

Yellow Rust Effects on Grain Yield, and Yield Components of Some Spring Bread Wheat Cultivars under Rainfed Conditions

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Abstract Stripe rust caused by *Puccinia striiformis*, is currently the major foliar disease of spring bread wheat (*Triticum aestivum* L.) in Tunisia, causing serious yield losses and affecting grain quality. Farmers often use foliar fungicide application or resistant cultivars to counter yield loss, however, this is hampered by a lack of resistant varieties. To investigate the effects of genetic resistance and foliar fungicide application on disease level and yield components, six improved varieties were evaluated at the regional experimental station in Beja during three consecutive growing seasons. Under natural stripe rust infection, three varieties were detected as completely resistant and the others are susceptible. The pathogen affected the leaf area in the susceptible varieties and reduces the above ground biomass at harvest, seed weight and grain yield. Fungicide application reduces the disease severity on the sensitive genotypes and improves biomass, seed weight, grain yield, and harvest index. Yield benefits were much greater in the use of resistant genotypes than fungicide application on the susceptible varieties; consequently the resistance to stripe rust can have more significant benefits to farmer and to the wheat industry.

Keywords: *Puccinia striiformis*, *Triticum aestivum*, resistant varieties, yield, fungicide.

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1. Introduction

Wheat is the main cereal crop that supplies energy, protein and fiber in our daily diet. The main production constraint is yield loss due to fungal disease and drought stress. Among the three main rusts affecting wheat, stripe rust, caused by *Puccinia striiformis* f. sp. *tritici*, is the most difficult to manage in Tunisia. It is the most damaging disease in wheat growing areas worldwide [1]. For its development; the disease requires cold and humid climatic conditions [2] and lower optimum temperature [3]. There are a limited number of resistant varieties available and new pathotypes that overcome the most widely deployed genes have arisen. Grain yield losses of 10 to 70% have been reported depending upon the cultivar grown and the environmental conditions during ear emergence [4]. Great losses of wheat production have been associated with yellow rust, when epiphytotics occurred under favourable conditions [5].

The application of foliar fungicide is profitable when susceptible varieties are planted under environmental conditions favourable for the disease development [6]. Important economic returns from fungicide use were reported. They depend on the severity of disease and varietal resistance. So far, genetic resistance remains the

most economical and preferred method for the control of diseases. Therefore, the alternative options for controlling diseases, under the varying level of genetic resistance, could be a combination among plant resistance and the tactical fungicides application. Previous studies related to disease severity and yield loss have focused on the effect of fungicide use that prevented yield loss, particularly on susceptible genotypes planted under environmental conditions favourable to disease development [8,14,15].

The use of foliar fungicide application on bread wheat genotypes with variable level of resistance planted under contrasting growing conditions can help farmers, increase grain yield, grain quality and biomass [15]. Here we report the effect of yellow rust disease and fungicide application on yield, yield components and biomass using improved bread wheat genotypes having different level of resistance.

2. Materials and Methods

2.1. Site Description and Experimental Design

Field experiments were conducted over three consecutive seasons (2015-2017) at the Oued Beja research station, belonging to the regional field crops research center of Beja, Tunisia (Latitude: 36°43'32" N; Longitude: 9°10'54"

E; sea level: 248 m). Plots were sown with spring wheat (*Triticum aestivum* L.) varieties Salammbô, Byrsa, Vagua, Haidra, Utique and Tahent. Salammbô and Byrsa were considered highly susceptible, Vagua moderately susceptible and Haidra, Utique and Tahent were resistant to the dominant yellow rust race 'Warrior' in Tunisia during the years in which the experiments were conducted. In all year's cropping seasons In all year's crop seasons, the varieties were planted on early November in experimental plots measuring 10 m length and 3 m width with a seeding rate of 350 plants m⁻² and a row spacing of 17 cm. All plots were fertilized by application of 300 kg ha⁻¹ granular ammonium-nitrate (33% N) at the growth stage 32 (Zadok's scale).

The experimental design was a split-plot design with three replicates, where fungicide application is the main plot factor, and variety is the subplot factor. In total; 36 plots were planted.

