Monitoring and Control of *Puccinia striiformis* f. sp. *tritici* in Wheat Fields Under Rainfed Conditions

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Abstract

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The current study was carried out to monitor the date of primary inoculum arrival of *P. striiformis* f. sp. *tritici* (*Pst*) to wheat fields in Sulaimani city and the subsequent development of yellow rust disease during two successive seasons. Results obtained revealed that the first inoculum of *Pst* arrived in Bakrajo wheat fields in March 2022 and 2023. However, the first yellow rust infection on the susceptible wheat cultivar 'Hsad' was observed on April 15 in the first year and April 10 in the second year. The number of uredospores gradually increased with the disease progress, reaching its peak at 51.3 spores/cm² on May 7, 2022, and 187.3 spores/cm² on May 9, 2023. However, uredospores number decreased by the end of the first week of June. Uredospores number per square centimetre was higher in 2023 compared to 2022. Yellow rust control was conducted by using two susceptible wheat cultivars,"Hsad" and "Tamuz-2", and two different fungicides, Amistar Xtra and Plant Growth Cleaner (PGC), applied at two different times. Results showed that Amistar Xtra treatment significantly reduced the mean coefficient of yellow rust infection in both wheat cultivars. "Hsad" x Amistar Xtra treatment resulted in 83.2 and 85.1% reduction of yellow rust severity for both applications, respectively, whereas "Tamuz-2" x Amistar Xtra treatment resulted in 42.5 and 45.9% reductions for the first and second applications, respectively. PGC treatment had varying effects on the mean coefficient of infection in both susceptible wheat cultivars. The first application of Amistar Extra resulted in changing the infection type from S to MR in "Tamuz-2", whereas the second application of Amistar Extra changed the infection type to R in Tamuz-2. Both Amistar Extra applications changed the infection type of "Hsad" to R-MR. Application of Amistar Extra significantly increased yield and yield components values in both cultivars suggesting its ability to efficiently control the disease and enhance plant characteristics.
Keywords: Fungal diseases, yellow rust, fungicides, disease resistance, plant growth cleaner, Iraq.

Introduction

Wheat, *Triticum aestivum* L. is one of the most important cereal crops in Iraq. It is currently grown on 2.4 million hectares. Wheat production is limited by various biotic and abiotic stresses. Fungal diseases have significantly restricted the national wheat production (Al-Maaroof, 2022; FAO, 2021). Diseases such as rusts, smuts, and septoria leaf blotches have drastically reduced wheat yields and quality (Al-Baldawi, 1993). Yellow rust disease incited by *Puccinia striiformis* f. sp. *tritici* is widespread in temperate zones where wheat is commonly grown (Bux *et al.,* 2012). The disease has been observed in almost all the countries where wheat is grown, and more than 60 countries have reported yellow rust presence (Wellings, 2011). Unfortunately, 88% of wheat cultivars worldwide are susceptible to yellow rust infection (Zhang *et al.,* 2022).

According to Hovmøller *et al.* (2011), *P. striiformis* belongs to the phylum Basidiomycota, class Urediniomycetes, order Uredinales, family Pucciniaceae, and genus *Puccinia*. Yellow rust infection can cause at least 5.5 million tons of yield and $1 billion annual losses globally (Beddow *et al.*, 2015). The disease affects the number, size, and weight of grains in the spike, number of spikes, plant height, size, and root growth (Wellings, 2011). Additionally, the produced seeds from the infected plants have lower vigor and poor emergence. The disease can result in grain yield loss of 10 to 70%, depending on the cultivar susceptibility, time of initial infection, disease period, and rate of disease development (Al-Maaroof & Nori, 2018).

IPM programs are effective in controlling rust disease by combining agricultural control practices, genetic resistance, and fungicide applications. However, cultural practices may not be profitable when used alone (Chen *et al.,* 2004; Pradhan *et al.,* 2016). Due to yellow rust's ability to accelerate rapidly, cause significant losses, and ability to invade isolated areas, early visual monitoring and the use of trap nurseries are required to allow field managers to make informed decisions to control the disease (Duveiller *et al.,* 2007; Gaunt & Cole, 1992). Once the disease is identified in susceptible cultivars in farmer fields, it will accelerate rapidly under favorable environmental conditions, if it is not managed properly (Farber, 2016). Advanced technologies have greatly improved development and screening of fungicides over the past few decades, resulting in a range of effective fungicides that work in different ways. The cost of fungicides has also decreased, making chemical control a more profitable option for controlling yellow rust and becoming a vital component of integrated management of the disease in many parts of the world (Chen & Kang, 2017a). Effective and economical yellow rust control depends on the application time, as the disease development can vary significantly due to weather conditions change (Chen, 2014). Currently, 40 different fungicides have been documented for managing yellow rust (Ali *et al.,* 2022). These fungicides

