Article

The incidence of yellow rust and the industrial quality of the grain and the dough in bread wheat

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Abstract

The occurrence of new races of foliar diseases with greater virulence in wheat affect the yield of the grain and its physical quality. The objective of this research was to evaluate the behavior of the physical quality of the grain and the mass by controlling the yellow rust (*Puccinia striiformis* f. sp. *tritici*) in tolerant and susceptible genotypes of seasonal bread wheat. The genotypes were planted in an experimental randomized block design with two replications in an array of plots divided into the large plot were the treatments with and without fungicide and in the girls the varieties. The incidence of yellow rust (was natural and the fungicide used was Folicur®. The percentage of incidence in the foliage of yellow rust was estimated and the industrial quality of the grain and mass was evaluated. An analysis of variance and Pearson correlations was performed and the means were compared with the Tukey test. The presence of yellow rust diminished the physical quality of the grain and the flour yield, but not the protein content in flour. The experimental lines and the Altiplano F2007 variety, with greater tolerance to rust, were associated with percentages of sucked grains of less than 20%, which was associated with high values of thousand grains, hectolitre weight and flour yield. While Nana F2007 with the highest incidence of the disease presented 70% of sucked grains and the lowest weight of a thousand grains and hectoliter weight. The protein content in flour and the variables evaluated in the mass did not show differences in most of the genotypes with and without the incidence of the disease. Therefore, the use of genotypes with genetic tolerance to yellow rust or the application of fungicide decreases the losses in the physical quality of the grain and flour yield.

Keywords: bread wheat, physical quality of the grain, quality of the dough, yellow rust.

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Introduction

In wheat flour producing areas (*Triticum aestivum* L.) in Mexico there are foliar diseases such as: yellow rust caused by *Puccinia striiformis* f. sp. *tritici*; leaf rust caused by *Puccinia triticina* as well as *Septoria* sp., *Cochliobolus Sativum* and *Pyrenophora triticina-repentis* (Huerta-Espino *et al*., 2014). The incidence of these diseases causes losses in the grain yield of 7.3 to 28.6% (Hortelano-Santa Rosa *et al*., 2016) or up to 60% due to the presence of yellow rust (Huerta-Espino and Singh, 2000), of 5.5 to 25.9% by leaf rust (Leyva-Mir *et al*., 2003). Likewise, the incidence of foliar diseases affects the physical quality of the grain, the rheological characteristics of the dough and the bakery quality (Morgounov *et al*., 2015; Castro and Simon, 2016; Castro and Simon, 2017; Fleitas *et al*., 2018).

One of the most important variables for the milling industry that includes the physical quality of the grain is the hectoliter weight which is related to the flour extraction capacity, these characteristics of the grain are influenced by the genotype, the environment and the management agronomic (Nuttall *et al*., 2017). In such a way that the incidence of yellow rust diminishes the filling of the grain and therefore increases the appearance of sucked grains, which are associated with losses in the weight of a thousand grains (Serrago *et al*., 2011; Jevtic *et al*., 2018) and low hectoliter weight that cause during the milling decrease in flour extraction or flour yield (Dimmock and Gooding, 2002). On the other hand, Blandino and Reyneri (2009) indicated that the chemical content of foliar diseases did not affect the protein content of the flour. But Watson *et al*. (2010) reported that the chemical control of *Septoria tritici* decreased the concentration of protein in grain while Castro *et al*. (2018) found an inverse result for the protein content.

On the other hand, Hortelano-Santa Rosa *et al*. (2016) concluded that the control of foliar diseases decreased the protein content due to the higher grain yield. Therefore, it is important to know the behavior of the variables of physical quality of the grain and of the mass depending on the genotypes and the presence of new races of yellow rust.

Tlaxcala and the State of Mexico produce more than 60% of the production of rainfed wheat in Mexico. This production is an option for the national milling industry due to its proximity to the main grinding and consumption centers, such as Mexico City and the state of Mexico, who demand more 60% of ground grain at the national level (CANIMOLT, 2015) but must meet the quality demanded by the national milling industry, which includes the physical quality of the grain, as well as the flour and dough.

