[a]	Geographical direction[b]	Latitude	Longitude	The first date of the symptom observation and severity of disease at the end of the growing season					
					2014-2015		2015-2016		2016-2017	
					Date[c]	Severity[d] (%)	Date	Severity (%)	Date	Severity (%)
1	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1442	48.3459	-	0	19-Feb	30	-	0
2	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1243	48.3214	-	0	19-Feb	10	11-March	10
3	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1101	48.3229	11-March	20	19-Feb	30	11-March	5
4	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1106	48.3003	-	0	19-Feb	30	-	0
5	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1114	48.2807	-	0	19-Feb	10	11-March	10
6	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1123	48.3307	-	0	19-Feb	20	11-March	10
7	Ahvaz-Khorramshahr Road	Ahvaz to the southwest	31.1158	48.3401	-	0	19-Feb	10	-	0
8	Ahvaz-Abadan Road	Ahvaz to the southwest	30.5327	49.2302	-	0	29-Feb	20	-	0
9	Ahvaz-Abadan Road	Ahvaz to the southwest	30.4245	48.4833	-	0	29-Feb	20	-	0
10	Ahvaz-Hendijan Road	Ahvaz to the southwest	30.3105	49.5736	-	0	29-Feb	30	11-March	10
11	Ahvaz-Hendijan Road	Ahvaz to the southwest	30.3701	49.5059	-	0	29-Feb	20	-	0
12	Ahvaz-Hendijan Road	Ahvaz to the southwest	30.3643	49.4955	-	0	29-Feb	20	-	0
13	Ahvaz- Hoveyzeh Road	Ahvaz to the west	31.4827	48.2615	21-March	10	21-March	10	21-March	10
14	Ahvaz-Hoveyzeh Road	Ahvaz to the west	31.5107	48.2218	-	0	21-March	20	-	0
15	Ahvaz-Shosh Road	Ahvaz to the west	32.2249	48.3121	-	0	21-March	30	-	0
16	Ahvaz-Susangerd Road	Ahvaz to the west	31.2934	48.2455	11-March	10	11-March	20	11-March	10

[a] The points where the data was recorded; [b] The geographical route where the points are selected from them; [c] The first date of the disease symptom observation, [d] The severity of disease at the end of the growing season. - The points that data were zero were deleted. - The points in the neighboring areas that had same severity were deleted.

Continued…

Table 1 continued. The first date of the disease symptom observation and severity of disease at the end of the growing season during 2014-2015, 2015-2016, 2016-2017.

Site number	Location[a]	Geographical direction[b]	Latitude	Longitude	The first date of the symptom observation and severity of disease at the end of the growing season					
					2014-2015		2015-2016		2016-2017	
					Date[c]	Severity[d] (%)	Date	Severity (%)	Date	Severity (%)
17	Ahvaz-Susangerd Road	Ahvaz to the west	31.4315	48.0116	29-Feb	10	29-Feb	20	29-Feb	10
18	Ahvaz-Hamidieh Road	Ahvaz to the west	31.4941	48.2531	-	0	11-March	20	21-March	10
19	Ahvaz-Hoveyzeh Road	Ahvaz to the west	31.2459	48.0804	-	0	29-Feb	20	-	0
20	Ahvaz-Shosh Road	Ahvaz to the northwest	32.0142	48.1748	-	0	29-Feb	10	-	0
21	Ahvaz-Shosh Road	Ahvaz to the northwest	32.1359	48.1957	21-March	10	11-March	10	21-March	10
22	Ahvaz-Shosh Road	Ahvaz to the northwest	32.1206	48.1007	21-March	10	11-March	30	21-March	10
23	Ahvaz-Shosh Road	Ahvaz to the northwest	32.1243	48.0721	21-March	10	11-March	20	21-March	10
24	Ahvaz-Shosh Road	Ahvaz to the northwest	32.1851	48.0808	-	0	11-March	20	-	0
25	Ahvaz-Shosh Road	Ahvaz to the northwest	32.2355	48.1208	21-March	20	11-March	20	21-March	10
26	Ahvaz-shooshtar Road	Ahvaz to the northwest	32.1351	48.2002	-	0	11-March	20	-	0
27	Ahvaz-Ramhormoz Road	Ahvaz to east	31.1819	49.3437	-	0	-	0	-	0
28	Ahvaz-Ramhormoz Road	Ahvaz to east	31.0134	49.4303	-	0	-	0	-	0
29	Ahvaz-Izeh Road	Ahvaz to the east	31.4114	49.5202	-	0	-	0	-	0
30	Ahvaz-Izeh Road	Ahvaz to the east	31.5108	49.4528	-	0	-	0	-	0