2.2. Fungicide Application and Data Collection

A foliar fungicide application was carried out on heading stage (GS 55). Ogam (125 g Epoxiconazole + 125 g Krésoxim methyl L-1) was applied at the rate of 700 ml ha⁻¹. Disease severity (percentage of leaf area covered in pustules) for reaction to *P. Striiformis* was visually estimated at adult plant stage using a standard scale of McNeal et al. [7]. This scale based on necrotic lesions containing pustules ranging from 0 to 9, where 0 = no presence of visible uredia and the plant is immune; 1 = very resistant plant with presence of some necroses; 2 = resistant plant characterized by necrotic zones without sporulation; 3-4 = resistant plant characterized by the presence of zones containing necrosis and chlorosis with limited sporulations; 5-6 = moderately resistant plant, moderate sporulation with necrosis and chlorosis; 7-8 = moderately sensitive plant characterized by the presence of pustules with chlorosis; 9 = sensitive plant characterized by abundant pustules that cover chlorosis. Plants were evaluated at 146 days after sowing (DAS), with corresponds approximately to early milk development (75 Zadocks growth stage) in each season.

Sampling measurements of yield parameters were made on elementary plots of 5 m². The full plots were harvested manually and the biomass was measured by weighting the above ground part. Ten spikes from each plot were beaten separately and obtained grains were weighted. The yield per spike is estimated through the calculation of the average.

After measuring the biomass of each plot, the spikes were beaten and the grains obtained were weighted in order to estimate the grain yield. The harvest index was calculated by the ratio between the grain yield and the biomass. The 1000-kernel weight (g) was determined for each genotype by weighting a thousand grain simples per plot

3. Data Analysis

Data of each year were analyzed using the SAS program, version 9.1 [16]. The analysis of variance was performed using PROC GLM of SAS. Mean separation

was done using Fisher's protected LSD test at the 5% level of significance.

4. Results and Discussion

4.1. Effect of Foliar Fungicide and Genotype on Disease Control

The genotype-by-fungicide interaction term in the ANOVA analysis was large and significant during all years of experimentation, indicating different responses of wheat genotypes to *P. striiformis* (Table 1).

Table 1. Analysis of variance with mean squares for yellow rust severity of six bread wheat varieties grown with two treatments (with or without fungicide application) during three years

Source of variation	DF	2015	2016	2017
Genotype	5	351.1***	2481***	6537***
Treatment	1	136.1*	3306***	3906***
Genot*Treat	5	61.1*	591***	693***
Error	22	9.4	26	18

DF= Degree of freedom; * Significant at 0.05 probability level; *** Significant at 0.001 probability level

In order to investigate the diversity in level of resistance within the six bread wheat varieties, these were evaluated for resistance to *P. striiformis* under natural infection. The results showed that all susceptible varieties had less yellow rust severity due to the foliar fungicide application when compared to untreated plots (Table 2). Susceptible genotypes such as Salammbô and Byrsa benefited from foliar fungicide application as compared to resistant genotypes such as Utique and Haidra. The response of susceptible varieties to fungicide application was variable and depended on specific environmental conditions. Similar results of significant effect of foliar fungicide in controlling yellow rust and other diseases were reported in previous studies [6,8,9]. Despite fungicide application on susceptible varieties, genetic resistance still be the more effective means for disease control and the most reassuring tool for farmers.

Table 2. Percentage of leaf area covered by pustules of *Puccinia striiformis*, of six untreated (F₀) and treated (F₁) bread wheat evaluated during three growing seasons (2015-2017).

Genotype	Year					
	2015		2016		2017	
	F ₀	F ₁	F ₀	F ₁	F ₀	F ₁
Tahent	5cd*	5cd	10ef	5fg	10f	5fg
Haidra	0d	0d	0g	0g	0g	0g
Utique	0d	0d	0g	0fg	0g	0g
Vagua	25a	10bc	43b	15de	72b	25e
Byrsa	10bc	10bc	65a	20cd	85a	45d
Salammbô	20a	10b	60a	25c	87a	50c

F₀: no fungicide application and F₁: with foliar fungicide treatment.

*: Means followed by the same letter in a given column and factor are not significantly different at p < 0.05 according to fisher's LSD test.