It is important to point out that in the spring-summer agricultural cycle of 2014, a new race of yellow rust was introduced in the High Valleys of Central Mexico that overcame the genetic tolerance of the main commercial varieties sown as Nana F2007 (Ramírez *et al*., 2014; García-León *et al*., 2015). Thus, before the incidence of diseases of greater virulence should be determined in each production cycle its effect on the industrial quality and productivity of the planted genotypes. Thus, the objective of the present investigation was to evaluate the behavior of variables of the physical quality of the grain and the mass in function of the presence and absence of yellow rust in tolerant and susceptible genotypes of seasonal bread wheat.

Materials and methods

Genetic material and field evaluation

The genotypes used were four varieties recommended for production under rainfed conditions: Tlaxcala F2000, Nana F2007, Altiplano F2007 and Don Carlos M2015, as well as two experimental lines generated by the Temporary Wheat Improvement Program of the Valley of Mexico Experimental Field (CEVAMEX) of INIFAP: Pamdoly (line 1) and Pamdoly-PABG (C7) (line 2). The genotypes were planted in Juchitepec, State of Mexico and Terrenate, Tlaxcala. Juchitepec is located between parallels 19° 01' and 19° 11' North latitude, meridians 98° 48' and 98° 59' West longitude and altitude between 2 300 and 3 100 meters above sea level. Its average annual temperature and precipitation vary from 10-16 °C and 800-1 100 mm, respectively (INEGI, 2009).

Terrenate is located between parallels 19° 25' and 19° 33' North latitude; the meridians 97° 51' and 98° 02' of West longitude with an altitude between 2 500 and 3 300 with an annual temperature range is 10-14 °C and precipitation of 600-900 mm (INEGI, 2009). The genotypes were planted in a randomized experimental block design with two replications in a split plot treatment arrangement, where the large plot was the fungicide-free and fungicide-free treatments and the small plots were the varieties. The experimental unit was four furrows 3 m long with a separation of 30 cm. The fungicide used was Folicur® whose active ingredient is tebuconazole, of which 500 mL ha^{-1} was applied in the enamel and anthesis stage to control the natural incidence of yellow rust.

In the field the incidence rate of yellow rust in the leaf area was estimated based on the Cobb scale modified by Peterson *et al*. (1948). Samples were harvested with a minicombinated when the percentage of moisture in grain was less than 14%.

Variables evaluated in the laboratory

Variables of physical quality of the grain, biochemistry in flour and kneading were determined in the Laboratory of Farinology of CEVAMEX-INIFAP. The determination of the percentage of filled and sucked grains was made in samples of 500 grains. In addition, their length and width (mm) were determined with the average of 10 grains. The weight (g) of 1 000 grains was determined. The hectolitre weight (kg hL^{-1}) was evaluated according to the 55-10 method of the American Association of Cereal Chemists (AACC, 2005) in 500 g of impure free grain. The hardness of the grain (%) was estimated by the pearling index based on the 55-20 method of the AACC (2005) with a Strong Scot-EUA type pearl. To obtain the refined flour, milling was carried out in a Bhuler mill (Brabender OHG, Germany) according to method 26-31 of the AACC (2005) and the flour yield (%) was calculated.

The protein content (%) was determined in the flour with the near infrared reflectance analyzer (NIR Feed & Forage 5000) using method 39-00 of the AACC (2005). The equipment was previously calibrated by the Kjeldahl method (Method 46-11[a], AACC, 2005). The sedimentation volume (mL) was obtained by the Zeleny test (Method 56-61A, AACC, 2005) in 3.2 g of flour in the presence of bromophenol blue and isopropyl alcohol. The optimal kneading time (min) was estimated by the mixograph (National Manufacturing Co., Lincoln, NE) using method 54-40A of the AACC (2005) for samples of 10 g of refined flour.

Statistical analysis

The data obtained were subjected to an analysis of variance. The percentage values of the analyzed variables were transformed to logarithm for the analysis. The Pearson correlations were obtained among the variables evaluated, using the GLM procedure (SAS Institute, 2002) and the means were compared using the Tukey test ($p \leq 0.05$).