[a] The points where the data was recorded; [b] The geographical route where the points are selected from them; [c] The first date of the disease symptom observation, [d] The severity of disease at the end of the growing season. - The points that data were zero were deleted. - The points in the neighboring areas that had same severity were deleted.

and homogenous climate. According to the studies (Movahedi *et al*., 2013), Khuzestan Province is divided into the following five climatic regions based on autumn and winter rainfall index, weather temperature, and humidity:

1- low precipitation with high humidity in the southwest of the province including counties of Abadan and Khorramshahr,

2- Warm and dry for the southern parts of the province, including counties of Ahvaz, Bandar-e Mahshahr, and Shadegan,

3- Humid and moderate in the center and southeast of the province, including counties such as Shooshtar, Masjid-e Soleyman, and Ramhormoz,

4- High raining index for eastern parts of the province like Izeh and Bagh-e Malek,

5- Mild with a moderate range of precipitation in northern parts of the province, like Dezful and Sardasht cities.

The Zagros Mountains are located in the northeast and east of the province with diminishing altitudes toward the southwest. Khuzestan province is divided into plain and mountainous regions. Mountainous parts are located in the north and east of the province, and plain areas start from the south of Dezful and continue to the Persian Gulf. From south, west, and southwest of the province to the east, northeast, and north of the province, the temperature decreases and rainfall increases. Thus, highlands play a significant role in the Khuzestan Province. Khuzestan region is influenced by three wind types: first, cold weather of mountainous areas blowing in east and northeast of the region. Second, the warm and humid wind coming from the Persian Gulf, blowing in the plain areas. Third, the wind comes from Saudi Arabia and always is sandy and humid (Dadrezaei *et al*., 2017).

The results of regional assessment reports of WLR, which had been carried out by the experts of the Agricultural Research Center of Khuzestan Province during 1993-2000, showed that the first symptoms of the disease appeared typically in the west parts of the Khuzestan Province (near to Hoveyzeh Marshe and Dasht-e Azadegan). This might be due to suitable wet conditions and the cultivation of susceptible cultivars. After conducting preventive measures and also due to the dryness of a big part of Hoveyzeh Marshe, which is the result of extensive dry periods in the whole region,