4.2. Effect of Genetic Resistance and Fungicide Application on Yield Components

A significant foliar fungicide \times genotype interaction was observed for grain yield during 2016 and 2017 seasons (Table 3). Grain yield differences were observed among genotypes and varied with the severity of the disease. Indeed during 2015 climatic conditions were not favorable for the development of the disease, thus the yield has not been affected compared to 2016 and 2017 (Table 4).

Table 3. Analysis of variance with mean squares for grain yield of six bread wheat varieties grown with two treatments (with or without fungicide application) during three years

Source of variation	DF	2015	2016	2017
Genotype	5	1768026**	3153863**	833147**
Treatment	1	456075**	1474605**	2183499**
Genot*Treat	5	66261 ns	343075 **	366153 **
Error	22	30629	29906	2175

DF= Degree of freedom; ** Significant at 0.01 probability level; ns: not significant.

Foliar fungicide application resulted in a large increase in grain yield on the susceptible varieties during favorable seasons for the development of the pathogen (2016-2017). In fact, the genotypes with higher disease severity such as Byrsa and Salammbô (disease severity during 2017>80%; Table 2) had benefited from fungicide application and the yield was multiplied by 2 and 5 respectively (Table 4). This increase of grain yield is the result of the efficacy of the foliar fungicide to control the disease and limits its effects. The results corroborate those reported by Lopez et al. and Bhatta et al. [10,15], which indicates that foliar fungicide application increase grain yield by about 10 to 50% in bread wheat. However, resistant genotypes showed similar grain yield between treated and untreated plots (belong to the same classes; Table 4). Consequently, using genetic resistance for yellow rust can substitute chemical alternative even under high pressure of the disease.

Table 4. Mean grain yield (g per 5m²) for each treated and untreated genotype during three growing seasons

Genotype	Year					
	2015		2016		2017	
	F ₀	F ₁	F ₀	F ₁	F ₀	F ₁
Tahent	3530a*	3271a	3433a	3461a	1823a	1648b
Haidra	3379a	3256a	3335ab	3194ab	1375cd	1416c
Utique	3307a	3319a	3048b	3319ab	1217e	1648b
Vagua	2155c	2026c	2055d	2426c	540g	1322d
Byrsa	2476b	2638b	1468e	2645c	698f	1428c
Salammbô	2559b	2550b	1381e	2118d	152h	1297d

F₀: no fungicide application and F₁; with foliar fungicide treatment.
*: Means followed by the same letter in a given column and factor are not significantly different at $p < 0.05$ according to fisher's LSD test.

Thousand kernel weight of susceptible varieties was significantly affected by disease severity, particularly for Byrsa and Salammbô during 2016-2017 growing seasons

(Table 6). A significant interaction of genotype \times foliar fungicide application was observed (Table 5). Thousand kernel weight average of Byrsa and Salammbô genotypes across 2016-2017 seasons was higher (40 and 31g respectively) in protected than unprotected (31.5 and 24g respectively) plots (Table 6). The increase in 1000 kernel weight may be attributed to the effects of foliar fungicide application in preventing stripe rust and thereby maintaining higher leaf greenness for long period of time. This result of increased grain weight from foliar fungicide application was in agreement with previous findings [8,14,17,18].

Table 5. Analysis of variance with mean squares for 1000 kernel weight of six bread wheat varieties grown with two treatments (with or without fungicide application) during three years

Source of variation	DF	2015	2016	2017
Genotype	5	114.43***	149.01***	132.84***
Treatment	1	0.67ns	77.44***	99***
Genot*Treat	5	0.06ns	31.43***	18.83***
Error	22	0.57	0.35	0.24

DF= Degree of freedom; *** Significant at 0.001 probability level; ns: not significant.

Also, this increase in mean kernel weight can be attributed to leaf area protection as foliar fungicide application leads to higher leaf area index [11,12], which enhances the efficiency of photosynthesis and therefore the grain filling [12].