Results and discussion

Significant differences were found between localities for most of the physical variables of the grain, except for yellow rust and sedimentation volume (Table 1). This is due to the differences in environmental factors between the localities where the genotypes were grown, as reported by De la O-Olan *et al.* (2010). Regarding the genotypes, the differences were for all the physical variables of the grain and the mass, except for the width of the sucked grain. These results are similar to those found by Hortelano-Santa Rosa *et al.* (2016) who indicated that the effect of the genotype is determinant in the physical and grain characteristics of the mass.

Table 1. Mean squares of the analysis of variance for the incidence of yellow rust and industrial quality variables of bread wheat.

FV	GL	RA	GLL	LLL	ALL	GCH	LCH	ACH
Location (L)	1	168.7 ns	444.1**	17.8**	24**	447.7**	6 ns	32.4*
Genotype	5	4023.3**	1921.8**	50.9**	4.4**	1919.4**	57.92**	4.1 ns
Fungicide (F)	1	9918.7**	10395.9**	36.8**	18.5**	10413.5**	8.4 ns	0.1 ns
L*F	1	33.3 ns	298*	18.2**	0.1 ns	301*	3.5 ns	34.4**
L*G	5	228.7**	91.1 ns	1.1 ns	2.4*	90.9 ns	5 ns	12.8*
G*F	5	428.7**	976.2**	5.5**	1.1 ns	974.7**	0.8 ns	5.2 ns
L*G*F	5	88.3 ns	42.7 ns	1.3 ns	0.4 ns	43.6 ns	4.6 ns	1.1 ns
CV		18.8	8.7	1.3	2.4	24.6	3.1	7.1
Error		55.5	41.1	0.8	0.6	40.8	4.5	4.1
FV	GL	PMG	PHL	DG	PH	RH	VS	TA
Location (L)	1	54.2**	27.2**	45.3**	3.9**	25.4*	2.6 ns	3.2**
Genotype	5	50.1**	79.7**	33.9**	1.2**	32.1**	221**	2.7**
Fungicide (F)	1	553.5**	306.5**	149.1**	0.1 ns	209**	73*	0.9*
L*F	1	0.2 ns	1 ns	$2x10^{-2}$ ns	1.2**	0.1 ns	84.1*	0.6 ns
L*G	5	2.2 ns	11.7**	17.8**	0.4*	1.1 ns	70.8**	0.8*
G*F	5	79.7**	23.4**	18**	0.3 ns	31.8**	2.6 ns	0.3 ns
L*G*F	5	9.1*	3.4**	3.3 ns	0.2 ns	7.9 ns	10.5 ns	0.2 ns
CV		4.8	1.8	3.9	3.4	3.6	7.4	15
Error		3.2	1.7	3.2	0.1	5.3	15.1	0.2

*= $p \leq 0.05$; **= $p \leq 0.01$; ns> 0.05; RA= incidence of yellow rust (%); GLL= full grains (%); LLL= length of filled grains (mm); ALL= full grain width (mm); GCH= sucked grains (%); LCH= length of sucked grains (mm); ACH= width of sucked grains (mm); PMG= weight of one thousand grains (g); PHL= hectoliter weight (kg hl^{-1}); DG= grain hardness (%); PH= protein in flour (%); RH= flour yield (%); VS= sedimentation volume (ml); TA= kneading time (min).

For the application (absence of the disease) or not (presence of the disease) of the fungicide, the variables in which no differences were found were for length and width of sucked grains, as well as protein in flour. On the other hand, for the interaction genotype by fungicide differences were observed for the incidence of yellow rust and for most of the physical variables of the grain and flour yield, but not for protein content in flour, sedimentation volume and time of kneading. The above, indicates that in a general way the physical quality of the grain depends on the use or not of the fungicide and the genotype, which agrees with the indicated with Wendale *et al*. (2106).

In the Table 2 shows the Pearson correlations between the incidence of yellow rust in the foliage and the physical variables of the grain and the mass. The presence of yellow rust correlated positively with the percentage of sucked grain and inversely with the weight of a thousand grains and hectoliter weight, which consequently decreased the flour yield. The above is similar to that reported by Vergara-Diaz *et al*. (2015) and Sharma *et al*. (2016) who indicated that the presence of yellow rust correlated negatively with the weight of a thousand grains and disadvantaged the components of grain yield. On the other hand, the flour yield correlated positively with the percentage, length and width of full grains, as well as with the weight of a thousand grains, hectoliter weight and grain hardness.

