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Field Scale Interactions of Maturation Period with Seasonal Patterns of Yellow Rust in Wheat Cultivars Planted at Different Dates

[1]Bita Naseri, [2]Shahryar Sasani and [2]Sharareh Fareghi

[1]Department of Plant Protection Research, Kermanshah Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization, Kermanshah, Iran

[2]Department of Horticulture Crops Research, Kermanshah Agricultural and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization, Kermanshah, Iran

ABSTRACT

Background and Objective: Associations among planting date, yellow rust, weather, and wheat yield. However, it is still needed to investigate how strongly wheat maturation is linked to these features. This study examined cultivar resistance, planting date seasonal patterns of yellow rust progress, weather, and yield in interaction with wheat maturation. **Materials and Methods:** A four-year study examined associations of wheat maturity with yellow rust, planting date, cultivar resistance, weather and yield under experimental field conditions. The H-test, correlations, and principal component analyses were used to examine datasets. The significance level was detected at 5%. Early maturing wheat cultivars planted at all four planting dates corresponded with the lower area under the yellow rust progress curve (AUYRPC), maximum disease incidence and severity rankings compared to late-maturing cultivars. A lower yield ranking was determined for late-maturing cultivars. **Results:** A late onset of yellow rust showed a 33% shorter maturity duration in comparison with early onset. Early plantings in October, had an 182% lower maturity ranking when compared to plantings at the optimum date, November. **Conclusion:** An early maturation of wheat cultivars corresponded with a warm spring, cold autumn and winter, fewer rainy days in spring, early planting of winter wheat, late disease onset less severe yellow rust, and high yielding.

KEYWORDS

Airborne, *Puccinia striiformis*, cereals, climate, stripe rust, maturity duration, AUYRPC

INTRODUCTION

Puccinia striiformis f. sp. *tritici* causing yellow rust reduces wheat (*Triticum aestivum*) production at appropriate agroecological conditions worldwide. In Iran, the disease epidemics develop in wheat cultivars following an early disease onset, late maturation of wheat cultivars, low resistance level, late planting, cool and rainy spring[1]. This epidemiological finding was followed by fitting specific and easy-to-use yellow rust progress curve elements to seasonal patterns of epidemics. For resistant and semi-resistant cultivars of wheat, early and optimum planting dates in October and November corresponded often with the lower area under the yellow rust progress curve (AUYRPC), maximum disease incidence and severity, and

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Gaussian parameters m and s^2. For instance, an earlier planting of wheat cultivars resulted in up to 50% slower yellow rust progress rate. The development of severe yellow rust epidemics was significantly associated with a moister mid-autumn (second month), warmer late (third month) winter, mild winter with fewer icy days, and further appropriate days with a minimum temperature within 7-8°C and relative humidity $\geq$60% from October to May[3]. In the next step, a higher wheat yield was produced following early planting, further rainy days in spring, later maturation of cultivar, later yellow rust occurrence, and higher resistance to the disease[4]. It is still needed to investigate how strongly wheat maturation is linked to seasonal patterns of yellow rust progress, weather, cultivar resistance, and planting date in particular to specific yellow rust descriptors which are notably associated with yield adaptability and stability across different environments.

Saleem *et al.*[5] reported a negative linkage of yield to either yellow rust incidence or the genetic resistance determined in 105 bread wheat genotypes at seedling and adult plant stages under controlled environment and field conditions. Elsewhere, Esmail *et al.*[6] observed susceptibility to yellow rust in resistant cultivars following dynamic changes in the final disease severity and area under the disease progress curve. In addition, the chlorophyll concentration and enzyme (catalase and peroxidase) activity increased, while the electrolyte leakage decreased in resistant cultivars. Moreover, all haustoria and hyphae of the pathogen were inhibited and became abnormal in resistant cultivars when compared to many hyphal growth and little sporulation in fast and slow-rusting cultivars, respectively. It should be noticed that planting different crops at appropriate dates improved the durability of genetic resistance and thus, yield levels produced by cultivars[7]. Hence, the study aimed to unravel complicated associations of wheat maturity with specific descriptors of yellow rust progress in wheat cultivars, planting date, genetic resistance, weather, and yield for sustainable production purposes.

