Performance of some Durum Wheat Cultivars in the Presence of Yellow Rust Disease Under Rain-Fed in Sulaimani, Iraq

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Abstract

Yellow rust, also known as stripe rust, is a significant disease that affects wheat in Iraq. The current study was conducted to study host-parasite interaction of some durum wheat cultivars with the new yellow rust (*Puccinia striiformis* f. sp. *tritici*) (Pst) races at adult plant stage in the field during the growing seasons, 2021 to 2023 under rain fed conditions in Sulaimani. Furthermore, Agricultural characteristics of the tested durum cultivar were also determined in the presence of the disease. The findings revealed that most durum wheat cultivars were moderately susceptible to susceptible to yellow rust disease under Sulaimani environmental conditions. The mean coefficient of yellow rust infection ranged from 1.73 in Ofanto to 23 in Cham-5. However, some cultivars, such as Cham-1, Fadda-98, and Ofanto, displayed moderate resistance response to the disease, while others, like Bhuth-5 and Acsad-65, showed moderate susceptibility. Yellow rust parameters (Diseases severity, infection type and coefficient of infection) were higher in 2023 season compared to 2022 in most of the tested cultivars. Additionally, the moderate resistant cultivar cv. Fadda-98 displayed distinct in some plant traits compared to other durum wheat cultivars, such as plant height (101.12cm), awn length (14.21cm), number of grains per spike (60.22), grain weight per spike (2.92g), biological yield (2292.4 g/m^2), and grain yield (783.13). The study finding enhances wide cultivation of cv. Fadda-98 in the hot spot of yellow rust lands in Iraq.

Keywords: *Triticum turgidum*, Stripe rust disease, Agricultural traits, Airborne diseases.

Introduction

Durum wheat, scientifically known as *Triticum turgidum* L. var. *durum*, is a cereal crop that grows during the cool season. It is an annual plant with 28 chromosomes (AABB, 2n = 4x) belongs to the Gramineae family (25). Durum wheat accounts for approximately 8% of the total wheat cultivation worldwide (32). Durum wheat grains are used in various food industries such as bulgur, spaghetti, pasta, and noodles, while crop straw and wheat industry residues like bran can be utilized in animal feed (26,30). Biotrophic fungal diseases such as yellow rust, leaf rust, stem rust, and powdery mildew are widespread and have the greatest effect on wheat production globally (2, 13, 21).

Biotic and abiotic factors, especially fungal diseases, significantly limit wheat production in Iraq (5, 19). Yellow rust, is a major problem in over 60 countries, and account for significant losses globally, with the exception of Antarctica, It affects over 88% of global wheat production, roughly 35% of wheat cultivation areas, leading to reduced grain quality and yield by decreasing grain number, size, and weight, as well as reduced plant dry matter due to decreased root growth, plant height, size, and spike number (31). Yellow rust epidemics have grown significantly in scope and extent over the past half-century, resulting in 5.5 MT losses estimated at 1 billion dollars (14). Moreover, seeds obtained from yellow rust-attacking plants show reduced plant vigour and poor emergence (15). Depending on the cultivar susceptibility, primary infection time, disease period and development rate, the disease could cause significant grain yield losses varying from 10-70% (4, 5). Integrated Disease Management (IDM) is a comprehensive approach to managing yellow rust diseases in wheat. Rather than relying on a single management practice, IDM combines cultural, fungicide, and resistant cultivars to manage diseases sustainably while minimizing environmental and societal impact. The approach considers disease influences before, during, and after the growing season (1).

Effective rust control programs require monitoring, breeding for resistance, predicting disease response in commercial cultivars, and reacting to pathogen dynamics (24). The population of yellow rust changes over time, impacting breeding programs. Monitoring for virulence changes is crucial for developing resistant wheat cultivars, as the pathogen can quickly grow into new races and spread over long distances through airborne dispersal (16). Reducing yield losses and controlling diseases in an environmentally safe manner can be achieved through breeding for disease resistance (29). The aim of this study is to evaluate performance of some durum wheat cultivars under rain fed conditions and presence of yellow rust disease under Sulaimani conditions, Iraq.

Materials and Methods

Host-parasite interaction of some durum wheat cultivars with *Pst* at adult plant stage in the field:

The experiments were conducted at the field of College of Agricultural Engineering Sciences, University of Sulaimani, Bakrajo, Latitude N 35°32 036, Longitude E 045°21 818, and Elevation 742m, during two successive seasons 2021–2023. Ten released durum wheat cultivars were used to evaluate their response to yellow rust disease at adult plant stage in the field (Table 1). The experiments were arranged in randomised complete block designs (RCBD) with three replicates. Seed of each cultivar were planted in rows within 2*2m plots. The spaces between rows were kept at 20 cm, 50cm between plots, and two meters between blocks. Seed of susceptible wheat cultivars (Morocco and Hsad) were sown throughout the experiment border as spreaders. The plants were periodically sprayed with water to encourage the development of the disease. all the agricultural practices were conducted according to ministry of agriculture recommendations.