Table 2. Pearson correlations between industrial quality variables and incidence of yellow rust in bread wheat.

	GLL	LLL	ALL	GCH	LCH	ACH	PMG	PHL	DG	PH	RH	VS	TA
RA	-0.80**	-0.07	-0.2	0.8**	0.08	-0.08	-0.59**	-0.76**	-0.33*	0.18	-0.48**	0.01	0.13
GLL		0.2	0.33*	-1**	-0.11	-0.19	0.77**	0.92**	0.61**	-0.15	0.71**	0.03	-0.2
LLL			0.54**	-0.2	0.73**	-0.15	0.57**	0.14	0.07	-0.38	0.44**	-0.62**	-0.58**
ALL				-0.33*	0.25	0.09	0.64**	0.27	0.53**	0.08	0.49**	-0.43**	-0.48**
GCH					0.11	0.19	-0.77**	-0.92**	-0.61**	0.15	-0.71**	-0.03	0.2
LCH						0.21	0.24	-0.17	-0.21	-0.42**	0.23	-0.61**	-0.48**
ACH							-0.09	-0.23	-0.05	-0.01	-0.11	-0.11	-0.09
PMG								0.72**	0.61**	-0.26	0.73**	-0.39*	-0.41*
PHL									0.52**	-0.15	0.57**	0.1	-0.03
DG										0.17	0.6**	0.08	-0.17
PH											-0.24	0.41**	0.14
RH												-0.34*	-0.45**
VS													0.47**

RA= incidence of yellow rust (%); GLL= full grains (%); LLL= length of filled grains (mm); ALL= full grain width (mm); GCH= sucked grains (%); LCH= length of sucked grains (mm); ACH= width of sucked grains (mm); PMG= weight of one thousand grains (g); PHL= hectoliter weight (kg hl^{-1}); DG= grain hardness (%); PH= protein in flour (%); RH= flour yield; CEN= ashes (%); TC= time of fall (s); VS= sedimentation volume (mL); TA= kneading time (min).

This coincides with Dziki and Laskowski (2004) who reported that grains of higher density were associated with greater flour yield and small grains decreased the extraction of flour. Likewise, it agrees with Dimmock and Gooding (2002) who related the control of foliar diseases with a reduction in the appearance of sucked grains that are associated with low hectoliter weights and consequently low flour extractions.

In the Table 3 shows the comparison of means with and without the application of the fungicide. Where it is observed that the presence of yellow rust disfavored the percentage, length and width of full grains, as well as the weight of a thousand grains and hectoliter weight which reduced the extraction of flour. The above is due to the fact that the incidence of yellow rust diminishes the photosynthetic foliar area and therefore there is less availability of carbohydrates for grain filling, which causes the increase of sucked grains according to that indicated by Robert *et al*. (2005). While with and without the presence of rust, the concentration of protein in flour was not modified, which is similar to that found by Blandino and Ryneri (2009); Devadas *et al*. (2014).

Table 3. Means of incidence of yellow rust and of physical and industrial quality variables of bread wheat produced under temporary, with and without the application of fungicide.

Variables	With fungicide	Without fungicide	DSH
Yellow rust (%)	25.2 b†	54 a	4.5
Full grains (%)	88.8 a	59.4 b	3.8
Length of full grain (mm)	7 a	6.8 b	0.05
Full grain width (mm)	3.5 a	3.3 b	0.05
Suction grain (%)	11.2 b	40.7 a	3.9
Weight of a thousand grains (g)	40.4 a	33.6 b	1
Hectoliter weight (kg hL^{-1})	73.5 a	68.5 b	0.8
Grain hardness (%)	47.8 a	43.5 b	1
Flour yield (%)	67 a	62.2 b	1.5
Flour protein (%)	10.6 a	10.6 a	0.2
Sedimentation volume (mL)	50.9 b	54 a	2.5
Kneading time (min)	2.8 b	3.2 a	0.3

DSH= honest significant difference; †= values with different letter in rows are statistically different.

