Epidemiology of Wheat Yellow Rust (*Puccinia striiformis*) in the Saïss plain during the 2017-2019 growing seasons

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Abstract

Wheat is one of the most widely consumed cereals globally, with bread wheat dominating the majority of cereal fields. However, in recent years, yields have declined due partly to infectious fungal diseases, particularly obligate crop pathogens like yellow rust (Yr). This study examines the epidemiology of yellow rust (*Puccinia striiformis*) across 99 wheat fields in the Saïss region, Morocco. The prevalence of yellow rust was found to be 56.2% in bread wheat and 43.7% in durum wheat. From 2017 to 2019, overall prevalence increased to 34.9%, with Taoujdate, L'Mhaya and Aïn Jemâa fields being the most affected. Most of the inspected wheat fields exhibited low yellow rust severity, with 78% of fields showing less than 5% severity. The highest severity recorded was 15% in Taoujdate, while the lowest was 1.15% in Haj Kaddour. These findings can feed decision support tools for managing yellow rust outbreaks, contributing to environmentally friendly and sustainable wheat production in Morocco.

Keywords: Yellow rust, wheat, Prevalence, Incidence, Severity, Epidemiology

INTRODUCTION

The cereal sector is one of the most vital components of Morocco's agricultural economy, holding a key position in the nation's agricultural production (Ait El Mekki and Ghanmat, 2015). Cereals constitute 75% of Local Nutritional Food (LNF) and contribute 15 to 20% of the agricultural GDP. This sector is crucial for job creation, particularly in rural areas, contributing 20.3% to the national economy (MAPMDREF, 2018). The socio-economic significance of the grain sector is primarily focused on bread wheat, durum wheat and barley (Mefleh, 2021). Wheat is one of the world's most important cereal crops, both in terms of production and consumption (He *et al.*, 2022), accounting for about 1/5 of the global calorie intake (Anonymous, 2010). Morocco ranks as one of the leading wheat importers globally, being the eleventh-largest consumer according to the World Map of Wheat Importers 2017-2018 (Khanfri *et al.*, 2018). Additionally, Morocco was recognized as a global leader in the use of barley for human nutrition (Singh Verma, 2019).

Wheat is the most consumed crop in Morocco, with an average consumption of 258 kg per person per year. However, wheat production faces threats from several diseases, particularly yellow rust caused by *Puccinia striiformis* (Pst), which is one of the most devastating wheat diseases globally. Yield losses due to yellow rust can range between 5% and 50%, depending on the year, region, and stage of wheat development (El Jarroudi *et al.*, 2020; Singh *et al.*, 2016). According to the FAO, yellow rust was widespread across nearly all regions in Morocco, with 40% of monitored fields showing an incidence of 50% or more (FAO, 2018; Alo *et al.*, 2018; Shahin, 2017).

While fungicides are effective means of controlling yellow rust, their use can have adverse health and environmental impacts. Moreover, repeated applications may lead to fungicide resistance in Pst strains (Chen and Kang, 2017). Therefore, alternative control measures are needed. The most effective, economical and environmentally friendly strategy for combating yellow rust is the use of resistant wheat varieties (Chen and Kang, 2017). Developing new varieties with long-lasting rust resistance has become a critical challenge for wheat breeders (Hussain *et al.*, 2017). The incorporation of resistance genes in wheat production has proven to be a highly effective approach to controlling yellow rust (Savadi *et al.*, 2018). Additionally, the use of antagonistic microorganisms for biological control is considered one of the most environmentally sustainable solutions (Berg *et al.*, 2017).

The Pst pathogen, however, exhibits significant genetic variability, which can influence the effectiveness of genetic resistance (Wan *et al.*, 2017). This variability is attributed to its high reproducibility, ability to spread over long distances and adaptability to different environments and host species (Chen, 2017; Mboup *et al.*, 2012; Wan *et al.*, 2017). Therefore, this study aims to assess the prevalence, frequency and severity of stripe rust, as well as its distribution in the Saïss Plain.