Table 1. Names, Pedigree/origin and the sources of durum wheat genotypes used in the study

Genotypes	Synonym	Scientific name	Pedigree	Year of release	Origin
Cham - 5	None	*T. durum*	JORI 69/HOURANI	1994	ICARDA
Mikki	None	*T. durum*	STJ3//BCR/LKS4	2016	ICARDA
LD.357	None	*T. durum*	(Heiti / Stewart /2/ Mindum / Carleton, Ld308) /3/ Nugget	1954	USA
Cimmitto	None	*T. durum*	Capeiti 8/ Valnova-	1988	Italy
Hawler - 3	None	*T. durum*	-	-	Iraq
Bhuth - 5	None	*T. durum*	-	1987	Iraq
Acsad – 65	None	*T. durum*	SNB//CMH79A955/3*CNO79/3/ATTILA	2013	CIMMYT
Cham - 1	None	*T. durum*	PLC/RUFF//GTA/RLT	1984	ICARDA
Fadda – 98	None	*T. durum*	-	-	-
Ofanto	Ovanto	*T. durum*	Adamello/ Appulo-	2011	Iraq

Disease Scoring:

During the field trials, disease severity and infection type of yellow rust on the leaves were carefully observed and recorded for each wheat genotype. Host reaction types were evaluated using the classical ordinal scales R, MR, MS, and S. while yellow rust severity was recorded using modified Cobb scale (27,33). Coefficient of infection (CI) was calculated by multiplying the severity with a fixed value of host response coefficient, which was assigned as follows: R=0.2, MR=0.4, MR-MS =0.6, MS=0.8, and S=1.0. This method enables the comparison and ranking of different genotypes based on statistical analysis (27). CI data were analysed by JIM software to determine the source of variance, compare between genotypes, and calculate the means by LSD test at a 5% probability level. Agricultural characteristics, yield, and yield components of wheat genotypes in the presence of yellow rust disease:

All the agricultural characteristics, yield, and yield component traits were calculated as follows; Plant height was recorded as the length in centimetres from the soil surface to the tip of the spike excluding awns from 10 randomly selected plants; Flag leaf area was determined by measuring the average area of the flag leaf from 10 randomly selected plants in each experimental unit after the flowering stage, and the measurements were recorded in square centimetres as shown below.

Leaf area index = mean leaf length × mean leaf width × 0.95

Awn length (cm), by measuring the length of ten spikes chosen from the end of the spike to the end of awns; Spike length (cm), by measuring the primary spikes of ten chosen wheat plants excluding the awn; Spike weight (g), by measuring the weight of fifty randomly chosen spikes from each plot during dough stage; Spikelet $Spike^{-1}$: by measuring the number of spikelet's/spikes from the average of 10 randomly selected spikes per plot; Spike $number.m^{-2}$, by calculating the number of spikes per square meter area located at the centre of each plot; Grains number $Spike^{-1}$, by counting kernels from 10 randomly selected spikes for each plot; Grain Weight $Spike^{-1}$ (g): by calculating the average of grain weight per spike from ten randomly selected spikes per plot; Thousand grain weight(g): by calculating thousand-grain weights randomly selected from each replicate; Biomass yield (m^{-2}): by measuring the weight of all living parts of the plants above the ground level per unit area within a meter and then converted into square meters; Grain yield (m^{-2}): was determined by randomly harvesting plant spikes in a one-meter square from the centre of each plot at dough stage, when the grain moisture was 14%. The harvested spikes were then threshed, and the weight of the grain per meter square was calculated. Harvest index (HI): The following equation is used to calculate the percentage of grain weight relative to biomass HI% =(Grain yield)/(biomass yield) (3).

Most criteria related to yield and yield components were determined at harvest.

Results And Discussion

Host-parasite interaction of durum wheat cultivars with *Pst* at adult plant stage in the field:

The host-parasite interaction of ten registered and released durum wheat cultivars with yellow rust disease during 2021/22 and 2022/23 growing seasons is shown in Table 2 and Figure 1. according to the combined analysis and ANOVA for CI, significant difference was detected between the cultivars in both growing seasons, the average of both seasons and the interaction between Cultivars x Years. However, no significant difference was detected between the seasons. Results showed that all the studied cultivars were positioned into four different groups as shown in Figure 2. The first group showed MR to yellow rust disease, including Cham-1, Fadda-98 and Ofanto. The disease severity and CI of this group ranged from 4.33% to 10.33%, and 1.73 to 4.13 respectively. The second group contains two local cultivars, Bhuth-5 and Acsad-65, exploring MS reactions to yellow rust, with a disease severity percentage of 17% and 14.5% and a coefficient of infection of 13.6 and 11.6, respectively. The third group involves three cultivars LD.357, Cimmitto and Hawler-3 representing MS-S reaction with disease severities range between 11% to 18.8% respectively and coefficient of infection ranging from 9.9 in