Experimental lines 1 and 2 showed a lower incidence of yellow rust with and without the application of fungicide, with readings of less than 20%. While for the rest of the genotypes even with the presence of the fungicide their rust readings were greater than 25% (Figure 1a). In this regard, Ramírez *et al*. (2016) they indicated that genetic improvement has accumulated genes in the new experimental lines that give greater tolerance to yellow rust while in commercial varieties their genetic resistance has been overcome as it is in the case of Nana F2007 that presented 90% yellow rust readings in the foliage without the application of fungicide.

Due to the presence of the disease in general in all the genotypes, the percentage of full grains was decreased and the sucked grains increased (Figure 1b and 1c). The length and width of the grains were reduced (Figure 1d, and 1e). However, lines 1 and 2 as well as the Altiplano F2007 variety presented percentages lower than 20%, with and without the presence of the disease, as a result of their greater tolerance to rust than the rest of the genotypes. Contrary behavior was presented by the varieties Don Carlos M2015, Tlaxcala F2000 and Nana F2007 that without the application of fungicide were associated with percentages of sucked grains greater than 40%. But with the use of chemical control of the disease, all genotypes did not exceed 20% of sucked grains (Figure 1b).

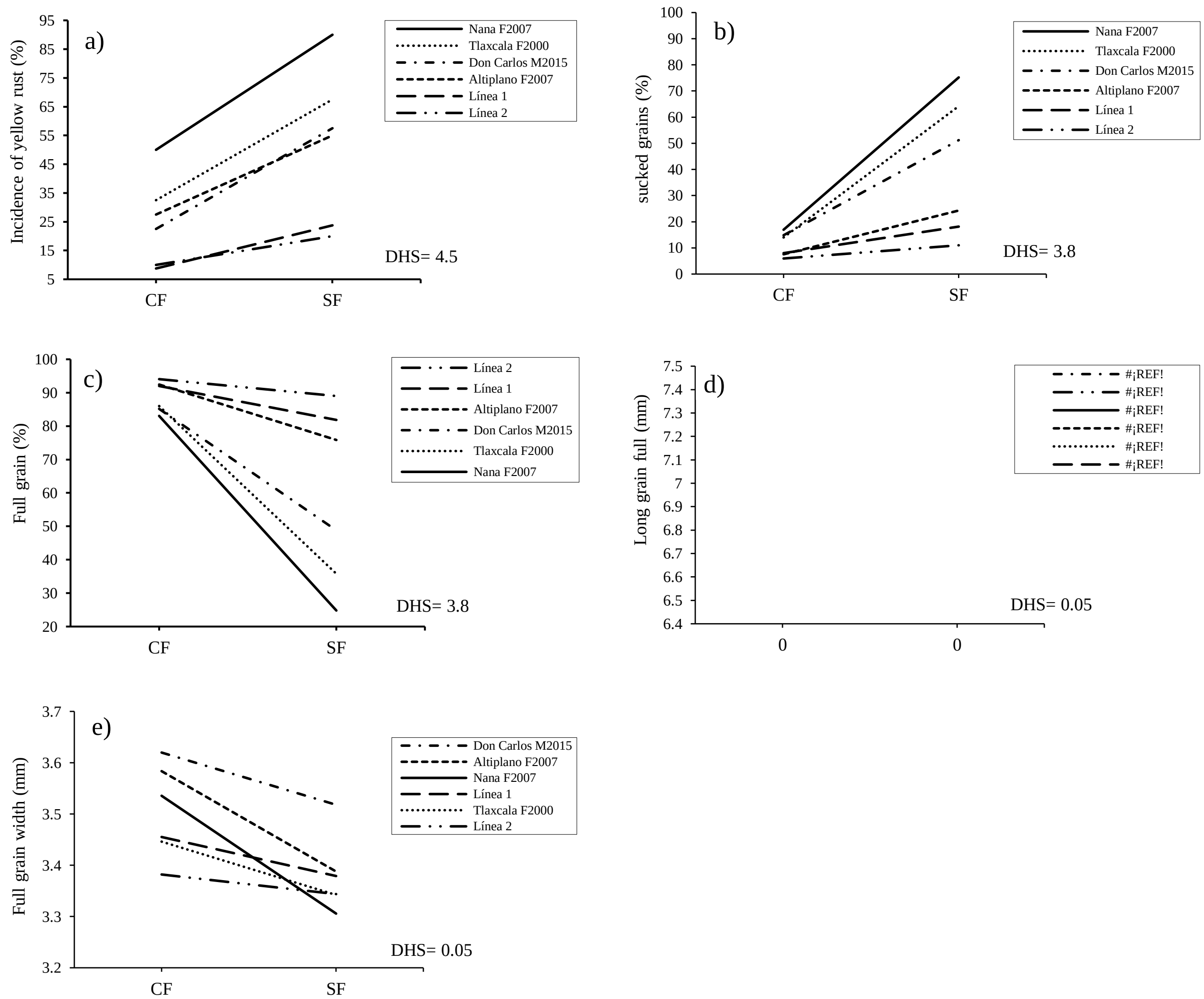

Figure 1. Behavior a) yellow rust incidence; b) percentage of sucked grains; c) percentage of full grains; d) long; and e) wide, of filled grains depending on the application of fungicide in temporary bread wheat. CF and SF= with and without application of fungicide, respectively. Lines 1 and 2= Pamdoly-PABG (C7) and Pamdoly, respectively. DSH= honest significant difference.