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include two main types of active ingredients: triazoles and strobilurins, and some fungicides include both (Marsalis & Goldberg, 2016; Pradhan *et al.,* 2016). The combined use of propiconazole and azoxystrobin has become the best choice for farmers to control wheat yellow rust as the chemicals consist of two modes of action by combining chemicals DMI and QoI (Ali *et al.,* 2022). Seed treatment with broad-spectrum systemic fungicide can also provide early protection (Bansept, 2013). However, fungicides application is environmentally unsafe and uneconomical compared to genetic resistance (Chen *et al.,* 2004).

The aim of this study is to determine the time of primary inoculum arrival of *P. striiformis* to wheat fields and assess the efficiency of some control measures in controlling yellow rust disease in wheat under Sulaimani's environmental conditions.

Materials and Methods

Arrival time of *P. striiformis* primary inoculum to wheat fields

All the field experiments were conducted at the experimental field of College of Agricultural Engineering Sciences at University of Sulaimani in Bakrajo (latitude N 35° 32 036; longitude E 045° 21 818 and altitude 742m) 10 km southwest of Sulaimani center and 400 km north of Baghdad, during two successive crop seasons 2021 and 2023. To determine the first arrival time of the primary inoculum of *P. striiformis* f. sp. *tritici* to wheat fields in Sulaimani, three microscopic slides covered with 4-5 ml layer of water agar blocks for each were distributed horizontally on a particular stand at three different locations within the susceptible cultivars plots. Water Agar media was prepared by suspending 20.0 g Agar/L of distilled water in a flask, and the medium was completely dissolved with a magnetic stirrer. The medium was sterilized by autoclaving at 15 lbs pressure and 121°C temperature for 15 min, then poured carefully into sterile petri plates under a laminar air flow hood (Atlas, 2006). The slides were located at the same level as the plant height and left in the field for 2h then taken to the laboratory to calculate number of trapped uredospores of *P. striiformis* f. sp. *tritici* in a one-centimeter square area of each slide. Uredospore counting was repeated every seven days from early March to late May in the 2021/22 and 2022/23 growing seasons.

Efficiency of some control measures in disease control of wheat yellow rust

The experiment was conducted to estimate the efficiency of the fungicide Amistar Xtra 280SC (Syngenta), (active ingredients: 200g/l Azoxystrobin, and 80g/l. Cyproconazole) and Plant Growth Cleaner (PGC) (Nanotech 2000 Alpha, USA) with two application dates (15/04/2023 and 30/04/2023) at the recommended dose against yellow rust disease control on two susceptible cultivars (Hsad and Tamuz2). Amistar Xtra and the plant growth cleaner were applied at a rate of 750 ml/ha, with detergent added at a rate of 0.2 ml/l water before spraying to lower the water surface tension. The treatments were applied by spraying the leaf surface and only water was used in the control treatment. The experimental design used was a factorial randomized complete block design (RCBD) with three replications. Seeds were sowed in rows within 2×2 m^2 plot, with 25 cm space between rows, 1 m between treatments, and 2 m between blocks.

Disease scoring of yellow rust was monitored periodically at 7-10 days interval, by recording infection type (IT) and disease severity (DS) for each treatment using a standard scale (Ramburan, 2003) and modified Cobb scale (Peterson *et al.,* 1948). The yellow rust coefficient of infection (CI) was determined for each treatment by multiplying the severity with a fixed value of host response coefficient, which was assigned as follows: R=0.2, R-MR=0.3, MR=0.4, MR-MS (M)=0.6, MS=0.8, MS-S=0.9, and S=1.0. This method facilitated the comparison and ranking of different genotypes or treatments based on statistical analysis (Roelfs, 1992).

$$CI = DS \times IT$$

where DS= Disease severity and IT = Infection type.

Grain yield, and yield components traits for each treatment, such as number of grains/spikes, grain weight/spike(g), 1000- kernel weight (g) and grain yield (per m^2), were also measured.

Statistical analysis

Collected data for CI, yield and yield components traits were analyzed by JIM software to determine the source of variance and comparison between treatments. Duncan's multiple range test at P=0.05 was used to compare means.

