Non-2NS blast resistant wheat genotypes evaluated in the Brazilian Cerrado

Natália Forchezato Webber[1], Maurício Antônio de Oliveira Coelho[2], Gisele Abigail Montan Torres[3], Paulo Roberto Cecon[4], Luciano Consoli[3], Carolina Cardoso Deuner[1]*

10.1590/0034-737X202370030011

ABSTRACT

Searching for novel sources of resistance to head blast is essential to strengthen wheat production in the Cerrado´s biome. The objective of this work was to evaluate disease intensity measures and yield for 2NS and non-2NS carriers wheat genotypes with varying heading times in Minas Gerais, Brazil. A total of fourteen wheat genotypes, two susceptible and twelve resistant to head blast, were sown in 2014, 2015, and 2017 at the Sertãozinho Experimental Station of Empresa de Pesquisa Agropecuária de Minas Gerais (Epamig) during three sowing dates without fungicide applications. The experimental design was a randomized complete block with three replicates. Blast incidence, severity, disease index and grain yield were influenced by the cycle of wheat genotypes and the sowing date, with the highest disease intensities and the lowest yields in the earliest sowing date. Blast incidence and disease index correlated negatively with grain yield and positively with percent yield losses. The group of wheat genotypes with higher grain yield (between 2,104.7 and 2,917.8 kg ha^{-1}) and lower yield losses (between 44.3 and 54.8%) includes BR 18 as well as other five that do not carry the 2NS/2AS translocation: BRS Angico, PF 909, BRS 229, Embrapa 27, and CPAC 07340.

Keywords: *Triticum aestivum*; *Magnaporthe oryzae*; brusone; incidence; productivity.

INTRODUCTION

In Brazil, wheat (*Triticum aestivum*) is mainly cultivated in the South region, with Paraná and Rio Grande do Sul states accounting for 87% of national production in 2021 (Conab, 2022). Despite the 23.2% increase of national production compared to 2020, it is estimated that the 7.7 million tons produced will be sufficient to supply 61% of domestic consumption. The Central Brazil region, in the Cerrado biome, is the current agricultural frontier for the expansion of wheat cultivation (Farias *et al.*, 2016). In this region with a hot and dry climate, wheat is produced in both rainfed (higher altitude areas) and irrigated conditions (Cunha *et al.*, 2011). Considering areas of high altitudes, the potential of this region for wheat cultivation is two to three million hectares (Albrecht *et al.*, 2007). However, the availability of wheat cultivars with resistance to wheat head blast is indispensable for strengthen such production.

Magnaporthe oryzae (syn: *Pyricularia oryzae*) is a fungal species that infects more than 50 species of grasses and causes the disease called blast. Different pathotypes are designated depending on the host plant. In wheat, *Magnaporthe oryzae Triticum* (MoT) pathotype causes disease symptoms on all above-ground parts of wheat plants but spike infection is more destructive. The penetration of the pathogen in the rachis prevents the translocation of assim-

Submitted on April 28th, 2022 and accepted on October 24th, 2022.

[1] Universidade de Passo Fundo, Passo Fundo, Rio Grande do Sul, Brazil. natywebber@hotmail.com; carolinadeuner@gmail.com
[2] Empresa de Pesquisa Agropecuária de Minas Gerais, Campo Experimental de Sertãozinho, Patos de Minas, Minas Gerais, Brazil. macoelho62@gmail.com
[3] Embrapa Trigo, Passo Fundo, Rio Grande do Sul, Brazil. gisele.torres@embrapa.br; luciano.consoli@embrapa.br
[4] Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil. cecon@ufv.br
*Corresponding author: gisele.torres@embrapa.br

ilates for grain filling. Grain development is impaired and the spikes become bleached. Disease symptoms are more severe the earlier the infection resulting in small and shriveled grains, with low test weight (Goulart *et al.*, 2007). Losses of up to 100% are reported depending on the susceptibility of wheat cultivars (Kohli *et al.*, 2011).