LD.357 to 20.25 in Cimmitto. The final group involves only Cham-5 and Mikki that showed susceptible reactions with 20.33% and 23% disease severity and the same coefficients of infection, respectively. The host-parasite interaction of the high susceptible cultivars with yellow rust disease was stable in both agricultural seasons, with no differences in the infection types except for Cimmitto and Hawler-3, which were MS in 2022 but it changed to S in 2023 and cv. LD.357 also changed from S in 2022 to MS in 2023. Moreover, it explores higher disease severeties and coefficients of infection in 2023. In comparison, groups one and four, infection types with MR and MS, showed no significant differences in the coefficient of infection in both years. Acsad-65 susceptibility aligns with previous findings (5). However, differences in Hawler 3, LD 357 and Cimmitto infection types were obvious between seasons. Moderately resistance of Cham 1 in this study differs from the previous study finding in the same location in 2009/10 cultivating season, which was resistant (6). Changes in disease reactions may be related to variations in the environmental factors and the change of infection type in some cultivars over time due to the appearance of new virulences in the pathogen population (10). Some cultivars may stay resistant for many years but become susceptible after a period. Other researchers confirmed this fact previously (9); they mentioned the ability of rust pathogens to develop themselves and produce new races that were not found before. Moreover, the increase in disease severity in the second year may be attributed to the difference in rainfall rates across the region, as shown in Figure 3. Relative humidity and rainfall are among the most important factors contributes to disease spread. Humid conditions during the season create favourable conditions for yellow rust infection and development (5, 24). In contrast, high humidity can induce spore germination. The pathogen responsible for wheat spoilage can germinate quickly under moist and optimal temperature conditions but lacks pathogenic properties, making shipping and storing wheat grains challenging, especially in humid environments. Additionally, high moisture levels can impact the spore dispersal, with the urediniospores group being more susceptible to dispersal than individual spores (16).

Table 2. Mean disease severity, infection types and coefficient of infection of some durum wheat cultivars with yellow rust at adult plant stage during the growing seasons 2021 to 2023 at Bakrajo, Sulaimani, Iraq

Cultivar name	2021/22			2022/23			MEAN		
	DS%	IT	CI	DS%	IT	CI	DS%	IT	CI
Cham-5	18.33	S	18.33	27.67	S	27.67	23	S	23
Mikki	7.33	S	7.33	33.33	S	33.33	20.33	S	20.33
Cimmitto	18.33	MS	14.67	26.67	S	26.67	22.5	MS-S	20.25

Hawler-3	12.67	MS	10.13	25	S	25	18.84	MS-S	16.96
LD.357	11	S	11	11	MS	8.8	11	MS-S	9.9
Bhuth-5	10.67	MS	8.53	23.33	MS	18.67	17	MS	13.6
Acsad-65	10	MS	8	19	MS	15.2	14.5	MS	11.6
Cham-1	10.67	MR	4.27	10	MR	4	10.33	MR	4.13
Fadda-98	5.67	MR	2.27	8.33	MR	3.33	7	MR	2.8
Ofanto	4.33	MR	1.73	4.33	MR	1.73	4.33	MR	1.73
Mean	10.9	MR-S	8.63	18.87	MR-S	16.44	14.88	MR-S	12.43
L.S.D (0.05) Cul.			9.68			3.78			12.095
Years									n.s
Cul. × Years									10.28

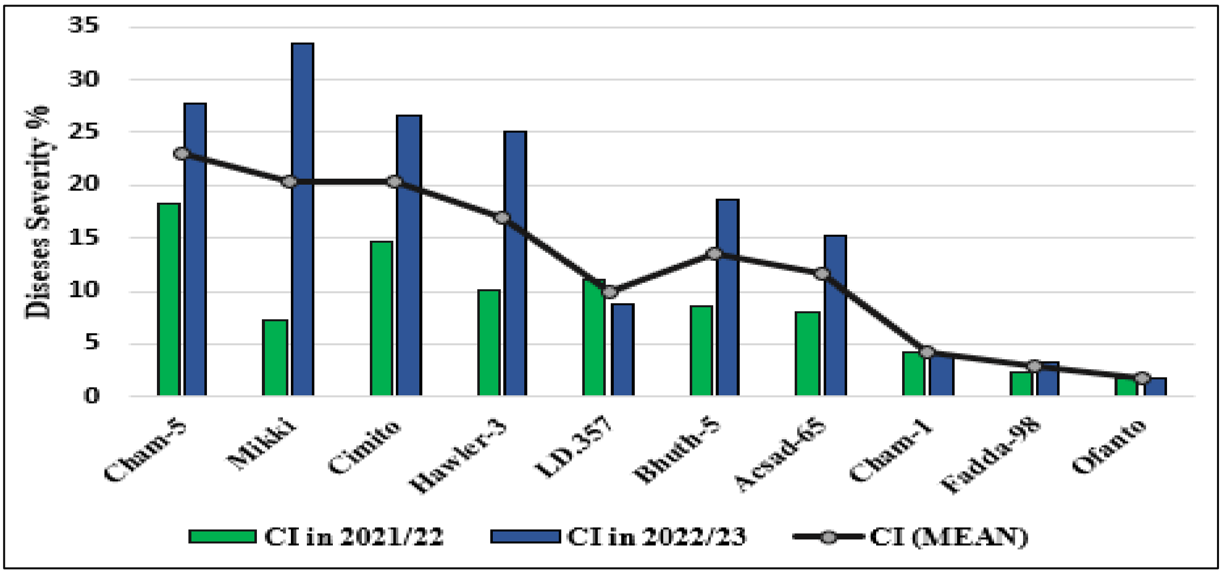

Figure 1. Yellow rust severity of some durum wheat cultivars at adult plant stages during the growing seasons 2021 to 2023 and their average at Bakrajo, Sulaimani, Iraq