This indicates that the decrease in the physical quality of the grain depends in part on the genetic tolerance of the genotype to yellow rust and the application of the fungicide, which agrees with that reported by O'Brien *et al*. (1990); Waqar *et al*. (2018) who indicated that genotypes susceptible to yellow rust increased the presence of sucked grains.

The Nana F2007 variety presented the highest readings of incidence of yellow rust and the highest percentage of sucked grains, without the application of the fungicide, associated with the lowest values of thousand grains weight and hectoliter weight, which agrees with Aktaş *et al*. (2016) who found in genotypes susceptible to yellow rust a high decrease in these variables. Due to the above, in the present investigation, it was not possible to evaluate the flour yield without the application of the fungicide of the Nana F2007 variety.

On the other hand, experimental lines 1 and 2 showed smaller losses in the weight of thousand grains, hectoliter weight and flour yield due to the presence of rust (Figure 2a, b and c). The Altiplano F2007 and Don Carlos M2015 varieties continued to perform this behavior, which reduced the weight of a thousand grains, hectoliter weight and flour yield in a similar way. While the Tlaxcala F2000 variety that showed the lowest values of thousand grains weight and hectoliter weight was reflected in the lowest flour yield of all the genotypes (Figure 2a, b and c). The results of this investigation coincide with what was found by Warechowska *et al*. (2013) who reported that the weight of one thousand grains increased linearly with the hectoliter weight as well as the flour yield percentages.