MATERIALS AND METHODS

Field experiments: During the 2013-2017 years, the progression of yellow rust in Iranian bread wheat cultivars was characterized across 282 field plots[2]. Experimental plots were prepared based on a split-plot design with three replicates per treatment, eight cultivars, and four planting dates. Such a methodology of field experiments effectively diversified patterns of yellow rust progress across the plots with different cultivars and planting dates[2]. According to the max. yellow rust severity recorded over the four study years, the cultivars Bahar, Baharan, Chamran II, Parsi, Pishtaz, Sirwan, and Sivand were classified as susceptible and cultivar Pishgam as resistant to yellow rust[1]. Based on common planting dates used by Iranian wheat growers, the following monthly basis of planting dates was investigated: October, November, December, and January from 2013 to 2017.

Yellow rust and yield measurements: The severity of yellow rust was recorded every week as the percentage leaf area sporulating in the forms of strips for the youngest leaves of at least 9 arbitrarily wheat plants per plot[1]. Therefore, the disease severity was recorded across plots 4-6 times per study year. This way of yellow rust recording provided a big dataset that involved 11664, 6804, 8505, and 9072 diseases from the first to the fourth year, respectively. Such a high diversity in seasonal patterns of yellow rust improved the predictive value of the disease progress curve elements[8]. Wheat yield was determined as the total weight of grains harvested in each plot (kg/ha).

Weather data: Weather data significantly associated with the yellow-rust-wheat pathosystem[1] was obtained over the four years as follows: Number of days with minimum temperature within 5-12°C and maximum relative humidity (RH) above 60% over the autumn, winter, and spring months, and the number of rainy days in the spring. This weather data was collected from a synoptic site adjacent to the study station (Table 1).

Data analysis: To summarize the seasonal patterns of wheat yellow rust progress variations across the treatments, years, and plots, the goodness of four-year yellow rust severity datasets fitted to the Gaussian model was determined by the GENSTAT software[2]. In this Gaussian model, the parameter b defines the

Table 1: Weather data collected at the research site for four years, 2013-2017

Climatic parameter	Number of days with minimum temperature within 5-12°C and maximum relative humidity $\geq$60% over autumn-winter-spring months	Number of rainy days in the second and third months of spring
2013-2014	41	6
2014-2015	24	2
2015-2016	49	10
2016-2017	48	5

height of the disease curve's peak, m is the position of the peak's center, and the parameter s is the width of the bell-shaped curve. The following yellow rust progress curve elements were used in this study: (1) The disease onset date; (2) The AUYRPC of the over-season recording of disease severity; (3) Maximum disease severity over the four years and (4) Parameters b, m, and s of Gaussian model[2].

Means of yellow rust severity and yield for diverse cultivars, planting dates, seasonal recordings, and years were provided earlier[1,8]. A H-test was performed to rank the AUYRPC, disease onset, Gaussian parameters, max. disease severity, cultivar resistance, and wheat yield according to the factor of maturation. This factor detected the number of days from planting to physiological maturity that involved the early ($\leq$261 days) and late (>261 days) levels. The maturation factor was also ranked according to the cultivar (considered as the resistance index), planting date, and year by using the H-test. Correlations among the continuous variables of yellow rust, cultivar resistance, weather, wheat maturity, and yield were analyzed using the GENSTAT. Advanced analysis of associations among the disease, planting date, weather, and wheat variables was conducted based on a Principal Component Analysis (PCA) as a powerful tool.