MATERIALS AND METHODS

Description of the study Area: Geographic scope of the survey

The 2018 wheat disease survey encompassed the wheat-growing areas of the Saïss Plain surrounding the National School of Agriculture, Meknès. Nine locations were inspected for wheat stripe rust, as depicted in the map (Figure 1). These locations include Haj Kaddour, Boufekrane, Sebaa Ayoun, El Hajeb, Ain Taoujdate, M'Haya, Ain Orma, Ain Jamaa and Bouderbala.

The number of inspected fields in each location is shown in Table 1.

Table 1: Locations were inspected for wheat diseases during the 2018 growing season

Location code	Location	Number of inspected fields
L1	El Haj Kaddour	10
L2	Boufekrane	15
L3	El Hajeb	20
L4	Sebaa Ayoun	14
L5	Ain Taoujdate	15
L6	M'Haya	7
L7	Ain Orma	4
L8	Ain Jamaa	6
L9	Bouderbala	7

Survey and sampling methods

Ninety-eight fields of durum and bread wheat were surveyed across nine localities in the Saïss Plain region between mid-April and late May 2018. The wheat crops were at the late anthesis to soft dough stages. Survey stops were made along roadsides every 8 to 12 km, where available wheat fields were inspected. In each field, 15 plants were randomly selected and observed for the presence of diseases. These plants were chosen approximately 10 meters away from the field borders, with a random walk pattern used to select them. Disease severity on the flag leaf of each tiller was evaluated using the modified Cobb scale for rusts.

Disease evaluation

Prevalence

At the end of the survey period, the prevalence of yellow rust was calculated by determining the percentage of wheat fields affected by the disease in relation to the total number of fields inspected in the Saïss region, as well as within each specific locality and commune. The calculation was performed using the following formula:

Prevalence (%) = 100 x (Number of field infected/Total number of field inspected)

Incidence

The incidence of yellow rust was calculated as the percentage of plants affected by the disease among the 15 randomly selected plants in each field, using the following formula:

Incidence (%) = 100 x (Number of infected plants/Total number of examined plants)

Severity

Observations involved assessing disease severity on the flag leaf as well as two additional leaves, using the modified Cobb scale for rust severity (Chen, 2017; Peterson *et al*., 1948; Roelfs *et al*., 1992). The average severity was then calculated for each field. Severity was determined by calculating the percentage of plant tissue covered by fungal spores using the following formula:

Severity (%) = 100 x (Infected leaf area/Total surface area of leaf examined)

Data collection and analyses

The disease estimates recorded for each field across the nine locations in the Saïss Plain were organized in a spreadsheet to facilitate data calculation and classification. The collected data was subjected to descriptive analysis using Microsoft Excel. Descriptive statistics were employed to summarize and structure the quantitative observations, providing accurate insights into the surveyed wheat fields. The results of these analyses are presented in the form of histograms and graphs. Additionally, the mapping of prevalence, severity, and incidence data was performed using ArcGIS 10.3 software.