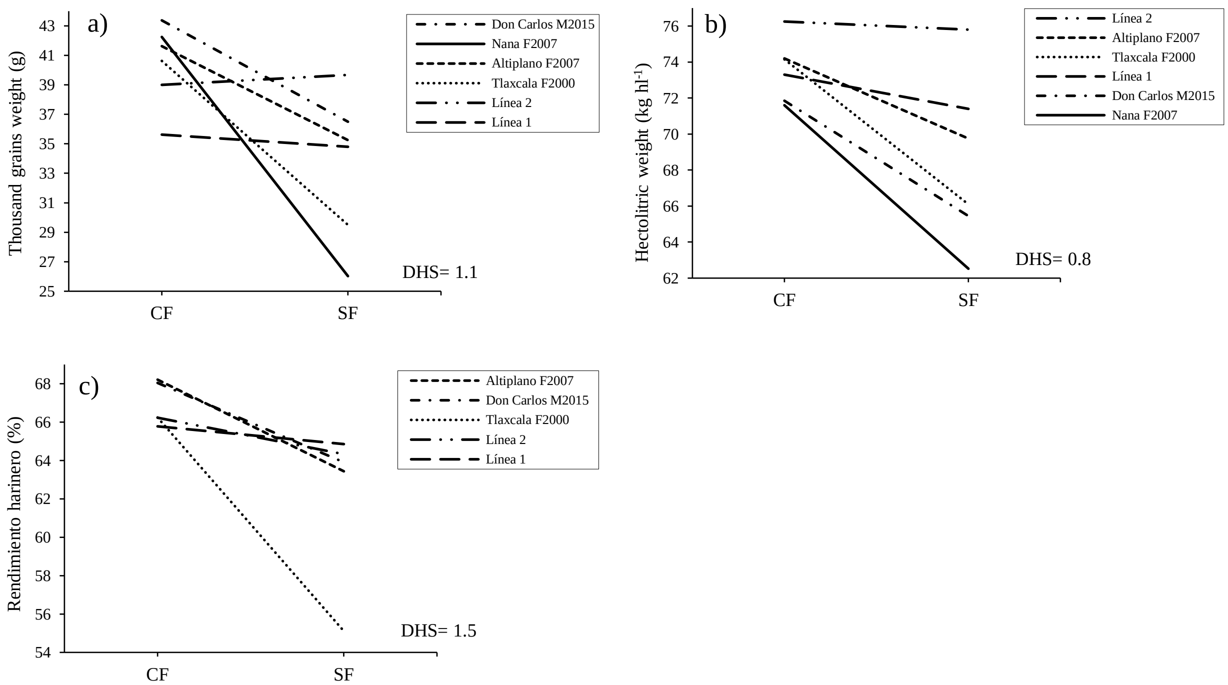

Figure 2. Behavior a) weight of a thousand grains; b) hectoliter weight; and c) flour yield, depending on the application of fungicide in seasonal bread wheat. CF and SF= with and without application of fungicide, respectively. Lines 1 and 2= Pamdoly-PABG (C7) and Pamdoly, respectively. DSH= honest significant difference.

Also agrees with Dziki and Laskowski (2005) who found that very sucked grains reduce the hectoliter weight and the amount of flour during grinding. It is significant to indicate that the varieties Altiplano F2007 and Don Carlos M2015 presented the highest values of flour yield, with the application of fungicide, with respect to experimental lines 1 and 2, which is partly due to their greater length and width of full grains despite having a higher percentage of sucked beans. The above with rope with Dziki and Laskowski (2004) and Cabral *et al*. (2018) who indicated that the grain size and its spherical shape is related to greater extraction of flour. It is important to point out that by using the fungicide the genotypes Altiplano F2007, Don Carlos M2015 and Tlaxcala F2000 were favored in the weight of a thousand grains, hectolitre weight and flour yield. In the case of Don Carlos M2015 and Tlaxcala F2000, the application of the fungicide allowed to obtain values higher than 71 kg ha^{-1} and flour yields higher than 65% (Figure 2a, b and c) which is desirable for the milling industry.

The genotypes Nana F2007, Altiplano F2007 and Tlaxcala F2000 modified their grain texture from semi-soft to semi-hard with the presence of the disease. This behavior is attributed to the presence of sucked grains, which caused lower pearling percentages and manifested as grains with greater hardness. While the lines 1 and 2 as well as the variety Don Carlos M2015 did not present changes in its grain hardness, classified as semi-hard. (Figure 3a). For the case of the percentages of protein in flour, sedimentation volume and mixing time, the experimental lines and the rest of the varieties did not change due to the presence of yellow rust. Only the Tlaxcala F2000 variety showed an increase in the protein content in flour, which is in agreement with that indicated by Fleitas *et al*. (2018) who indicated that the increase or decrease in the concentration of the protein may be due to their level of tolerance to yellow rust.