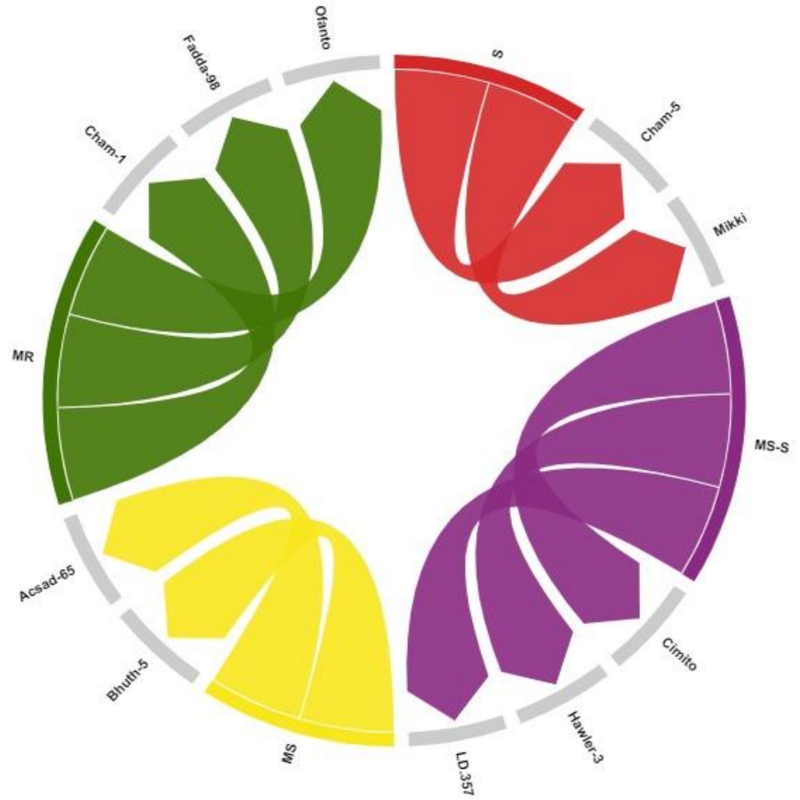

Figure 2. Classification of durum wheat cultivars according to their response to yellow rust disease during 2021 to 2023 growing seasons at Bakrajo, Sulaimani, Iraq

Figure (3) shows that the precipitation average in the cultivation season 2021/22 was 436.4 mm and in 2022/23 was 718.8 mm. The high precipitation rate and the relative humidity in 2022-23 growing season and better rainfall distribution between months led to an increase or change in the disease severity, infection type and coefficient of infection compared to the 2021/22 growing season.

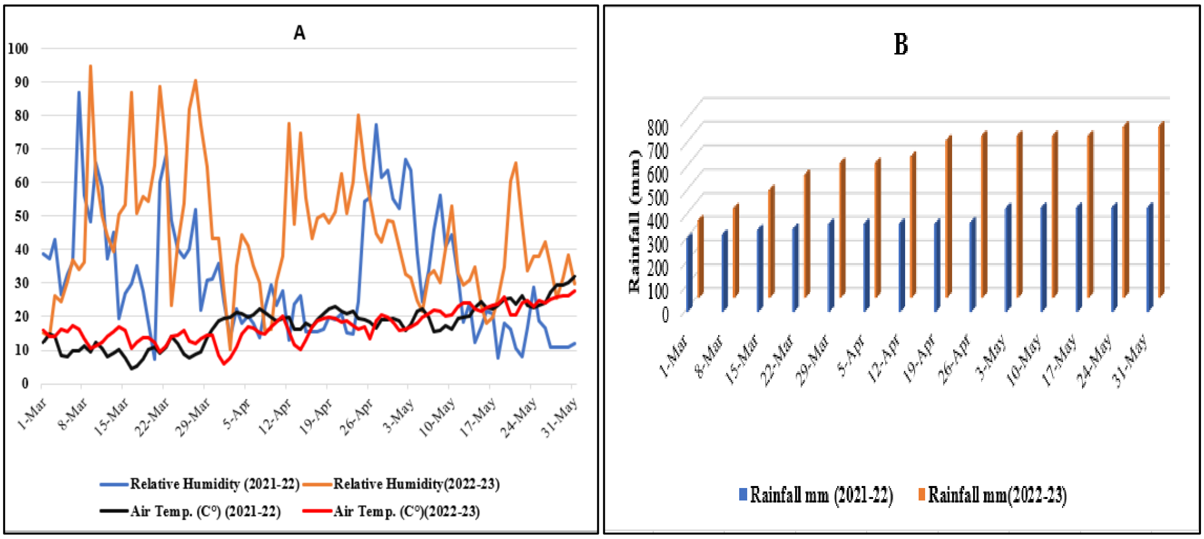

Figure 3. (A) Relative humidity (RH), air temperature (C°), and (B) precipitation averages during the experiment period between Nov. to May 2021/22 and 2022/23 at Bakrajo, Sulaimani

Table 3 presents the agricultural characteristics of the released Iraqi durum wheat cultivars in the presence of yellow rust disease at the field of College of Agriculture, Sulaimani, during the growing season 2021-23 representing a rain-fed cultivation system. The analysis of variance conducted on thirteen agricultural traits of ten durum wheat cultivars over two agricultural seasons revealed significant differences between the tested cultivars in both years and their average except the spike length and number of grains spike^{-1}in the first season and the harvest index in the second season which showed no significant differences. Multi-year comparisons from combined analyses in two consecutive growing seasons (2021/22 and 2022/23) revealed significant variations between different cultivars once again expected spike length and 1000 Kernel weight. Significant differences were also observed in the interaction of Cultivars x Years. However, no significant differences were found between Cultivars x Years for spike length, awn length, spike weight, number of spikelet spike^{-1}and 1000 kernel weight. The study also revealed significant differences between years for all the characters except for awn length and 1000 kernel weight, which showed no significant differences. The study shows a wide range of variations in the response of durum wheat cultivars to agricultural characteristics, yield, and yield components in the presence of yellow rust disease in the field in both seasons.