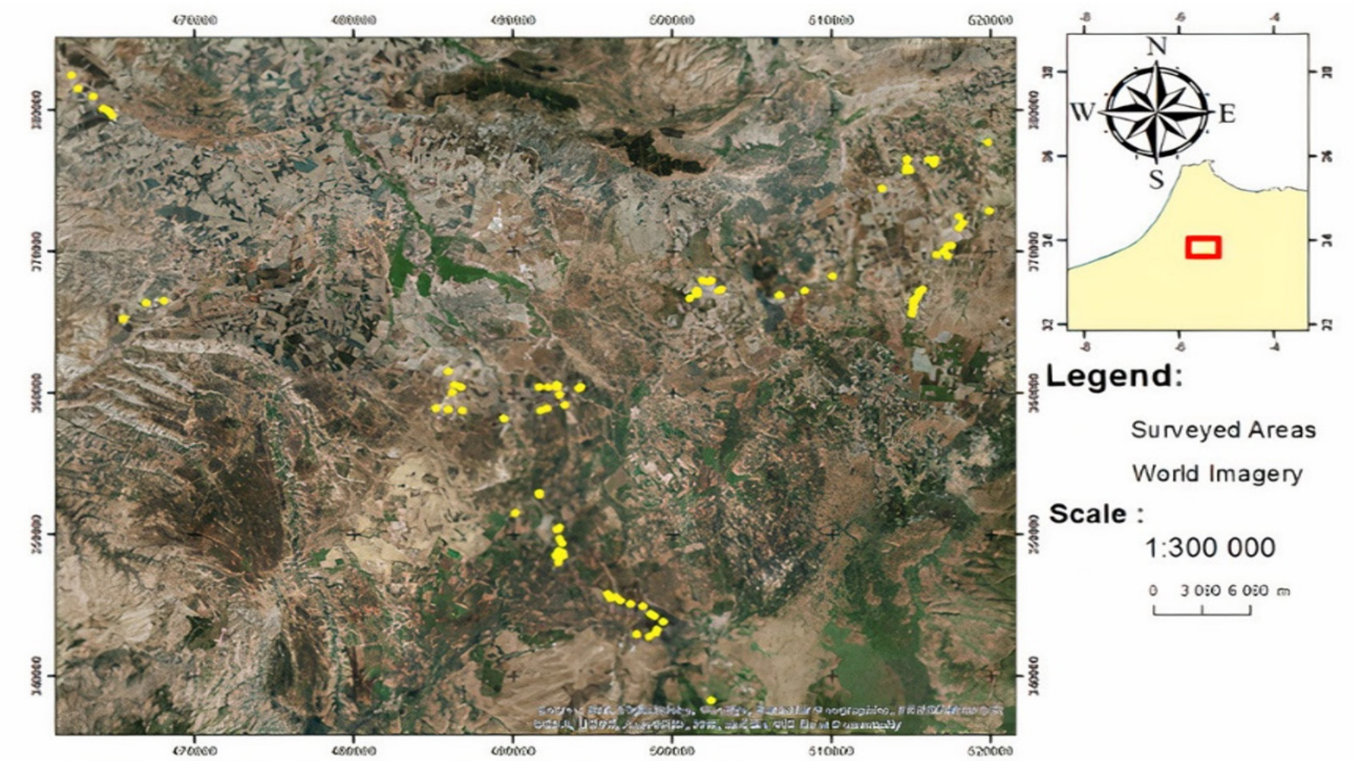

Figure 1: Fields surveyed for wheat diseases during 2017-2018 and 2018-2019 cropping seasons in the Sais plain in Morocco

RESULTS

Prevalence of stripe rust by location

During the 2017-2018 campaign, the overall prevalence of yellow rust in the Saïss Plain reached 47.9% ($p<0.05$). The communes of Taoujdate, El Hajeb, and Bouderbala were the most affected, with moderate prevalences ranging from 53.3% to 57.1%. In contrast, the 2018-2019 crop year saw a significant increase in overall yellow rust prevalence, reaching 82.8% in the Saïss Plain. In the communes of Taoujdate, L'Mhaya and Aïn Jemâa, the disease was present in all inspected fields. In Boufekrane, Sebaa Ayoun, and Aïn Orma, prevalence reached 81.8%. Yellow rust was observed in 72.7% of the fields in both Bouderbala and Haj Kaddour, while El Hajeb reported a prevalence of 54.5% (Figure 2). This indicates that nearly half of the fields were affected by stripe rust.

The absence of stripe rust in the other 51% of fields could be attributed to factors such as fungicide application, host resistance or unfavorable environmental conditions. Given that the weather of this year was conducive to disease development and that most wheat varieties in Morocco are susceptible to stripe rust, it is likely that fungicide applications played a key role in protecting the 51% of fields that remained disease-free. Stripe rust was most prevalent in Bouderbala, followed by El Hajeb, Ain Taoujdate, Haj Kaddour and Aïn Orma. In other locations, the slightly lower prevalence suggests that different wheat varieties may be cultivated in these areas.

Effect of wheat species on stripe rust prevalence

Table 2 shows that stripe rust is more prevalent in bread wheat than in durum wheat. An independent samples t-test conducted in SPSS revealed significant differences in severity ($p<0.05$) between bread wheat and durum wheat, indicating that the bread wheat varieties cultivated in the area are more susceptible to the disease than the durum wheat cultivars. This finding suggests that promoting the cultivation of durum wheat in the Sais Plain could be beneficial, potentially reducing the overall impact of stripe rust on wheat crops in the region.