Results and Discussion

Arrival time of the primary inoculum of *P. striiformis* f. sp *tritici* to wheat fields and development of the disease

Figure 1 shows the arrival date of the primary inoculum of *P. striiformis* f. sp. *tritici* to Bakrajo wheat fields during two successive seasons, 2021/22 and 2022/23 and the development of the disease on the susceptible cultivar Hsad (Figure 2). In 2022, 0.33 uredospores/cm^2 were captured on the trap stands on 15 March 2022, whereas in 2023, 1.33 uredospores/cm² were captured on the traps on 31 March. However, despite the early presence of the uredospore on the traps, no germination of the primary inoculum of yellow rust pathogen was observed in March due to the unfavorable environmental conditions (Figure 3). The primary infection of yellow rust was observed on the susceptible cultivars on April 15 in the first year and April 10 in the second year. The uredospores' numbers gradually increased with the development of yellow rust on the susceptible cultivars, reaching its peak of 51.3 uredospore/cm² on 7 May 2022 and 187.3 uredospore/cm² on 9 May 2023, when the disease severity on Hsad was 73.3% in 2022 and 75% at milky stage in 2023 (Figures 2 and 3).

The number of uredospores decreased as the disease progressed and the plants matured due to the decrease of relative humidity and precipitation, coupled with an increase in temperature by the end of first week of May. The number of uredospores/cm^2 was as expected, increased in 2023 compared to 2022 due to more favourable environmental conditions during the growth period, including increased rainfall and relative humidity, which promoted the development and spread of the disease in the second year (Figure 3).

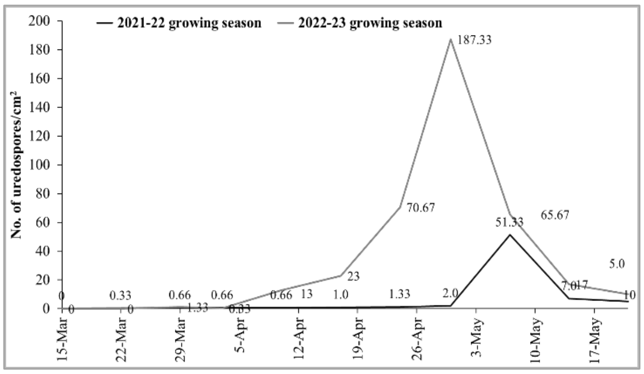

Figure 1. Number of *P. striiformis* urediospores detected on the traps in the susceptible wheat fields during two successive seasons, 2021- 22 and 2022-23 seasons at Bakrajo, Sulaimani, IKR, Iraq.

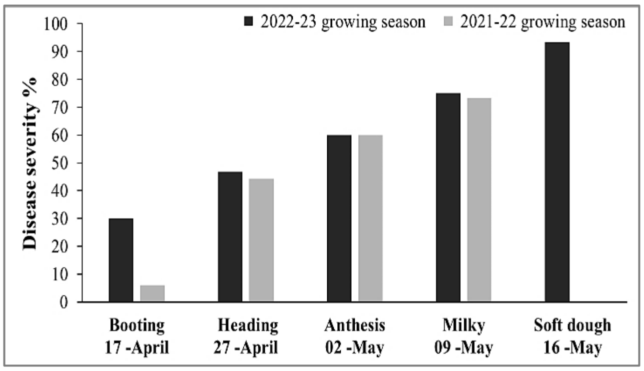

Figure 2. Yellow rust disease development on the susceptible wheat cultivar Hsad during 2021/22 and 2022/23 seasons at Bakrajo, Sulaimani, IKR, Iraq

Decreasing the relative humidity to 50% and rise of temperature above 25°C reduced the uredospore production on the susceptible cultivars (Al-Maaroof & Nori, 2018). Pustules continue to produce uredospores for one week, and the highest production occurred on the fourth day at a moderate temperature (Tomerlin *et al.*, 1984). However, it is important to note that the highest number of uredospores does not necessarily correspond with increased disease severity; could be due to unviable or physiologically incompatible uredospores with the tested host plants. Uredospore's germination and invasion of the host tissues require 100% humidity for 3-4h; thus, any changes in daily temperature and relative humidity may affect them (Agrios, 2005). These conditions were available in the experiment location during the arrival of the primary inoculum to wheat fields, since the dew stayed for a long time on the host plant in the morning, which favours a successful condition for uredospore germination and subsequent infection. The Iraqi Kurdistan region falls under the epidemiological Zone 7, known for spreading new races of yellow rust in Asia. Yellow rust disease has been a frequent problem in most wheat fields in Iraq over the past few decades. In 1995, severe epidemics of the disease were observed in some wheat fields in northern Iraq, particularly Nineveh, Kirkuk, and Salahaddin, resulting in high infections in the commercial bread wheat cultivars fields (Al-Maaroof, 2022). The first epidemic of yellow rust was observed in 1998 in some wheat fields in the middle zone, especially in Babylon and Baghdad. During the disease epiphytotic, infection rate ranged from 0.09 to 0.35 per unit per day (Al-Maaroof *et al.*, 2003). During the period 1997 to 2020, the disease has consistently appeared in various locations annually.