RESULTS

H-test analysis: According to the H-test results, the AUYRPC (Chi $p<0.087$; adjusted H = 2.93), max. yellow rust incidence (Chi $p<0.050$; adjusted H = 3.84) and severity (Chi $p<0.051$; adjusted H = 3.80) were ranked based on the maturity duration (Table 2). Early maturing wheat cultivars planted at all four test dates corresponded with a lower AUYRPC ranking compared to the late maturing cultivars. Late maturing cultivars showed greater rankings of yellow rust incidence and severity in comparison with early maturing cultivars studied. Gaussian parameters did not affect the maturity duration in eight commercial wheat cultivars planted at October, November, December, and January dates in four years under experimental field conditions. This suggested that the duration of maturity in the cultivars of wheat was ineffective on the rate of yellow rust progression at the field scale (Table 2).

The maturity duration detected for the eight cultivars of wheat was not affected (Chi $p = 0.522$) by the disease resistance factor (Table 3). This suggested non-significant differences in the level of genetic resistance index between the two groups of early and late-maturing cultivars. For the yield of wheat cultivars (kg/ha), a lower yield ranking was determined for late-maturing cultivars which affected the (Chi $p<0.001$; mean H = 27.95) seed productivity. This suggested those wheat cultivars maturing longer than 261 days produced a lower yield in comparison with the early maturing cultivars (Table 3).

The third H-test determined a non-significant effect for wheat maturity factor on the resistance index of wheat cultivars ranging from 0 for cv. Chamran II to 70 for cv. Pishgam (Chi $p = 0.920$; Table 4). The date of yellow rust onset affected (Chi $p = 0.030$; mean H = 4.71) the maturity duration in the eight commercial wheat cultivars with different planting dates. This observation ranked a late onset of yellow rust with a 33% shorter maturation duration under field conditions. The factor of planting date significantly affected (Chi $p<0.001$; mean H = 70.59) wheat maturation, suggesting the correspondence of early plantings with 182% lower maturity ranking when compared to the optimum date. Then, the duration of cultivar maturation increased as the date of planting changed from the optimum date to the very late date. This indicated the increase of 117% in maturation ranking determined for very late plantings in January in comparison with

Table 2: Rankings of area under yellow rust progress curve, disease onset, Gaussian parameters, maximum disease incidence, and severity based on wheat maturity

	Maturity levels	
Disease descriptors	Early	Late
AUYRPC		
Adjusted H = 2.93	52.04	42.56
Chi p = 0.087		
Disease onset		
Adjusted H = 2.27	50.69	44.57
Chi p = 0.132		
Gaussian parameter b		
Adjusted H = 1.74	43.73	50.96
Chi p = 0.187		
Gaussian parameter m		
Adjusted H = 2.39	43.03	51.60
Chi p = 0.122		
Gaussian parameter s		
Adjusted H = 2.86	42.68	51.93
Chi p = 0.091		
Maximum incidence		
Adjusted H = 3.84	41.91	52.63
Chi p = 0.050		
Maximum severity		
Adjusted H = 3.80	41.89	52.65
Chi p = 0.051		

AUYRPC: Area under yellow rust progress curve

Table 3: Rankings of yellow rust resistance index and wheat yield based on wheat maturity

	Maturity levels	
Descriptors	Early	Late
Yellow rust resistance index		
Adjusted H = 0.41	49.36	45.80
Chi p = 0.522		
Wheat yield (kg/ha)		
Adjusted H = 27.95	63.02	33.24
Chi $p<0.001$		

the optimum plantings in November during the four study years. Planting the cultivars at the optimum date in November shortened the maturity period by 60% compared with the late plantings in December. The year factor also affected the maturity duration (Chi $p<0.001$; mean H = 23.33), showing the longest and shortest maturity durations determined in the 2015-2016 and 2014-2015 years, respectively (Table 4).