Table 3 shows results of variance analysis for plant height. Significant differences were found in durum wheat cultivars for both seasons and their average, which aligns with previous research (11,12, 18).

The variation in plant height indicates the presence of diversity in the genotypes' heights, ranging from 67.5 cm to 114.56 cm. Fadda-98 had the highest plant height of 87.67, 114.56 and 101.12cm in the 2021/22, 2022/23 growing season and the average of both years, respectively. In the first growing season and the average of both years, Bhuth-5 exhibited the minimum height at 67.5cm and 76.25cm, respectively, while Cimmitto had the lowest plant height of 83.56 cm in the second year. Variations in plant height between different durum wheat cultivars may be attributed to their genetic makeup, which affects their response to environmental factors such as light, temperature, and wheat development. Plant height is an essential morphological characteristic that directly impacts the susceptibility of plants to lodging and airborne diseases. Additionally, it is related to the productivity potential of the cultivars, which is consistent with previous research findings (23).

Spike length is one of the significant trait in determining grain production and yield per plant. Long spikes with high fertility of florets associated with higher grain yields. Spike length is determined by genetics and can also be affected by environmental effects. According to Table 3 and Figure 4, during the second year, cv Hawler-3 had the highest spike length value of 7.09cm, while Mikki recorded the lowest spike length of 5.94cm. However, there were no significant differences between durum wheat genotypes in the first year and average of both years.

Fadda-98 had the longest awn length of 14.69cm in 2021-22 season, while Ofanto had 15.2cm and14.22cm in 2022/23 growing season, with an average of both years, respectively. On the other hand, Mikki had the shortest awn length of 9.88cm, 10.19 m, and 10.04cm in both years and the average of both years, respectively. According to (3), awns length plays a significant role in grain yield filling of wheat as a main photosynthetic organ of the spike.

Flag leaf area is essential in both synthesis and transportation of photo-assimilates to wheat grains. First year and the average, the local durum wheat cultivar Cimmitto exhibited the largest flag leaf area with 41.3cm^2 and 45.2cm^2 respectively. Additionally, LD.357 had the largest flag leaf area of 50.1cm^2 in the second growing season. Whereas, Hawler-3 had the smallest flag leaf area in both the first season and the average of the two years, measuring 28.8cm^2 and 30.7cm^2, respectively. However in the second season, Cham-1 had the smallest flag leaf area of 30.4cm^2.

Table 3. Means of the field traits of some durum wheat cultivars in the presence of yellow rust disease during 2021 to 2023 growing seasons at Bakrajo, Sulaimani, Iraq

Cultivar name	Plant Height (cm)			Spike Length (cm)			Awn length (cm)			Flag leaf area (cm2)			Spike weight (g)			No. of Spikelet / Spike			Grain Weight/ Spike (g)		
	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean
Cham-5	86.08	107.78	96.93	7.61	6.47	7.04	12.09	12.63	12.36	34.12	40.75	37.44	3.54	4.16	3.85	16.67	18.33	17.5	2.51	2.94	2.725
Mikki	81.08	96.78	88.93	6.96	5.94	6.45	9.88	10.19	10.04	34.11	38.59	36.35	3.4	3.63	3.51	17.33	19.11	18.22	2.55	2.8	2.675
LD.357	80.44	95.22	87.83	7.65	7.03	7.34	12.03	12.22	12.13	39.96	50.11	45.04	3.56	4.39	3.98	19.55	22	20.78	2.3	3.14	2.72
Cimito	79.67	83.56	81.615	8.289	6.63	7.46	12.29	13.3	12.8	41.25	49.14	45.2	4.75	5.68	5.21	18.89	19.89	19.39	2.95	3.69	3.32
Hawler-3	85.67	89.11	87.39	7.69	7.09	7.39	12.8	12.65	12.73	28.84	32.48	30.66	4.03	4.2	4.11	15.67	18.33	17	2.85	2.78	2.815
Bhuth-5	67.5	85	76.25	7.57	6.64	7.105	11.8	11.48	11.64	38.93	46.32	42.63	4.14	3.75	3.94	18.67	18.78	18.73	2.46	2.48	2.47
Acsad-65	73.67	99.22	86.445	7.17	6.23	6.7	12.8	13.26	13.03	34.56	39.95	37.26	3.5	4.04	3.77	18.89	19.11	19	2.57	2.67	2.62
Cham-1	79.67	93	86.335	7.11	6.04	6.575	12.05	12.76	12.41	33.33	30.42	31.88	3.33	3.19	3.26	18.55	19.11	18.83	2.26	1.9	2.08
Fadda-98	87.67	114.56	101.12	7.08	6.07	6.575	14.69	13.72	14.21	36.1	39.75	37.93	4.21	4.61	4.41	17.89	20.89	19.39	2.71	3.12	2.915
Ofanto	68.67	84.22	76.45	7.8	6.38	7.09	13.24	15.2	14.22	29.59	43.22	36.41	3.45	4.16	3.81	18.33	20.44	19.39	2.63	3.06	2.85
Mean	79.01	94.85	86.93	7.49	6.45	6.97	12.37	12.74	12.55	35.08	41.07	38.08	3.79	4.18	3.98	18.04	19.6	18.82	2.58	2.86	2.72
L.S.D (0.05)																					
Cul.	5.338	6.94	4.23	n.s	1.75	n.s	1.95	1.75	1.27	4.484	6.3	3.73	0.51	0.72	0.43	1.7	0.77	1.4	0.35	0.504	0.3
Years			5.52			0.63			n.s			1.73			0.34			1.31			0.15
Cul. xYears			5.98			n.s			n.s			5.28			n.s			n.s			0.42