The most severe outbreaks were observed in 2010, affecting numerous wheat fields across various agrological zones. Yellow rust infection rate was exceptionally high, as documented earlier (Al-Maaroof *et al.,* 2009; 2010; 2015). It is believed that *Pst* uredospores can travel long distances due to their airborne nature and resistance to short-wave rays and other unfavourable conditions (Chen, 2005; Roelfs, 1992). Yellow rust disease is the most common type of rust disease in wheat that grows in cooler and humid regions. Previously, this disease was only found in the mountainous areas of the northern parts of Iraq, but now it has spread to other areas as well. This disease was rarely seen earlier in Iraq's central and southern parts (Al-Baldawi, 1993; Al-Maaroof *et al.,* 2001). The pathogen spores likely reach Iraqi Kurdistan region wheat fields from neighbouring countries such as Iran, Türkiye and Syria, which have the same epidemiological zone 7 and are known as sources of new races of yellow rust fungi in Asia. The absence of an alternate host in Iraq supports this theory (Al-Maaroof, 2022). New races of fungi have been spreading in Asia, particularly in Iraq, north-eastern Syria, south-eastern Türkiye, Iran, north-western Afghanistan, and southwestern former Soviet Federation countries (Stubbs, 1988); these countries fall under epidemiological zone 7, which is considered the source of spread. It is possible that the increase in the infection rate is not directly related to the highest number of uredospores; this could be because some of the uredospores may be non-viable or incompatible with the host plants. Additionally, the daily temperature and relative humidity might have affected the viability of the uredospores, as the germination and invasion process require 100% humidity for at least three to four hours (Al-Maaroof, 2022; Zhang *et al.,* 2022). Depending on the temperatures, uredinia (commonly referred to as pustules or sori) appear from chlorotic areas around 11-14 days after inoculation (Chen & Kang, 2017a). This is the reason why the spores were found at the beginning of March, but the disease did not appear on the susceptible cultivar Hsad until mid to late March in both years, respectively (Figure 3).

Efficiency of some control measures in disease control of yellow rust on wheat

Fungicides are chemical compounds used to prevent or eliminate the fungal growth and spore germination (Carmona *et al.,* 2020). It comes in second place to genetic resistance as a mean of controlling yellow rust. Technology advancements have significantly enhanced fungicides screening and development over the past few decades, leading to the production of more potent fungicides with different modes of action. The cost of fungicides has also decreased, making it a more profitable option for controlling yellow rust and other cereal diseases. As a result, fungicide application has become an essential component of integrated control of yellow rust worldwide (Chen & Kang, 2017b).

Table 1 summarizes the results obtained for the control of yellow rust in cvs Hsad and Tamuz-2, using two applications of each Amistar Xtra and PGC. Data was analyzed using factorial CRBD with two factors: factor one represents the susceptible cultivars and factor two represents application date. Results revealed that Amistar Xtra significantly decreased the mean coefficient of infection of yellow rust in cv Hsad by 95.96 and 98.15% at the first and second application, respectively, compared to the control treatment, and by 91.6 and 98.29% at the first and second application in cv. Tamuz 2. However, PGC significantly decreased the mean coefficient of infection of yellow rust in cv. Tamuz 2 by 37.86% and 57.15% in both applications compared to the control treatment. In contrast, no significant differences were found between both PGC applications and the control in cv. Hsad.