Table 2: Prevalence of stripe rust on bread and durum wheat

***Triticum* spp**	**Prevalence (%)**
Bread wheat	56.2
Durum wheat	43.7

The stripe rust incidence and severity

Field data collected during the 2018 growing season shows that stripe rust incidence varied from 0% to 100% of plants infected in the inspected fields (Figure 3). However, this parameter alone does not reflect the severity of the disease on the crop leaves. A single infected plant may exhibit a minimal amount of disease (low severity) or be severely affected, reaching 100% severity (Figure 4). The regression analysis of disease severity on disease incidence highlights this difference. Therefore, incidence alone does not provide an accurate representation of the

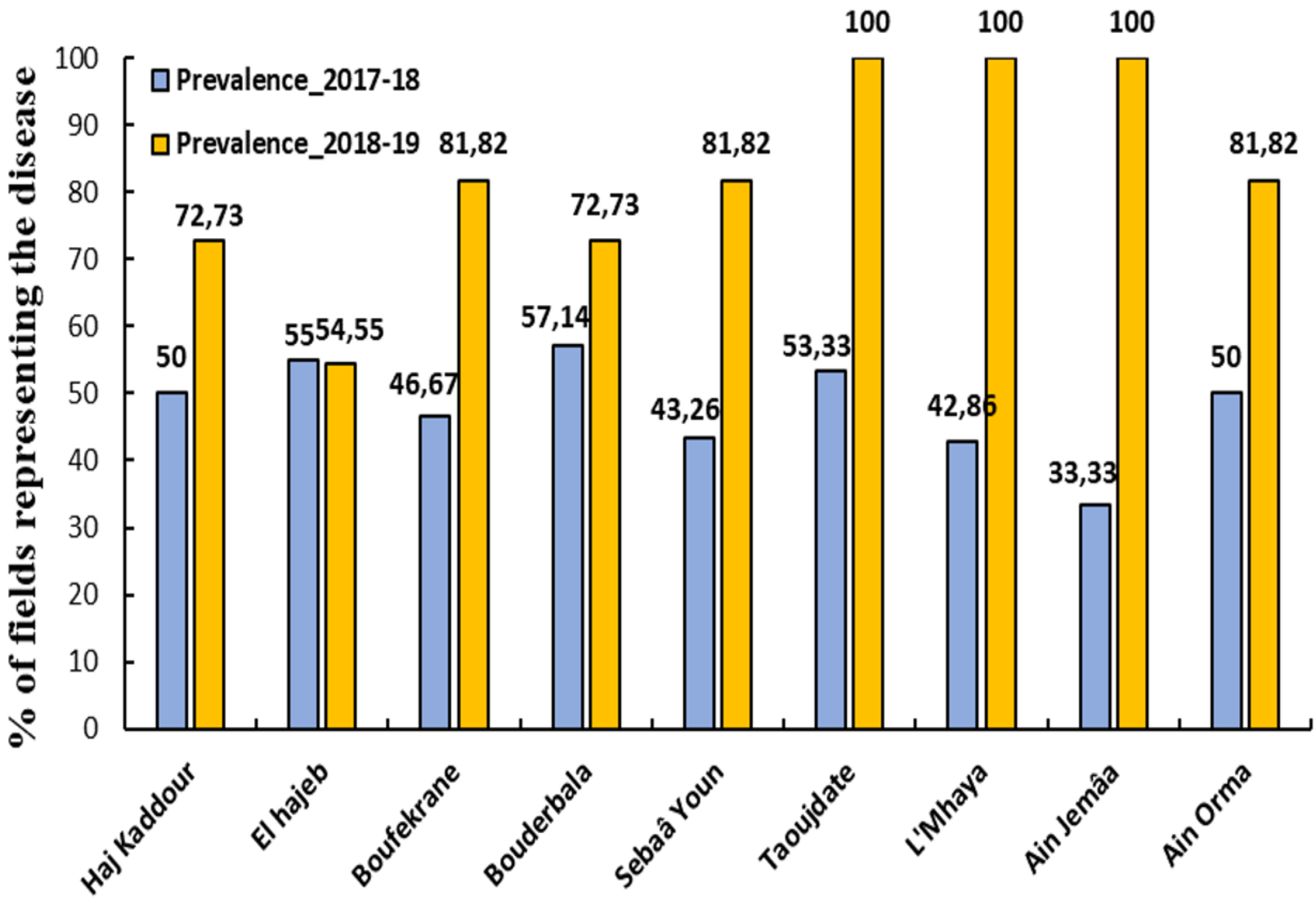

Figure 2: Prevalence of yellow rust during the two crop years 2017-2018 and 2018-2019

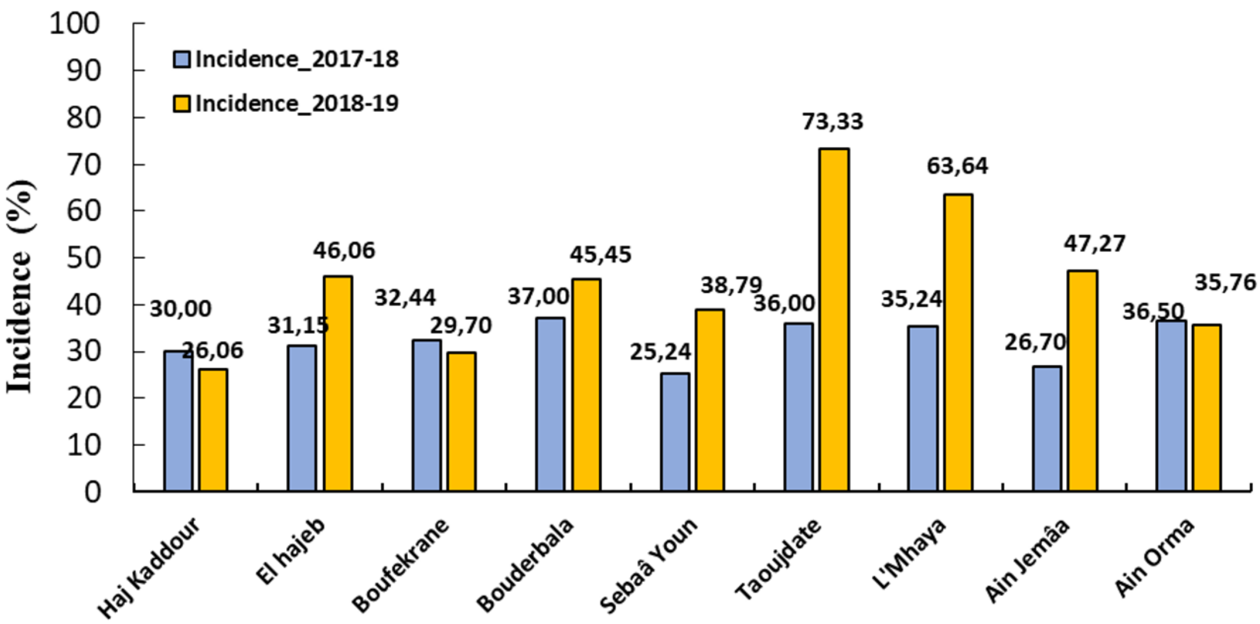

Figure 3: The Incidence of yellow rust in the Saïss Plain during the 2017-2018 and 2018-2019 campaigns