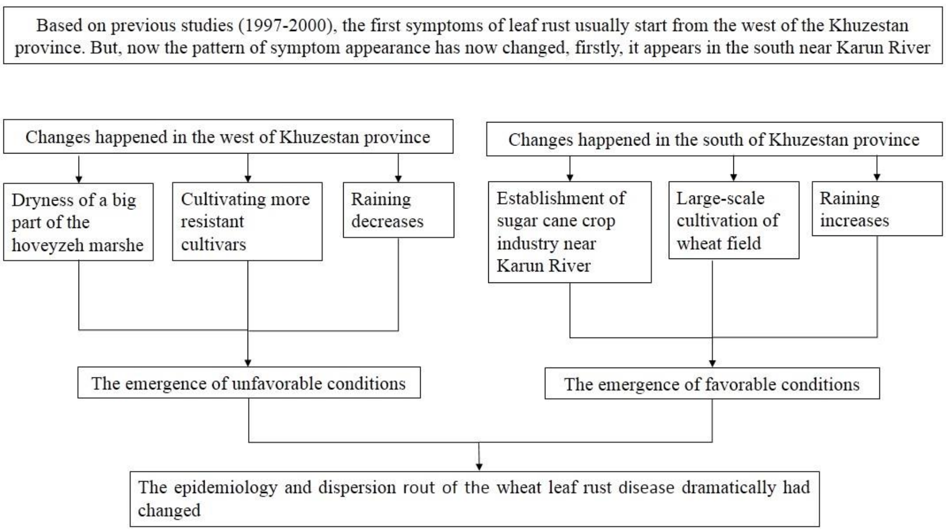

Figure 2. General reasons for the change of regional patterns of WLR in Khuzestan Province over the past two decades.

the first symptoms of WLR are not reported from this region anymore. Our results showed that the epidemiology of leaf rust had changed dramatically, which might be because of the presence of widespread agricultural agroindustries in the south of Ahvaz (Ahvaz-Khorramshar Road) (Figure 2). In fact, the first appearance of symptoms were observed around the Karun River and fields located next to Sugar Cane Crop Industry on the Ahvaz-Khorramshahr Road. Consequently, the disease's symptoms spreaded the west over 10 to 15 days and led to the slight growth of the disease in those regions. Then, the disease symptoms were observed in the northern parts within 10 to 15 days, and sometimes appeared in the north and west simultaneously. According to our monitoring reports during the three years of study, the disease was not observed in the east of Khuzestan Province, although ignorable single pustules were reported in regions near the Ramhormoz. Environmental conditions around Karun River are very favorable for the WLR, due to the development of agricultural industries and presence of warm and humid microclimates in this region. The outbreak of epidemics in early growing season and lack of suitable disease management programs can cause significant loss. Regions with the highest temperature in the province are located in the center, south, west, north, and east, respectively. The southern areas have high humidity for the following reasons: winds which blow from the Persian Gulf and Oman Sea, the presence of Karun River in this region, and presence of agricultural industries. Apparently, based on the temperature and humidity rate required for leaf rust, the first symptoms appear in the south of the province. In the west of the province, unlike to past years, delayed symptom appearance is due to dryness of Hoveyzeh Marshe, warm winds that blow from Saudi Arabia, and cultivation of more resistant wheat cultivars such as Mehregan and Chamran 2. In the northern parts of the province, including areas with mild and moderate rainfalls that are suitable conditions to the disease development in early March, practically no sever epidemics occur. This might be due to the crops ripening and lack of green tissue of wheat that is susceptible to WLR. In the eastern parts of Khuzestan Province, the disease cannot infect susceptible cultivars, because of the presence of the Zagros Mountains and low temperature in the early season. Moreover, in the late growing season, the green area was diminished, and preventive measures were implemented; therefore, the disease could not develop anymore.

Climatic changes would influence wheat production and the occurrence of severe leaf rust. Studies indicate that the side effect of climate changes on the crop yield and disease is beyond its positive effects (IPCC, 2014). In central Europe, rainfall is high in winter, but it decreases in the summer and results in dryness. This condition is similarly available in Khuzestan Province, especially in its south and west. These conditions affect the disease growth based on the region and wheat cultivars (Mikkelsen *et al*., 2015). Results indicated that there was less rainfall during the growing season of 2014-2015 and 2016-2017 than 2015-2016, and during March, which is the time of symptom's appearance, the rainfall rate was almost half of the other periods. Comparing meteorological data of February, March, and April indicated that, in 2015-2016, weather temperature was one to two °C higher than both 2014-2015 and 2016-2017. Regarding favorite weather conditions for leaf rust development, the weather conditions had been more suitable for the development of disease in 2015-16 than the two preceding and following years.