On the other hand, Hsad x Amistar Xtra treatment resulted in 83.2 and 85.1% reduction of yellow rust severity. In both applications, respectively, whereas Tamuz-2 x Amistar Xtra resulted in 42.5 and 45.9% reductions in response to the first and second application, respectively. Yellow rust infection type changed from susceptible to resistant in Amistar Xtra-2 treatment in cv Tamuz-2 and to R-MR in cv Hsad. However, the first application of Amistar Xtra changed the infection type from susceptible to moderate resistance in Tamuz-2 and to R-MR in cv. Hsad. Significant differences were detected in the mean CI of the susceptible cultivars. Yellow rust CI in the control treatment of Hsad (86.67) was significantly higher than yellow rust CI of control treatment in cv. Tamuz-2 (46.67). In case of both treatment application rates, significant differences in yellow rust on both cultivars, Hsad and Tamuz-2, were observed. Figure 4 showed that the highest value recorded by the control treatment which significantly differed from all other treatments. However, the lowest CI values were recorded by Amistar Xtra-2 and Amistar Xtra-1 treatments, respectively. According to the experiment's findings, Amistar Xtra effectively suppresses wheat yellow rust when applied at early stages of disease development. Amistar Xtra acts as preventive by blocking spore germination and curative by preventing mycelial growth and sporulation. The high efficiency of this fungicide in controlling yellow rust disease in wheat may be attributed to the combined effect of its active ingredients, Azoxystrobin and Cyproconazole. PGC impact in decreasing yellow rust infection by 57% is mainly attributed to the antimicrobial effect of the essential oils of this natural product and identified as a safe product by the Food and Drug Administration (FDA) and more accepted by consumers than the synthetic chemicals. The antifungal activity of the essential oils might be caused by the properties of Terpenes, terpenoids which have high lipophilic nature and low molecular weight. They are capable of disturbing the fungal cell membrane, resulting in cell death and inhibiting the sporulation and germination of fungal spores (Nazzaro *et al.,* 2017).

Freiezleben & Jager (2014) indicated that the antifungal activity of the essential oils can deactivate the fungus by disrupting the structure and function of the fungal cells organelles membrane or inhibit nuclear functions or protein synthesis. This outcome is consistent with the findings of Alemu & Mideksa (2016), who found that when fungicides were applied, yellow rust severity was considerably decreased to the lowest level when compared to untreated fields. Fungicides, which either kill or stop fungal growth have emerged as one of the main components of plant disease control strategies in recent years. However, fungicides can have unfavourable side effects and can inhibit non-target fungi (Wiik, 2009).

It is strongly advised to apply fungicides to susceptible wheat cultivars at early stages of disease development. Depending on the disease pressure level, it should be carried out at or shortly after flag leaf emergence (GS 39). At high disease pressure, repeated fungicide applications are required. On the other hand, the application might not provide sufficient protection against the infection if it is carried out at later stages, particularly at early or mid-anthesis stages. (Viljanen-Rollinson, 2002). The ability of non-penetrating fungicides to be absorbed by plant tissues is limited, and they do not move within the plant. Instead, they form a protective barrier on the plant surfaces that prevents spore germination and mycelial growth. However, rain or irrigation can easily wash this fungicide away from the plant's surface. In contrast, penetrating and systemic fungicides are applied to plant surfaces, absorbed by leaf tissues, and transported upward through the xylem vessels. Depending on their chemical properties, they can move over short distances (local systemic movement) or long distances within the plant (true systemic fungicide) from the uptake point.

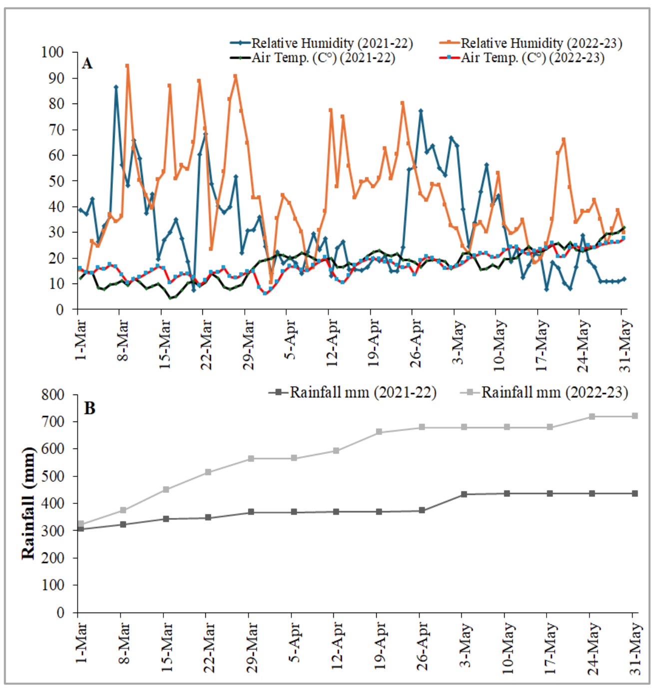

Figure 3. (A) Relative humidity (RH), air temperature (°C), and (B) precipitation averages during the experimental period between November to May at the College of Agricultural Engineering Sciences field, Bakrajo, Sulaimani, during 2021/22 and 2022/23.