Figure 4: a: symptoms on leaf, b: Heavily infected field in Ain Jamaa

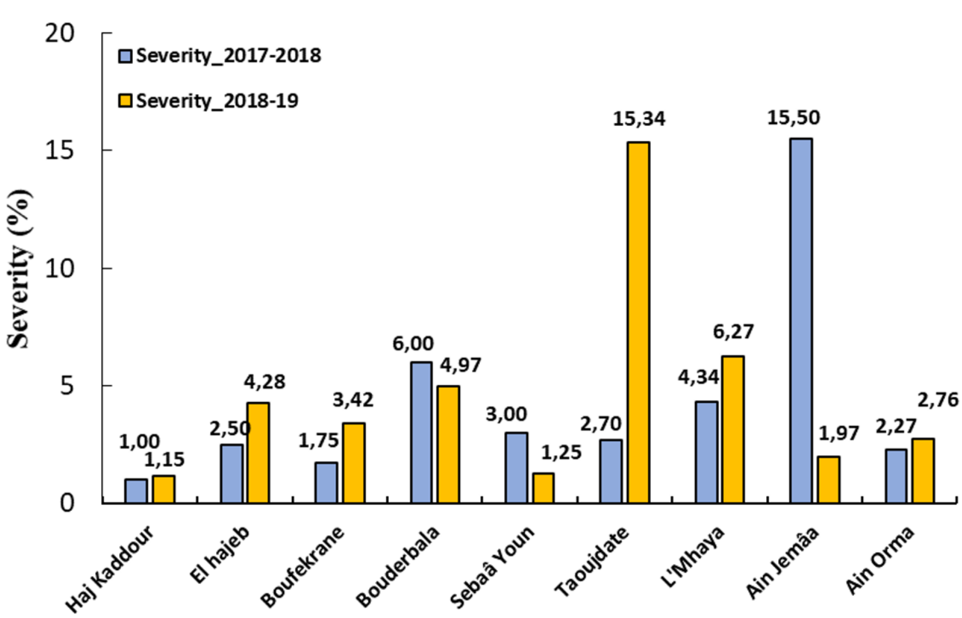

Figure 5: The severity of yellow rust in the Saïss Plain during the 2017-2018 and 2018-2019 campaigns

disease's impact in the fields, suggesting its limited usefulness in future studies. Researchers may find it more effective to focus on disease severity.

During the 2018-2019 campaign, the incidence and severity of yellow rust were lower compared to other diseases, such as tan spot and Septoria. The average severity of yellow rust was generally low across the majority of surveyed wheat fields, with 78% of fields showing less than 5% severity (Figure 5). The highest severity recorded was 15% in Taoujdate, while the lowest, at 1.15% ($p<0.05$), was observed in Haj Kaddour (Figure 6). This low severity is likely due to the widespread use of chemical control measures and the cultivation of resistant varieties, such as the Faiza variety.