Correlations: Correlation analysis showed significant relations between the duration of wheat maturity and the yellow rust progress curve variables, the AUYRPC (r = 0.23), Gaussian parameters m (r = 0.25) and s (r = 0.20), maximum disease incidence (r = 0.23) and severity (r = 0.24), and yellow rust onset (r = -0.28; Table 5). For relations of the maturity duration with the two weather variables, the number of rainy days in spring and the number of days with min. temperature within 5-12°C and max. RH $\geq$60% during the autumn-winter-spring months was correlated significantly with the maturity variable (r = 0.49). Weather variables were linked often significantly to the disease progress variables. The resistance index was correlated with the AUYRPC (r = -0.32), max. yellow rust incidence (r = -0.35) and severity (r = -0.36) variables. Wheat yield was linked to the max. disease incidence (r = 0.22) and the number of days with min. temperature within 5-12°C and max. RH $\geq$60% during autumn-winter-spring months (r = -0.37). The yield was also associated significantly with wheat maturity (r = -0.49), indicating greater productivity following a shorter maturity duration in the cultivars planted at different dates studied (Table 5).

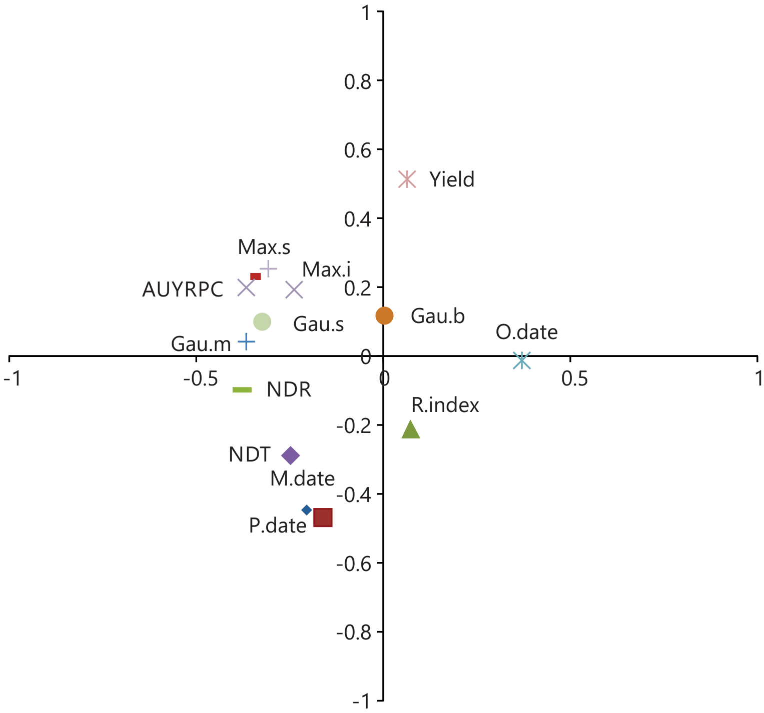

Fig. 1: Principal component analysis of eight wheat cultivars differing in maturation (M.date) and planting date (P.date)

Disease development, AUYRPC: Area under yellow rust progress curve, Gaussian parameters: Gau.b, Gau.m and Gau.s, Max.i: Max. incidence, Max.s: Max. severity, O.date: Disease onset, R.index: Disease resistance, yield (kg/ha) and weather (number of days with min. temperature within 5-12°C and max. relative humidity $\geq$60% over autumn-winter-spring months: NDT; and number of rainy days in second and third months of spring: NDR) variables

Table 4: Rankings of wheat maturity period (number of days from planting to maturity) according to yellow rust onset, planting date, year, and cultivar resistance

Descriptor	Descriptor levels							
Cultivar	Bahar/30	Baharan/40	Chamran II/0	Parsi/40	Pishgam/70	Pishtaz/50	Sirwan/10	Sivand/20
Adjusted H = 2.60 Chi p = 0.920	45.00	53.57	51.61	44.54	40.50	44.68	45.82	54.07
Disease onset				Early				Late
Adjusted H = 4.71 Chi p = 0.030				58.81				44.25
Planting date		Early		Optimum		Late		Very late
Adjusted H = 70.59 Chi p<0.001		13.12		36.94		59.24		80.28
Study year		2013-2014		2014-2015		2015-2016		2016-2017
Adjusted H = 23.33 Chi p<0.001		56.00		23.07		58.81		50.05