Table 1. Efficiency of some control measures on disease control of yellow rust in two susceptible wheat cultivars during 2022/23 growing season at College of Agriculture field, Bakrajo, Sulaimani, Iraq.

Cultivars	Treatment	Infection type	Disease severity (%)	Coefficient of infection
Hsad	Control	S	86.67	86.67 ab
	PGC-1	S	76.67	76.67 b
	PGC-2	S	90.00	90.00 a
	Amistar Xtra -1	R-MR	11.67	3.50 e
	Amistar Xtra -2	R-MR	5.33	1.60 e
Tamuz-2	Control	S	46.67	46.67 c
	PGC-1	S	29.00	29.00 d
	PGC-2	S	20.00	20.00 d
	Amistar Xtra -1	MR	9.67	3.87 e
	Amistar Xtra -2	R	4.00	0.80 e

* The first chemical applications were applied on 15-04-2023, and the second chemical applications were applied on 30-04-2023.

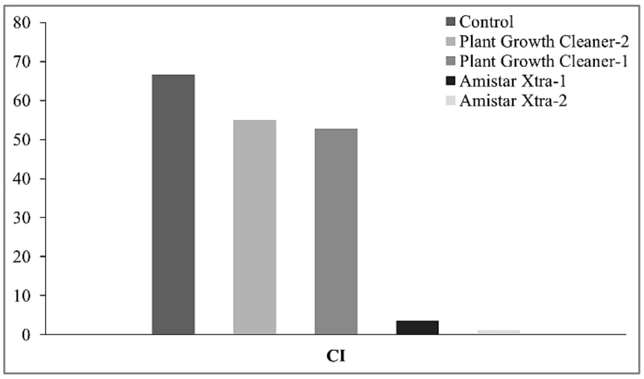

Figure 4. Effect of some control measures on the mean coefficient of infection of the susceptible wheat cultivars with yellow rust disease during 2022/23 growing season at College of Agriculture field, Bakrajo, Sulaimani, Iraq**.**

The study indicated that in the northern region of Iraq, particularly in Sulaimani Province, wheat rust diseases pose a significant problem, making cultivating of susceptible to moderately susceptible wheat cultivars without chemical applications is useless.

Results obtained (Table 2) showed the influence of fungicide applications on yield and its components in two susceptible cultivars, with significant differences between the genotypes for four studied characteristics. Additionally, the interaction between cultivar and treatment was significant, and the understanding of such interaction is essential for improving crop yield. The maximum number of grains per spike was observed in Tamuz-2 x Amistar Xtra-1 with 64 grains/spike, whereas the lowest mean value was found in Hsad x control with 34.1grains/spik, which is likely due to the improved growth of roots, increased nutrient uptake, and better overall growth due to the control of yellow rust. The highest grain weight per spike was detected in Tamuz-2 x Amistar Xtra-2 at 3.15 g, and the lowest spike grain weight was recorded in Hsad x control at 1.23 g, which is in agreement with a previous report. The thousand kernels weight of Hsad x Amistar Xtra-2 treatment produced the highest thousand kernels weight at 50.03g, whereas Hsad x control treatment produced the minimum value at 39.13 g, which is in agreement with previous reports (Alemu & Mideksa, 2016; Xi *et al.,* 2015). The Hsad x Amistar Xtra-1 treatment gave the highest grain yield of 929.45 g/m2, whereas Hsad x control treatment produced the minimum grain yield of 534.98 g/m^2 which is in agreement with previous reports (Alemu & Mideksa, 2016; Kelley, 2001; Wanyera *et al.,* 2009).

The results clearly showed the impact of fungicides application on wheat characteristics. Application of Amistar Xtra resulted in significant increase of grain number per spike by 10 and 52% in Tamuz 2 and Hsad, respectively, compared to control treatment, significant increase in 1000 kernel weight by 13 and 27% in Tamuz 2 and Hsad, respectively compared to control treatment. Grain yield also increased by 21 and 73% in Tamuz 2 and Hsad cvs., respectively, compared to the control treatment. Meanwhile, application of PGC led to significant increase in grain number per spike by 14 and 20% in Tamuz 2 and Hsad, respectively, compared to the control treatment, with significant increase in 1000 kernel weight by 13 and 27% in Tamuz 2 and Hsad cvs., respectively, compared to the control treatment. Grain yield also increased by 12 and 40% in Tamuz 2 and Hsad cvs., respectively, compared to the control treatment.