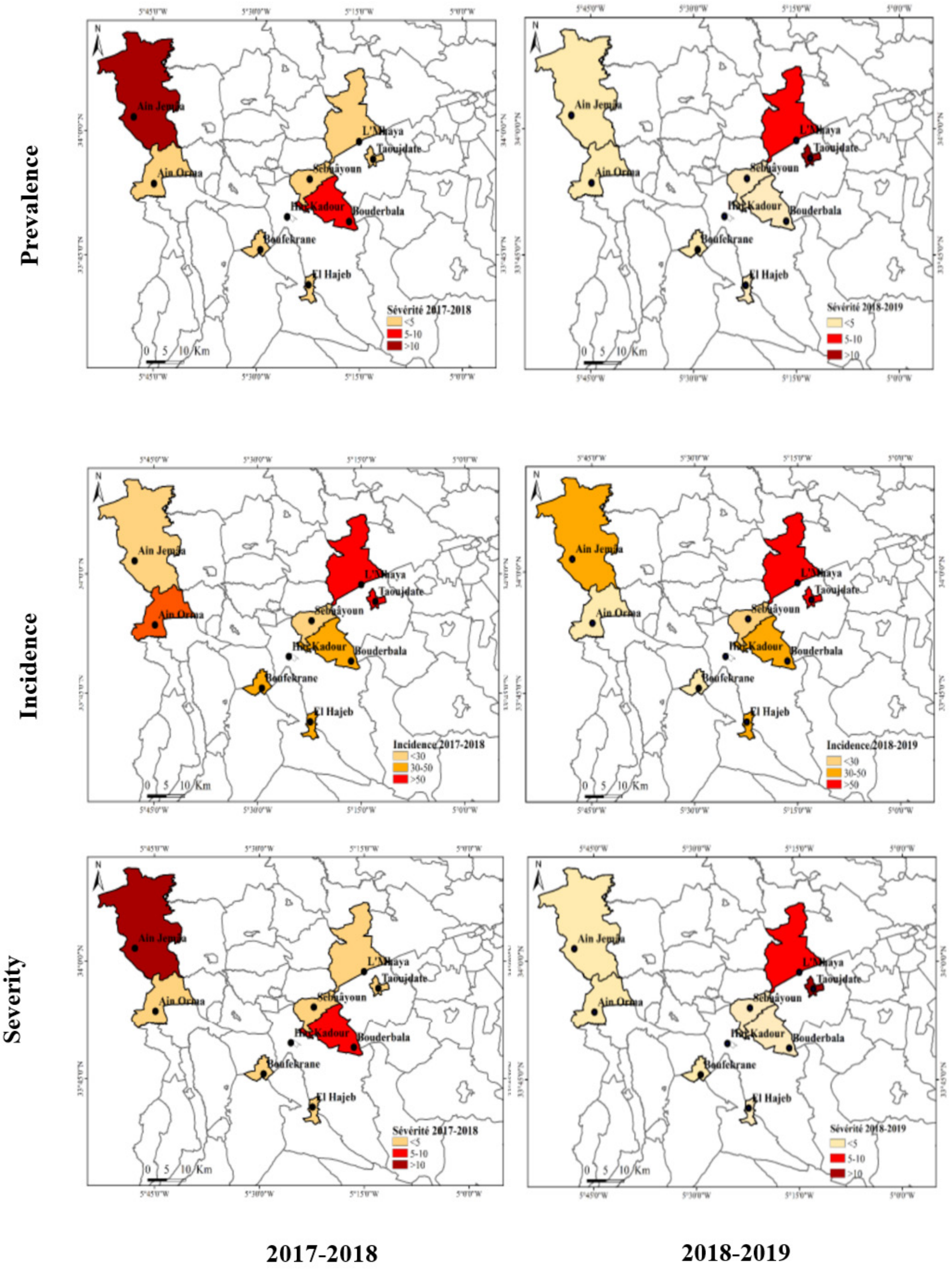

Figure 6: Map showing differences in epidemiological parameters between the two campaigns 2017-2018 and 2018-2019

DISCUSSION

During the 2018-2019 crop year, the percentage of fields affected by yellow rust in the Saïss region increased compared to the 2017-2018 crop year, when overall prevalence was 49% (Khanfri *et al.*, 2018). This increase is likely due to weather conditions that facilitated the dispersal of fungal spores, particularly wind, which is a major factor in the spread of fungal diseases. Notably, strong winds occurred during the last week of March 2019, from March 26 to 28, which likely aided the dispersal of *P. striiformis* spores, even among more resistant wheat varieties.

Despite the higher incidence, the severity of yellow rust during the 2018-2019 campaign remained generally low across most surveyed fields. This is likely attributed to the widespread use of fungicides among cereal growers in the region. In fields with higher severity, the lack of chemical control may be due to concerns about phytotoxicity exacerbated by drought conditions, as this crop year coincided with a drought.

Currently used fungicides for yellow rust control include propiconazole, azoxystrobin, a combination of propiconazole and trifloxystrobin, strobilurin, and a combination of azoxystrobin and propiconazole (Chen and Kang, 2017). Field trials in the United States over a decade demonstrated that fungicide applications, particularly propiconazole, reduced the Area Under Disease Progress Curve (AUDPC) by over 80% (Chen, 2014). However, chemical control increases production costs and can have negative impacts on health and the environment. Moreover, repeated applications may lead to the development of fungicide-resistant strains of Pst.