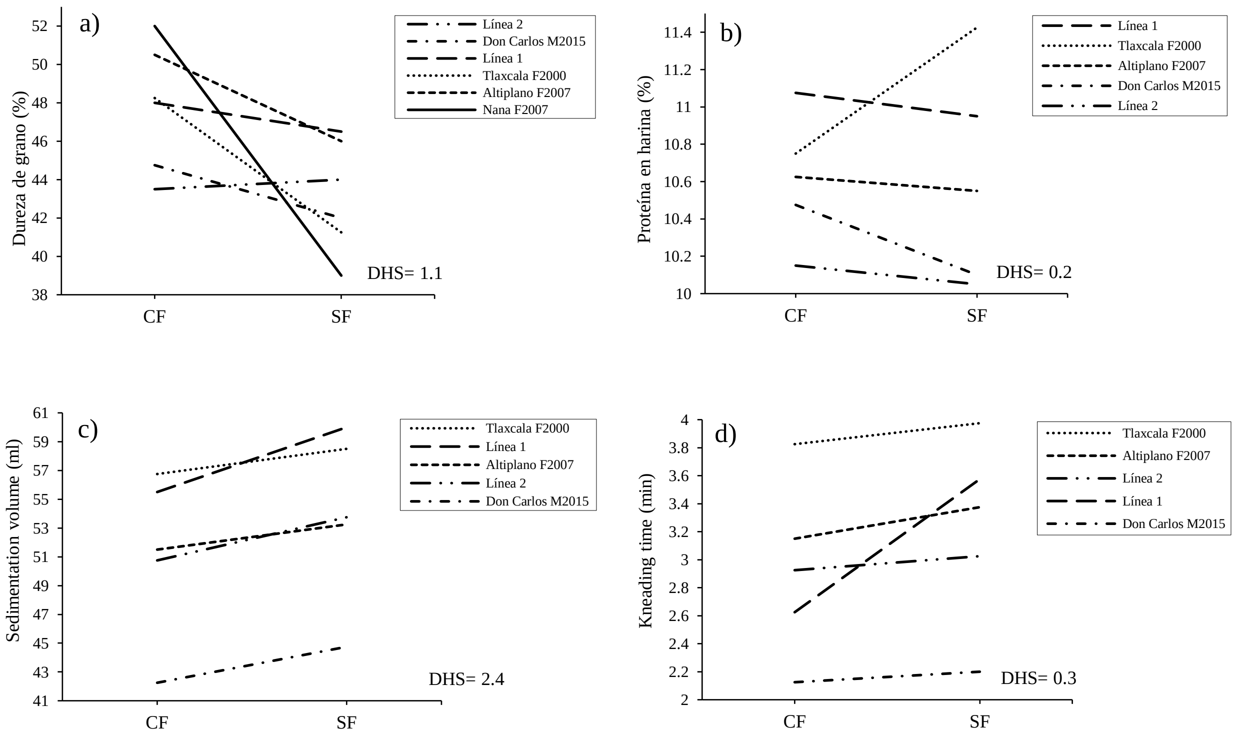

Figure 3. Behavior a) grain hardness; b) protein in flour; c) sedimentation volume; and d) kneading time, depending on the application of fungicide in temporary bread wheat. CF and SF= with and without application of fungicide, respectively. Lines 1 and 2= Pamdoly-PABG (C7) and Pamdoly, respectively. DSH= honest significant difference.

Based on their volume of sedimentation and time of kneading, all genotypes were classified as having a strong mass, with and without the presence of the disease, with the exception of the variety Don Carlos M2015, which showed the lower values of sedimentation volume and shorter kneading times which are characteristic of strong average masses appropriate for the semi-mechanized or artisanal baking industry in Mexico. The characteristics of the mass of the varieties and lines analyzed agree with Villaseñor *et al*. (2017) since these genotypes have been selected for the production of bread for the mechanized industry.

Conclusions

The planting in temporary zones of the varieties Altiplano F2007, Don Carlos M2015 and Tlaxcala F2007 diminishes the losses in the physical quality of the grain and flour yield due to its tolerance to the yellow rust. However, the application of the fungicide for the control of the disease benefits its quality which helps to meet the quality demanded by the milling industry. While to maintain these acceptable characteristics in the Nana F2007 variety, it is essential to apply fungicide to control the rust. On the other hand, the minor losses in the industrial quality of the grain and flour yield in the experimental lines, even with the incidence of yellow rust, indicate that the genetic improvement is a transcendental strategy to guarantee its quality.

In such a way, that the losses in the variables of physical quality of the grain, flour yield and quality of the mass depend on the level of genetic tolerance of each genotype, as well as the chemical control of the yellow rust.

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