There are notable differences in the cultivars' genetic makeup during growing seasons, these variances may be attributed to varying levels of rainfall experienced during both seasons as shown in Figure 3, which affect the availability of soil water, relative humidity, and temperatures.

This study showcases the impact of various local durum wheat cultivars on spike weight. Cimmitto recorded the highest spike weight with 4.75g, 5.68g, and an average mean of 5.21g for both seasons, while Cham-1 recorded the lowest spike weight with 3.33g, 3.19g, and 3.26g in both growing seasons and their average. According to (17), spike weight of different cultivars may be affected by the genetic and environmental factors, which can influence yield characteristics.

The number of spikelets/spikes greatly influences the grain yield of wheat. Most wheat cultivars produce between 10-20 spikelets per spike, and each spikelet can develop into 9-10 florets. Varieties significantly impact the number of spikelets/spikes, as observed in Table 3 and Figure 4. Durum wheat cultivar LD. 357 had the highest spikelets/spikes, with 19.55, 22, and 20.78 in both seasons and their average, respectively. In contrast, Hawler-3 produced the lowest spikelets/spikes with 15.67 and 17 in first year and their average means. However, in the second year Hawler-3 and Cham-5 with 18.33 recorded the lowest spikelets/spikes. The number of spikelets/spikes varied significantly due to varieties. Varietal differences in spikelets were also observed by (28).

Grain weight per spike is an important parameter for increasing wheat grain yield. Recently released high-yield potential wheat cultivars characterized by high kernel weight per spike. Table 3 and Figure 4 illustrates the mean values of growth characteristics for the studied durum wheat cultivars. Variance analysis of the collected data reveals significant differences between the genotypes regarding grain weight per spike. Cimmitto exhibited the highest kernel weight per spike with values of 2.95g, 3.69g, and 3.32g in both years and their average, respectively, surpassing all other genotypes. On the other hand, Cham-1 recorded the lowest spike kernel weight with values of 2.26 g, 1.9 g, and 2.08 g in both growing seasons and their average, respectively.

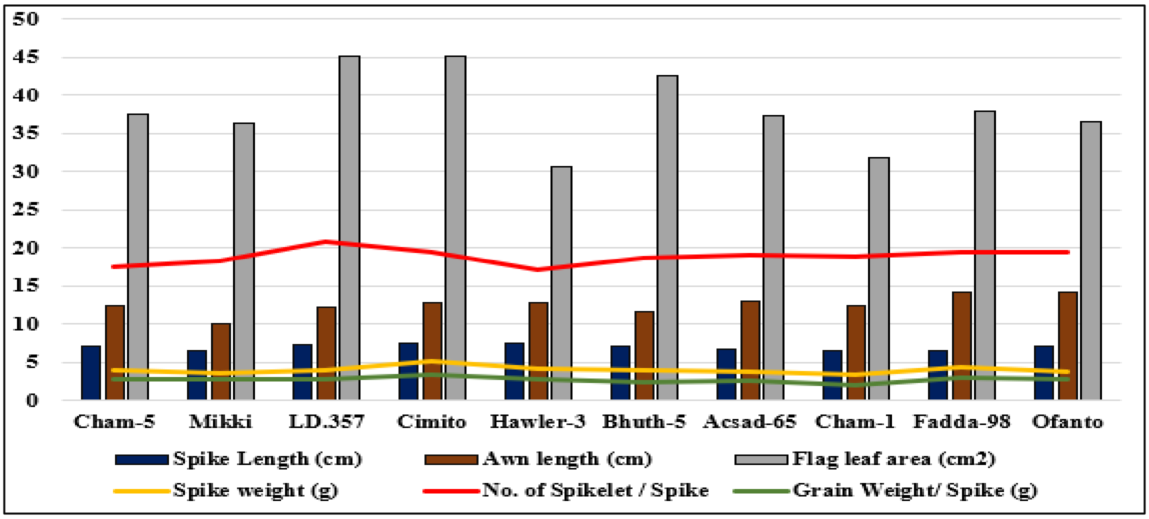

Figure 4. Some field traits of the Iraqi durum wheat cultivars in the presence of yellow rust disease during 2021 to 2023 growing seasons at Bakrajo, Sulaimani, Iraq

Grain yield and its components of some durum wheat cultivars in the presence of yellow rust disease.