The lower severity observed during the 2018-2019 crop year may also be due to the use of resistant varieties, such as the widely grown Faiza variety in the Saïss region, known for its high resistance to yellow rust. Although tan spot and Septoria were more severe during this period, the potential future impact of yellow rust remains significant. Pst, the pathogen responsible for yellow rust, evolves rapidly, developing new, more virulent races that can affect a broader range of wheat varieties (Liu *et al.*, 2017; Wan *et al.*, 2017). Unlike other wheat diseases, yellow rust is characterized by high variability due to its high reproducibility, ability to spread over long distances and adaptability to different host species and environments (Mboup *et al.*, 2012). Recent observations have identified Pst populations in several countries that have adapted to warmer climates, with high-temperature-tolerant isolates demonstrating better survival and reproduction in hot environments than other isolates (Wang and Chen, 2017). Additionally, these new races exhibit greater virulence, allowing them to infect more wheat varieties (Liu *et al.*, 2017).

Stripe rust is one of the most destructive plant diseases globally and has been a major concern for wheat in Morocco since 2010 (Khanfri *et al.*, 2018). Extensive surveys conducted during the 2010 and 2011 wheat growing seasons covered key wheat-producing areas including Saïss, Gharb, Middle Atlas, Tadla, Zair, Zemmour, Pre-Rif, High Atlas, and Oasis. In 2010, yellow rust was detected in 64% of bread wheat fields and 32% of durum wheat fields, with infection rates ranging from 0% to 80%. The highest infection rates were observed in Saïss, Tadla and the Middle Atlas (El Jarroudi *et al.*, 2019).

By 2011, stripe rust was present in all surveyed areas, affecting 70% of bread wheat fields, while it was nearly absent in durum wheat fields. Severity was generally mild, with 35% of the fields showing less than 5% severity. However, in 2013, stripe rust severities exceeding 50% were observed in over 40% of bread wheat fields, with commercial cultivars such as Marchouch, Mahdia, Achtar and Amal being particularly susceptible.

In 2010, stripe rust was a significant problem in the Middle East and North Africa, including Morocco, due to the emergence of new aggressive pathotypes of Pst. The loss of effectiveness of the Yr27 resistance gene resulted in significant crop losses across several CWANA countries (Pakistan, Morocco, Algeria, Tunisia, Turkey, Iran, Yemen, Azerbaijan, Georgia, Uzbekistan and Afghanistan) (Coffman, 2012; Singh *et al.*, 2008). Despite favorable environmental conditions in many CWANA regions in 2011 and 2012, severe stripe rust epidemics did not occur, highlighting the year to year variability of plant disease impact (Coffman, 2012). In 2013, early yellow rust infections and serious outbreaks on susceptible cultivars were reported, although the overall severity was slightly less than in 2010.

The study findings indicate that bread wheat cultivars are more susceptible to yellow rust compared to durum wheat varieties. The reduced disease intensity in durum wheat may be attributed to the introduction of new cultivars with higher resistance levels since 1972 (Liu, *et al.*, 1996).

CONCLUSION

Based on these results, yellow rust was more prevalent during the 2018-2019 crop year compared to the previous year. This increase is likely attributed to the weather conditions, particularly strong wind waves, which facilitated the disease's dispersal. Since yellow rust development is closely linked to weather conditions, fungicide applications should be carefully timed based on weather parameters. This approach enhances the effectiveness of chemical control and minimizes the risk of phytotoxicity, especially during drought years.

Although yellow rust is currently less severe than other wheat diseases such as tan spot and Septoria, it poses a potential threat in the future due to the high variability of Pst populations. These populations can rapidly develop more aggressive and virulent races, potentially affecting a wide range of wheat varieties. This risk is particularly significant in Morocco, where most wheat varieties exhibit low resistance to yellow rust. Therefore, characterizing pathogen races is a crucial strategy for disease management, as it helps breeders understand pathogen virulence and assess the risk of epidemics.

This study assessed key epidemiological parameters of yellow rust, including prevalence, incidence, and severity, and examined its distribution in the Saïss Plain. Ongoing surveys of wheat diseases are essential for gathering data to implement effective control measures, improve yields, and support the industry. In conclusion, stripe rust remains a significant disease in wheat cultivation in the Saïss Plain, with a higher prevalence in bread wheat compared to durum wheat. The 2018 prevalence of approximately 50% suggests that half of the fields were disease-free, likely due to extensive fungicide use. The higher susceptibility of bread wheat underscores the potential benefits of shifting to durum wheat cultivation to reduce the impact of the disease.

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