The effect of fungicide treatments on grain yield and yield components in both susceptible cultivars are shown in Figure 5. The analysis of variance revealed that Amistar Xtra-1 explored the highest value for all the studied characters, indicating that this fungicide significantly decreased the mean coefficient of infection of yellow rust in both cultivars by 98% compared to the control treatment and improved grain yield and yield components in both cultivars. Furthermore, Amistar Xtra extended the vegetative period of wheat and offered prolonged the photosynthesis period. PGC, basically as plant tonic, boosted the physiological properties of the crop, by increasing the total grain yield, although there were no significant differences between coefficient of yellow rust infection between PGC and the control treatments in cv. Hsad. The current findings are consistent with an earlier study conducted in Iraq (Al-Maaroof, 2014) and reports from other countries (Gomes *et al.*, 2016; Mercer & Ruddock, 2005; Teshome *et al.,* 2020).

Table 2. Effect of some fungicide applications on the yield and yield component traits of the susceptible wheat cultivars in the presence of yellow rust disease at Bakrajo, Sulaimani.

Cultivars	Treatment	No. of Grains/Spike	Grain Weight/ Spike(g)	1000 Kernel weight(g)	Grain Yield (g/m^2)
Hsad	Control	34.00 b	1.23 e	39.13 e	534.98 d
	PGC-1	41.80 b	1.75 de	41.16 cde	723.75 b
	PGC-2	41.00 b	1.81 de	40.30 de	763.70 b
	Amistar Xtra-1	58.50 a	2.89 abc	49.80 a	929.45 a
	Amistar Xtra-2	56.30 a	2.80 abc	50.03 a	916.05 a
Tamuz-2	Control	55.82 a	2.48 bc	41.12 cde	602.05 cd
	PGC-1	61.03 a	2.28 cd	44.93 bc	661.34 bc
	PGC-2	61.33 a	2.34 cd	44.15 bcd	673.40 bc
	Amistar Xtra-1	64.00 a	3.09 ab	46.68 ab	730.66 b
	Amistar Xtra-2	63.10 a	3.15 a	46.35 ab	730.04 b

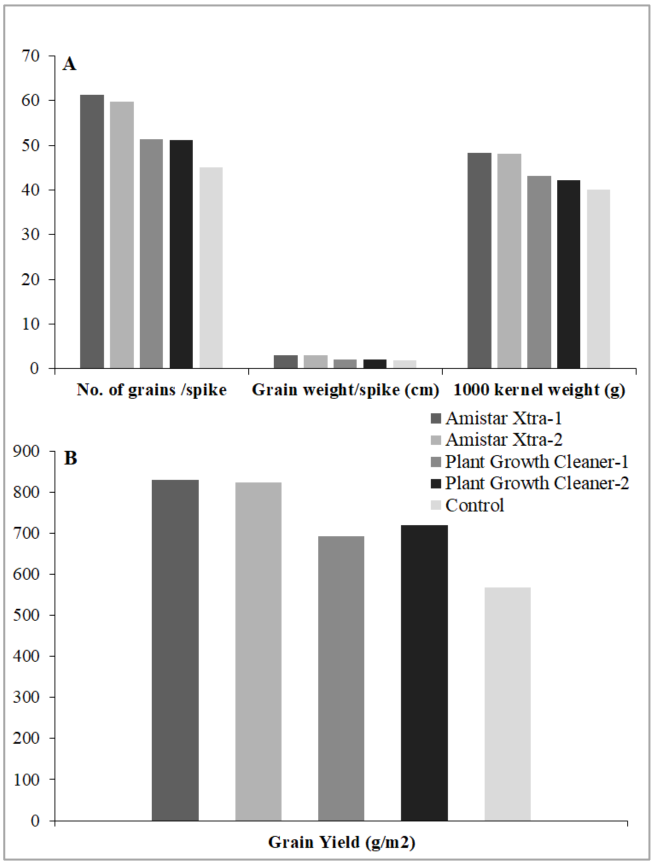

Figure 5. Effect of fungicide treatments on grain yield and yield components of two susceptible wheat cultivars in the presence of yellow rust disease at Bakrajo, Sulaimani.