Durum wheat cultivar Acsad-65 revealed the highest number of spikes m^{-2} (495.83) in the first year and significantly surpassed all other cultivars except Mikki. Cham-5 had the highest spikes, with 858.67 and 628.83 in the second year and the average of both years, respectively. The lowest spike number m^{-2} was found in cv Bhuth-5, with 317.33 in the first season, and cv Ofanto with 525 and 443.92 spikes in the second growing season and average of both growing seasons, respectively (Table 4 and Figure 5). The number of spikes per unit area depends on the genotype and the environment, seed rate and plant density also playing a significant role. Higher temperatures promote faster plant development but may lower tillering (22).

According to the results, significant differences were observed among the tested durum wheat cultivars in the number of grains per spike during the second year and the average of both years. However, no significant differences were observed during the first year. In 2022/23 growing season, Cimmitto had the highest grain number (68.73), followed by LD.357 and Fadda-98. LD.357 had a maximum grain number of 61.05 for an average of both seasons while cv. Bhuth-5 gave the lowest number of grains (47.6). Cham-1 had the lowest number (48.54) in the second year (Table 4). Many biotic and abiotic factors may decrease the number of kernels per spike, and a higher seed rate may also result in low spike grains (7).

The study detected significant effects of durum wheat cultivars on thousand-grain weight, Cimmitto with 57, 54.7, and 55.8g thousand-grain weights surpassed all other cultivars in both growing seasons and their average, except Hawler 3. In contrast, Cham-1 had the lowest thousand-grain weight values of 42.26, 38.81, and 40.54g in both years and their average, respectively. This result may be related to the spike weight and grain weight per spike, which was the same for the highest and lowest values recorded by Cimmitto and Cham-1, respectively. Thousand-grain weight is influenced by biotic and abiotic stresses, and early sowing can increase the 1000 kernel weight, while late sowing can decrease the weight of the grain (20).

Results in Table 4 and Figure 5 indicate significant differences between the genotypes in response to biological yield during both seasons. Analysis of variance revealed that effect of years and their interactions with cultivars were also significant at $p < 0.05$. Fadda-98 had a higher biological yield of 1905.17g.m^{-2} and 2292.4g.m^{-2} during 2021/22 growing season and the average of both years, respectively. Acsad-65 had the highest yield of 2864.17g.m^{-2} during 2022/23 growing season. However, Cham-5 had the minimum biological yield of 1327.67g.m^{2}-1 during the first season, and Bhuth-5 had a yield of 2122.94 g.m^{2}-1 and 1824.28 g.m^{2}-1 during the second season and the mean of both seasons, respectively. The variation in response of cultivars to each season may be due to the genetic variation between the cultivars, and their adaptations to certain climatic conditions.

The results presented in Table 4 and Figure 5 indicate a significant variation in grain yield per meter square among the durum wheat cultivars. Mikki had the highest grain yield with 718.11g.m^{-2} and 847.72g.m^{-2}, respectively, outperforming all other cultivars in the first growing season and the average of both years. Cimmitto had the highest yield in the second year (989.92g.m$^{-2)}$, while cv Bhuth-5 produced the lowest grain yields with 476.25 g.m^{-2}, 737.85 g.m^{-2}, and 607.05 g.m^{-2} in both years and their average, respectively. Differences in grain yield are mainly attributed to the interaction between the genetic makeup of the cultivars during growth periods and the prevailing environmental factors during their development.

The harvest index calculates the ground dry biomass yield, also known as biological yield. The significant differences ratio between grain yield and the total above were observed between durum wheat cultivars in the first year, but no significant differences were observed in the second year. A combined analysis of two years data showed significant differences between cultivars, years and their interactions. Table 4 indicates significant differences between durum wheat cultivars in the harvest index in the first year and the average of both years. Cham-5 produced the maximum values of 0.53 and 0.43, respectively, while Bhuth-5, with 0.32 in the first year and Bhuth-5 and Cham-1 with 0.34 average of both years, recorded the minimum values. However, in the second year, no significant differences were detected between the cultivars in harvest index; this is expected as the same cultivar had the lowest mean value for biological yield and the normal mean value for grain yield, resulting in the highest mean value for harvest index. The differences between wheat cultivars are due to the variation in grain yield and biological yield.

The relationship between yellow rust infection and various agricultural characteristics, yield, and yield components in the study revealed that cv

Fadda-98 exhibited differences from most other durum wheat cultivars in certain important traits such as plant height, awn length, number of grains per spike, grain weight per spike, biological yield and grain yield. This particular cultivar displayed moderate resistance to yellow rust disease, with the second lowest values for disease severity and CI across both years and their average. However, some susceptible cultivars such as Mikki and Cham-5, and MS-S cultivars such as Hawler-3, LD-357, and MS cultivar Bhuth-5, exhibit the lowest values for the most studied characteristics. Consequently, yellow rust severity impacts yield, and yield components. As it was mentioned in previous research findings (7,8,9).