Principal component analysis: The first principal component (x-axis) suggested that the variables of AUYRPC, Gaussian parameter m, max. yellow rust severity and the disease onset were significantly linked to the rainy days in spring (Fig. 1). Furthermore, the disease onset showed a reverse linkage to each of the AUYRPC, Gaussian parameter m, max. disease severity and the number of rainy days in the second and third months of spring. According to the second principal component (y-axis of Fig. 1), wheat yield provided the greatest correspondence with this axis, followed by the maturity and planting date variables. This observation suggested that a higher yield was associated with shorter maturity duration and earlier planting of the cultivars studied. Supporting the H-test and correlation results, this PCA demonstrated a reverse interaction of wheat maturity and planting date with the yield variable.

Table 5: Correlation analysis of maturation date (M.date)

Indicators	AUYRPC	Gau.b	Gau.m	Gau.s	Max.i	Max.s	O.date	NDR	NDT	M.date	R.index	Yield
AUYRPC	1.00											
Gau.b	-0.01	1.00										
Gau.m	0.71	-0.03	1.00									
Gau.s	0.67	-0.01	0.76	1.00								
Max.i	0.76	0.15	0.53	0.51	1.00							
Max.s	0.93	0.12	0.63	0.65	0.84	1.00						
O.date	-0.72	0.05	-0.97	-0.69	-0.51	-0.64	1.00					
NDR	0.68	-0.14	0.83	0.59	0.55	0.61	-0.85	1.00				
NDT	0.36	-0.18	0.43	0.30	0.23	0.28	-0.44	0.77	1.00			
M.date	0.23	0.09	0.25	0.20	0.23	0.24	-0.28	0.48	0.49	1.00		
R.index	-0.32	-0.15	0.04	-0.11	-0.35	-0.36	-0.06	0.01	0.03	-0.13	1.00	
Yield	0.03	0.06	-0.08	-0.07	0.22	0.08	0.11	-0.11	-0.37	-0.49	-0.13	1.00

Disease development, AUYRPC: Area under yellow rust progress curve, Gaussian parameters: Gau.b, Gau.m and Gau.s, Max.i: Max. incidence, Max.s: Max. severity, O.date: Disease onset, R.index: Disease resistance, yield (kg/ha) and weather (number of days with minimum temperature within 5-12°C and max. relative humidity $\geq$60% over autumn-winter-spring months: NDT; and number of rainy days in second and third months of spring: NDR) variables

DISCUSSION

There are many epidemiological findings characterizing just 2-3 descriptors of yellow rust, planting date, cultivar resistance, weather, wheat maturity, and productivity at the field scale. For instance, Saleem *et al.*[5] reported a reverse association of yield with either yellow rust incidence or the genetic resistance in wheat genotypes at seedling and adult plant stages under controlled environment and field conditions. Elsewhere, Esmail *et al.*[6] described associations of resistance to yellow rust with variability in the final disease severity and area under the disease progress curve, chlorophyll concentration, enzymes (catalase and peroxidase) activities, and electrolyte leakage in wheat cultivars. However, interactions of these crop and disease descriptors with weather parameters influencing wheat maturation are still little understood. Weather fluctuations appear to impact wheat yellow rust progress curves, planting date, and genetic resistance as powerful disease management tools when interacting with the maturity in wheat[7]. Therefore, the present study attempted to advance our understanding of the joint associations of wheat maturity with the cultivar resistance, progression of yellow rust, planting date, weather, and yield examined within a single experimental framework.