Here, it was supposed that the time and the place of leaf rust disease appearance had changed due to the dry climate of the Khuzestan Province, significant reduction in rain, dryness of Hoveyzeh Marshe, and the widespread agroindustries in the south of Khuzestan. Since temperature and rainfall influence the disease severity (El Jarroudi *et al*., 2014a; El Jarroudi *et al*., 2014b), climate data for a three-year period were collected.

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Our results indicated that in growing season of 2015-2016, in which weather temperature in February and March was 1 to 2°C higher than the other periods, the occurrence and disease severity were remarkably higher. This is in agreement with previous studies such as Launay *et al*. (2014) and Racca *et al*. (2015). Also, in addition to climate changes, the cultivation system plays a prominent role in altering the disease occurrence and its severity as well (Juroszek and von Tiedemen, 2015).

CONCLUSIONS

Overall, the data provided in this study can aid us in better use of decision support systems such as choosing cultivars, changing the cultivation time limit, changing the fungicide application time limit, or inhibit side effects on crop yield. Since under favorable conditions, the disease-causing agent can produce many spores that are transported to remote distances by wind, studying the cultivation models of the region, identifying infection centers, time and place of the first symptoms of the disease, and its dispersion model to use fungicides can influence the control of the disease in the coming years.

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پایش منطقه ای دینامیک زنگ برگی گندم (*Puccinia triticina* Eriks) در جنوب غربی ایران-استان خوزستان

م. حسن زاده، ن. صفایی، م. ر. اصلاحی، س. ت. دادرضایی، و س. ن. طباطبایی

چکیده

در این مطالعه ظهور اولین علائم بیماری زنگ برگی گندم در استان خوزستان از دی ماه ۱۳۹۳ با فاصله ده روز تا زمان برداشت، به مدت سه سال مورد پایش قرار گرفت. همچنین، تغییرات آب و هوایی وتاثیر آن بر روی توسعه این بیماری مطالعه گردید. طی سال زراعی ۹۴-۱۳۹۳ اولین علائم با شدت 5MS در جنوب و غرب استان به ترتیب در نیمه سوم اسفند ماه و نیمه اول فروردین ماه مشاهده گردید. در شمال استان علائم بسیار جزئی بیماری با شدت 10MS در نیمه دوم فرودین ماه بروز پیدا کرد. در سال زراعی ۹۵-۱۳۹۴ اولین علائم با شدت 5MS در اواخر بهمن ماه در قسمت های جنوبی استان ظاهر شد. در غرب استان خوزستان اولین علائم بیماری با شدت 20MS در ۲۰ اسفند ماه مشاهده گردید. در نواحی شمالی استان بروز اولین علائم در اوایل اسفند ماه با شدت 10MS اتفاق افتاده و تا 30MS پیشرفت کرد. در سال زراعی ۹۶-۱۳۹۵ اولین علائم بیماری در اطراف رودخانه کارون با شدت 5MS در تاریخ ۲۰ اسفند ماه مشاهده شده و نهایتا در تاریخ ۱۰ فروردین به 10MS رسید. در نواحی غربی استان خوزستان اولین علائم در اواسط اسفند ماه با شدن 5MS بروز و سپس متوقف گردید. یک هفته بعد در شمال استان علائم بیماری با شدت 5MS بروز پیدا کرده و در ۱۰ فرودین ماه با شدت 15MS متوقف گردید. بر اساس مطالعات قبلی انجام گرفته، اولین علائم بیماری زنگ برگی معمولا از غرب استان شروع می شود. اما هم اکنون الگوی علائم بیماری به در استان خوزستان به صورت چشمگیری تغییر پیدا کرده است و اولین علائم در جنوب استان خوزستان نزدیک رودخانه کارون و صنایع کشت و صنعت نیشکر بروز پیدا می کند که احتمالا به دلیل اقدامات مدیریتی انجام گرفته در غرب استان خوزستان و خشک شدن بخش بزرگی از تالاب هویزه می باشد.

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