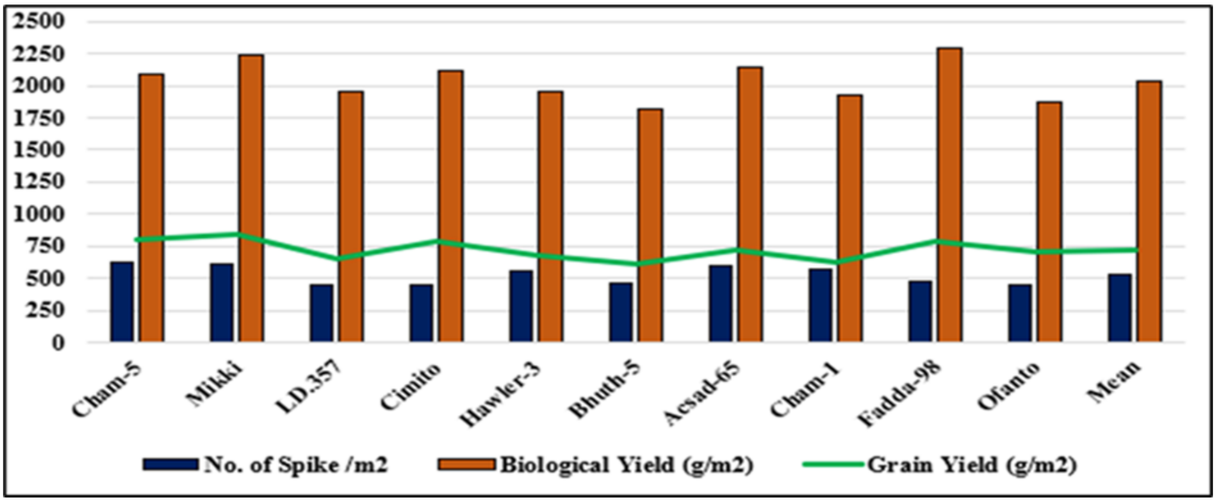

Figure 5. Grain yield and its components of the Iraqi durum wheat cultivars in the presence of yellow rust disease during 2021 to 2023 growing seasons at Bakrajo, Sulaimani, Iraq

Table 4. Means of yield and its components of some durum wheat cultivars in the presence of yellow rust disease during the growing season 2021 to 23 at Bakrajo, Sulaimani, Iraq

Cultivar name	No. of Spike .m^{-2}			No. of Grains. Spike-1			1000 Kernel weight (g)			Biological Yield (g.m^{-2})			Grain Yield (g.m^{-2})			HI%		
	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean	21-22	22-23	Mean
Cham-5	399	858.67	628.83	54.2	63.1	58.65	47.22	46.84	47.03	1327.67	2856	2091.8	702.31	899.37	800.84	0.53	0.32	0.43
Mikki	481.83	737.33	609.58	55.27	54.59	54.93	46.83	49.39	48.11	1764	2708.61	2236.3	718.11	977.33	847.72	0.41	0.36	0.39
LD.357	350	549.5	449.75	53.6	68.5	61.05	42.53	46.55	44.54	1433.83	2485	1959.4	538.17	761.41	649.79	0.38	0.31	0.35
Cimito	361.67	529.67	445.67	52.27	68.73	60.5	57	54.65	55.83	1491.26	2747.5	2119.4	588.14	989.92	789.03	0.39	0.36	0.38
Hawler-3	452.67	677.83	565.25	51.33	51.63	51.48	54.98	54.23	54.61	1543.5	2356.67	1950.1	628.1	744.15	686.13	0.41	0.32	0.37
Bhuth-5	317.33	621.83	469.58	46.4	48.8	47.6	51.98	50.65	51.32	1525.61	2122.94	1824.3	476.25	737.85	607.05	0.32	0.35	0.34
Acsad-65	495.83	690.67	593.25	52.8	57.6	55.2	48.93	46.84	47.89	1412.32	2864.17	2138.3	542.57	897.54	720.06	0.38	0.32	0.35
Cham-1	389.67	759.5	574.59	52.07	48.54	50.31	42.26	38.81	40.54	1343.22	2500.56	1921.9	497.89	743.49	620.69	0.37	0.3	0.34
Fadda-98	355.83	611.33	483.58	54.53	65.9	60.22	49.34	47.57	48.46	1905.17	2679.57	2292.4	619.86	946.39	783.13	0.33	0.36	0.35
Ofanto	362.83	525	443.92	52.18	64.9	58.54	50.78	47.95	49.37	1342.83	2401.91	1872.37	537.72	864.52	701.12	0.4	0.36	0.38
Mean	396.67	656.13	526.40	52.47	59.23	55.85	49.19	48.35	48.77	1508.94	2572.29	2040.62	584.91	856.2	720.56	0.39	0.34	0.37
L.S.D (0.05)	45.43	90.81	49	n.s	9.18	5.42	2.67	4.22	2.41	207.02	285.78	170.33	85.44	147.69	82.35	0.11	n.s	0.061
Years			41.84			5.63			n.s			170.16			62.86			0.016
Cul. x Years			69.31			7.67			n.s			240.88			116.47			0.09

Conclusion

Yellow rust is one of the most devastating disease to wheat production in Iraq (5). Most of the investigated durum wheat cultivars in this study explored moderately susceptible to susceptible response to the newly emerging *Pst* races, the causal agent of yellow rust disease under rainfed cultivation under Sulaimani condition Ofanto explored moderate resistance to the disease. Outperforming other durum wheat cultivars by cv. Fadda-98 in term of plant height, awn length, number of grains per spike, grains weight per spike, biological yield, and grain yield in the presence of yellow rust disease facilitate the wide cultivation of this durum wheat cultivar in the hot spot of yellow rust lands in Iraq.

Conflict of interest

The authors declare no conflict of interest.

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