Table 6. Mean 1000 kernel weight (g) for each treated and untreated genotype during three growing seasons

Variety	Year					
	2015		2016		2017	
	F ₀	F ₁	F ₀	F ₁	F ₀	F ₁
Tahent	42.4a*	42.2a	41.5bc	41.2b	40.9a	41.5a
Haidra	37.4c	37.1c	38d	37.7d	33.1d	33.2d
Utique	40.6b	41.2b	40.5c	40.4bc	29.9f	30.3e
Vagua	34.4d	34.3d	33.7e	34.1e	29.3b	35.6g
Byrsa	42.1a	42.5a	32.7f	42.6a	30.3f	37.4b
Salammbô	31.6e	32.4e	24.3g	32f	23.7h	29.9fg

F₀: no fungicide application and F₁; with foliar fungicide treatment.
*: Means followed by the same letter in a given column and factor are not significantly different at $p < 0.05$ according to fisher's LSD test.

Grain yield per spike is another important component of yield. In this research, the biggest yield per spike was found in the resistant varieties under the two treatments (treated and untreated) whereas the lowest average yield per spike was recorded for the Salammbô variety with values of 0.43 grams per ear for the untreated plot (Table 8). As a result of a considerable attack by yellow rust, yield per ear decreased by 64%, 22% and 37% respectively in Salammbô, Vagua and Byrsa varieties. The genotype-by-treatment interaction for grain yield per spike was large and highly significant indicating different reactions of treated and untreated wheat genotypes. The mean effect of genotype was also large suggesting a significant variation on the mean response of genotype to treatment (Table 7). The obtained result show that the foliar fungicide application had a positive effect on grain filling and thus on grain yield per spike. This result was in

agreement with those reported by Leilah and Al-Khateeb and Zakizadeh et al. [19,20].

Table 7. Analysis of variance with mean squares for grain yield per spike of six bread wheat varieties grown with two treatments (with or without fungicide application) during three years

Source of variation	DF	Year		
		2015	2016	2017
Genotype	5	0.10636***	0.3287***	0.2925***
Treatment	1	0.00188*	0.4994***	0.5776***
Genot*Treat	5	0.00222***	0.1038***	0.1751***
Error	22	0.00029	0.0008	0.0011***

DF= Degree of freedom; *** Significant at 0.001 probability level;

* Significant at 0.05 probability level.

Utique, Haidra and Tahent varieties did not show any significant differences between treatments. This confirms their high level of resistance. These results are in agreement with previous reported works [6,13].

Table 8. Mean grain yield per spike (g) for each treated and untreated genotype during three growing seasons

Genotype	Year					
	2015		2016		2017	
	F ₀	F ₁	F ₀	F ₁	F ₀	F ₁
Tahent	1.46c*	1.52b	1.56ab	1.58a	1.39ab	1.36bc
Haidra	1.40ef	1.43d	1.46de	1.47de	1.42a	1.30de
Utique	1.58a	1.60a	1.49cd	1.52bc	1.18f	1.33cd
Vagua	1.19j	1.23i	1.10h	1.31f	0.74h	1.17f
Byrsa	1.41de	1.38f	0.87i	1.42e	1.07g	1.37abc
Salammbô	1.32g	1.29h	0.72j	1.26g	0.43i	1.2e

F₀: no fungicide application and F₁; with foliar fungicide treatment.

*: Means followed by the same letter in a given column and factor are not significantly different at $p < 0.05$ according to fisher's LSD test.

For the biomass, since disease severity was low during the first year (2015) of evaluation, no significant differences were observed between treated and untreated plots. However; it was found that the treatment has a high significant effect on biomass during 2016-2017 growing seasons due to the high disease pressure. A high significant difference was observed between varieties that revealed different levels of resistance to yellow rust disease (Table 9).

Table 9. Analysis of variance with mean squares for above-ground biomass of six bread wheat varieties grown with two treatments (with or without fungicide application) during three years

Source of variation	DF	2015	2016	2017
Genotype	5	6918765**	4864940**	1366774***
Treatment	1	26569 ns	1928858**	8644580***
Genot*Treat	5	12267ns	479214***	1065159***
Error	22	14832	11124	13217

DF= Degree of freedom; *** Significant at 0.001 probability level; ** Significant at 0.01 probability level; ns: not significant.