This study demonstrated that effective pathogen control increased green leaf area retention and yield, particularly in the susceptible cultivars. The timing of fungicide application is crucial for effective and economical control of yellow rust, as disease development can vary greatly due to weather conditions, severity of yellow rust, disease onset timing and duration of yellow rust development (Chen, 2014). According to previous studies, fungicide application times determine effective control of yellow rust, and delaying the application of fungicides during the exponential growth of yellow rust epidemic led to less profitable outcomes due to the losses caused by the disease (Carmona *et al.*, 2020). It is important to follow the labelled instructions and apply them properly, considering the level of disease present in the field to ensure the maximum fungicides effectiveness. The efficacy of different fungicide products has been determined through direct comparisons in field tests based on a single application of the recommended rate. Wheat rust management strategies typically involve breeding for resistance and chemical control (Al-Maaroof e*t al.,* 2020). However, chemical control is not commonly used by Iraqi farmers. Several fungicides have been tested and registered for use in wheat as an important component for rust management.

It can be concluded from this study that regular verification and evaluation of new fungicides against wheat rust diseases is essential to sustain wheat production and productivity. In addition, determining the proper time of fungicide application at early yellow rust onset is critical to effectively reduce the disease severity and boost grain yield in susceptible cultivars. Breeding programs should utilize various methods to control the disease and improve wheat grain quality to enhance yellow rust disease resistance in Iraq. By reducing the frequency of fungicide applications, these programs can effectively manage yellow rust disease and at the same time minimize negative impacts on human health and the environment and reduce disease control costs.

الملخص

المعروف، عماد محمود وسركوت حمه صالح علي. 2025. التحري عن الفطر *Puccinia striiformis* f. sp. *tritici* ومكافحته في حقول القمح تحت ظروف الزراعة المطرية. مجلة وقاية النبات العربية، 43(3):344-352. https://doi.org/10.22268/AJPP-001323

أجريت الدراسة الحالية لرصد توقيت وصول اللقاح الأولي للفطر *P. striiformis* f. sp. *tritici* (*Pst*) إلى حقول القمح في منطقة السليمانية وتطور مرض الصدأ الأصفر خلال موسمين متتاليين. أظهرت النتائج رصد أول لقاح للمسبب المرضي بالصدأ الأصفر في حقول القمح في بكره جو خلال شهر آذار/مارس في عامي 2022 و 2023. في حين تمّ رصد أول إصابة بهذا الممرض على صنف القمح الحساس "حصاد" في 15 نيسان/أبريل في السنة الأولى و10 نيسان/أبريل في السنة الثانية. ارتفع عدد الأبواغ اليوريدية تدريجياً مع تطور المرض، ليصل إلى ذروته (51.3 بوغ/سم^2) في 7 أيار/مايو 2022 و 187.3 بوغ/سم^2 في 9 أيار/مايو 2023، في حين انخفض عدد الأبواغ اليوريدية في نهاية الأسبوع الأول من حزيران/يونيو 2023. كما ازداد عدد الأبواغ اليوريدية في السنتيمتر المربع عام 2023 مقارنة بعام 2022. تمّت مكافحة مرض الصدأ الأصفر باستخدام مبيدين فطريين مختلفين هما Amistar Xtra و Plant Growth Cleaner (PGC) على صنفيي القمح "حصاد" و"تموز-2" الحساسين للمرض. أظهرت النتائج أن معاملات Amistar Xtra أدت إلى خفض معنوي في متوسط معامل الإصابة بالصدأ الأصفر في كلا صنفيي القمح، حيث أدت معاملة Amistar Xtra إلى خفض شدة الإصابة في الصنف "حصاد" بنسبة 83.2 و 85.1% بعد الرشتين الأولى والثانية، على التوالي، وقابلتها النسب 42.5 و 45.9%، على التوالي، في الصنف "تموز". أسفرت معاملة PGC عن تأثيرات متفاوتة في متوسط معامل الإصابة في كلا صنفيي القمح، حيث أدت الرشة الأولى من Amistar Xtra إلى تغيير درجة الإصابة من حساس إلى متوسط المقاومة في الصنف "تموز-2"، بينما أدت الرشة الثانية إلى تغيير درجة الاصابة من حساس إلى مقاوم في الصنف نفسه. أدت كلتا معاملتي رشّ المبيد الفطري Amistar Xtra إلى تغيير درجة إصابة الصنف "حصاد" من حساس إلى مقاوم أو معتدل المقاومة. نتج عن معاملة المبيدات الفطرية زيادة معنوية في قيم غلّة المحصول ومكوناتها المدروسة مما يدل على تأثيره العلاجي وتعزيز خصائص النبات.

كلمات مفتاحية: الأمراض الفطرية، مرض الصدأ الأصفر، مبيدات الفطور، مقاومة المرض، منظف نمو النبات.

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