Although the progression of yellow rust in wheat genotypes about the planting date, maturation, and yield of wheat has been partially reported earlier[4,6], it is critical to explore the complex interaction of wheat maturity with yellow rust progress not only at various planting dates but also by using specific descriptors of yellow rust occurrence and progress. Moreover, such a remarkable interaction was investigated under field conditions during four study years. Thus, such a noticeable association of a shorter duration of wheat maturity with an earlier planting, fewer rainy days in spring, later yellow rust onset, less prevalent and severe disease development, slower disease progress, a higher resistance index, fewer days with min. temperature within 5-12°C and max. RH $\geq$60% during autumn-winter-spring and a higher yield appears to be novel for the literature. The current information on these agroecological indicators assists with future breeding studies. Hence, wheat breeders are advised to consider these highly effective aspects of farming systems based on the present findings to develop more durable and higher resistance to yellow rust, earlier maturity, and more stable high-yielding genotypes worldwide.

The significant effect of the study year also on the maturity duration in commercial wheat cultivars demonstrated the longest and shortest maturations in the 2015-2016 and 2014-2015 seasons, respectively. This observation supports previous findings on significant associations of maturation with abiotic and biotic stresses, and planting date. The susceptibility of plants to the water stress increased towards wheat maturity[9]. In Kazakhstan, drought and heat stresses at the initial growth stage in early plantings of spring wheat delayed maturation and decreased resistance to pests[10]. According to the current findings, the shortest wheat maturity duration was observed in 2014-2015 having the fewest rainy days over the second and third months of spring, along with the fewest appropriate days (with min. temperature within 5-12°C and max. RH $\geq$60% over autumn-winter-spring) for yellow rust development when compared to the other years studied. The reverse climatic condition happened in 2015-2016 when the most severe epidemics of yellow rust occurred in spring[1]. It was suggested that such weather conditions may have lowered and increased the progression of yellow rust in wheat cultivars during 2014-2015 and 2015-2016, respectively. Thus, such fluctuations in maturation and yellow rust levels may be partially attributed to the current information on the disease-maturity-weather interplay.

Previous publications reported the highest and lowest wheat yield of 67.71 kg/ha in 2013-2014 and 25.82 kg/ha in 2016-2017, respectively[4]. The cold winter followed by a flood spring in 2016-2017 might have exerted abiotic stresses on wheat cultivars that resulted in pre-maturation and yield losses. Furthermore, the present study advanced our understanding of the early planting of wheat in October, and early autumn, corresponding with a shorter duration of maturation which in turn lowered yellow rust development and increased yield. Such a beneficial relevance of early planting with early maturing in wheat at field scale could be considered in future breeding programs aimed to improve the durability and level of genotype resistance to yellow rust, and the stability and adaptability of high yielding in wheat.

Esmail *et al.*[6] observed susceptibility to yellow rust in resistant cultivars due to increases in the final disease severity and area under the disease progress curve. Moreover, increases in the chlorophyll concentration and enzymes (catalase and peroxidase) activity and decreases in the electrolyte leakage were observed in resistant cultivars. In addition, all haustoria and hyphae of the pathogen were inhibited and became abnormal in resistant cultivars when compared to many hyphal growth and little sporulation in fast and slow-rusting cultivars, respectively. There are a large number of previous documents reporting the early maturity in wheat to be responsible for resistance to wheat diseases[11]. The present study revealed the correspondence of a shorter maturation with a later yellow rust occurrence and slower progress rate that appear to be the first report for this destructive pathosystem in main wheat growing areas worldwide.

CONCLUSION

This study clarified the complex association of wheat maturity with genetic resistance, planting date, weather, yellow rust, and productivity needed for sustainable cultivation. The current observations indicated that an early maturation of wheat cultivars corresponded with cold autumn and winter, and warm spring with fewer rainy days, early planting of winter wheat, late disease onset and less severe yellow rust, and high yielding. Such information assists with deploying more durable and higher levels of genetic resistance to yellow rust in future breeding programs for sustainable wheat production. Moreover, the present noticeable associations of wheat maturation with yellow rust, planting date, resistance index, and weather add value to more accurate yield estimations in the future.

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