The lowest average of biomass was recorded for the variety Salammbô with values of 3033 grams (2017) in the untreated plot. Yellow rust reduced above-ground biomass at harvest 38%, 35% and 24% for the unprotected varieties Salammbô, Vagua and Byrsa, respectively. The varieties Utique, Haidra and Tahent did not show any significant differences between treatments, which confirms their high levels of resistance (Table 10).

Table 10. Mean biomass (g per 5m²) for each treated and untreated genotype during three growing seasons.

Genotype	Year					
	2015		2016		2017	
	F ₀	F ₁	F ₀	F ₁	F ₀	F ₁
Tahent	7954c [#]	7890c	7780a	7415b	4961c	4726d
Haidra	8600a	8700a	7460b	7530b	4850cd	5300b
Utique	8250b	8300b	6415d	6850c	4900c	5600a
Vagua	5940f	6120f	4960g	6316d	3416f	5266b
Byrsa	6210e	6300e	5466f	6033e	3933e	5233b
Salammbô	7320d	7230d	5460f	6100e	3033g	4933c

F₀: no foliar fungicide application and F₁: with foliar fungicide application.

[#]: Means followed by the same letter in a given variety, factor and year are not significantly different at $p < 0.05$ according to fisher's LSD test.

Biomass reductions were due to the effects of disease associated with a reduced capacity of the canopy to absorb solar radiation, suggesting that this biotrophic pathogen could affect the photo-synthetic activity at the leaf or canopy level [21].

The harvest index (HI) was calculated following the traditional procedure (i.e. grain yield \times the total above-ground biomass⁻¹).

A high significant difference in HI was found between varieties and treatments. A significant interaction between foliar fungicide and genotype was observed for HI. This interaction due to significant reduction of HI particularly for the untreated susceptible varieties such as Byrsa and Salammbô during the growing seasons 2016 and 2017 (Table 11).

Table 11. Analysis of variance with mean squares for Harvest index of six bread wheat varieties grown with two treatments (with or without fungicide application) during three years

Source of variation	DF	2015	2016	2017
Genotype	5	0.01***	0.03***	0.03***
Treatment	1	0.01***	0.01***	0.04***
Genot*Treat	5	0.001*	0.01***	0.01***
Error	22	0.001	0.001	0.0001

DF= Degree of freedom; *** Significant at 0.001 probability level; Significant at 0.05 probability level.

Resistant and high yielding varieties have the highest Hi even without foliar fungicide application. Salammbô was found to have the lowest Hi at the untreated plots. The highest harvest index was recorded for the variety Tahent, under the two treatments (treated and untreated) which was the most efficient in terms of grain yield, 1000 grain weight and above ground biomass.

Table 12. Mean harvest index for each treated and untreated genotype during three growing seasons.

Genotype	Year					
	2015		2016		2017	
	F ₀	F ₁	F ₀	F ₁	F ₀	F ₁
Tahent	0.44a*	0.41abc	0.44abc	0.47ab	0.37a	0.35b
Haidra	0.39cde	0.37def	0.45abc	0.42cd	0.28cd	0.27def
Utique	0.40ab	0.39ef	0.47a	0.48ab	0.25g	0.30c
Vagua	0.36cdef	0.33g	0.41cd	0.38de	0.16h	0.25fg
Byrsa	0.39abc	0.41bcd	0.27f	0.44bc	0.18h	0.27de
Salammbô	0.35fg	0.35f	0.25f	0.35e	0.05i	0.26efg

F₀: no fungicide application and F₁; with foliar fungicide treatment.

*: Means followed by the same letter in a given column and factor are not significantly different at $p < 0.05$ according to fisher's LSD test.

5. Conclusion

The present work showed one-time application of foliar fungicide against yellow rust at ZGS 55 decreased disease severity (up to 60%) for the susceptible bread wheat varieties. Consequently, a benefit in grain yield and positive effects on yield components could be observed. The disease can induce enormous losses in grain yield, 1000 kernel weight, yield per spike and biomass. These losses depend of the genotype resistance level and the inoculum abundance of the disease. Large variation in grain yield and biomass production within varieties and between years was observed. This may be related to the yield potential of the used genotypes and their interactions with the environment. Using resistant varieties to yellow rust could have significant benefit to farmers than susceptible ones which need foliar fungicide application to control disease.

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