Blast is present in all wheat producing regions of Brazil and for 30 years it was restricted to countries of South America (Bolivia, Paraguay and Argentina) (Kohli *et al.*, 2011). In 2016, wheat blast was reported in Bangladesh with wheat yield reductions ranging from 5-51% in the affected fields (Islam *et al.*, 2016). Bangladesh is close to Asian countries that rank among the world's top ten wheat producers (China, India, and Pakistan). During the 2017-2018 rainy season, wheat blast symptoms were observed in Zambia, Africa (Tembo *et al.*, 2020). The intercontinental spread of wheat blast poses serious threats to food security since wheat is the staple crop for 40% of world population (Giraldo *et al.*, 2019).

The use of resistant cultivars is the most economic and environmental friendly strategy to control wheat blast. The search for resistant cultivars has been the focus of research on wheat blast and thus far five genes of specific resistance to MoT isolates have been described (Ferreira *et al.*, 2020). In addition to these genes, it was found that the presence of a chromosomal translocation (2NS/2AS) from *Aegilops ventricosa* in wheat confers resistance to the pathogen (Cruz *et al.*, 2016). Resistance sources carrying this translocation have been used in South America and Bangladesh crops to control the disease (Cruppe *et al.*, 2020). However, the high genetic variability of the pathogen and the strong isolate-cultivar interaction are widely known (Maciel *et al.*, 2014). Even the resistance conferred by the 2NS translocation is not so effective faced to new isolates of the pathogen (Cruz & Valent, 2017). Therefore, searching for novel sources of wheat resistance to blast is imperative.

Annually, the Brazilian Wheat and Triticale Research Commission publishes data about the reaction to blast of wheat cultivars indicated for cultivation in the country (RCBPTT, 2020). One hundred seventeen wheat cultivars were currently registered for use in Brazil and for 41 (35%) of them some degree of blast resistance is reported. Nevertheless, no data concerning wheat yield performance under conducive disease conditions is presented. In the context of tropical and subtropical regions of wheat cultivation in Brazil, more than characterize spike reaction it is essential to evaluate crop losses under field conditions. A strong correlation between blast incidence on the spikes and yield loss was found for early cycle genotypes evaluated in a hotspot site for wheat blast (Dianese *et al.*, 2021). In this work, the objective was to assess disease intensity and yield losses for 2NS and non-2NS carriers wheat genotypes with different heading times in the Cerrado of Minas Gerais under conditions of wheat cultivation.

MATERIAL AND METHODS

Field experiments were carried out at the Sertãozinho Experimental Station (-18.52^{o}S, -46.44^{o}W, and 932 m above sea level) of Empresa de Pesquisa Agropecuária de Minas Gerais (Epamig) in the municipality of Patos de Minas, in the state of Minas Gerais, Brazil, along three years of cultivation: 2014, 2015 and 2017. Three sowing dates were considered for 2014 (March 10th, April 4th and April 29th) and for 2015 (February 26th, March 24th and April 20th) and only one for 2017 (February 24th). Eleven wheat genotypes previously characterized under wheat blast hotspots conditions were evaluated: BRS 229, BRS Angico, CBFusarium ENT014, CPAC 07340, CPAC 07434, Embrapa 27, Huanca, PF 909, Safira, Thatcher, and Trigo Chapéu (Table 1). These genotypes were selected due to their lower blast incidences than Trigo BR 18-Terena, hereinafter called BR 18. For comparison of disease and yield data, one resistant (BR 18) and two susceptible checks (Anahuac 75 and BRS 209) were also sown. Among the 12 resistant genotypes, two of them (CBFusarium ENT014 and CPAC 07434) possess the 2NS/2AS translocation. Three classes of cycle were represented by wheat genotypes with different heading times (in days): early (from 54 to 62 days), medium (from 66 to 73 days) and late (from 82 to 86 days). Each experimental unit consisted of five 4-m row, which was replicated three times per genotype. The distance between rows was 0.2 m. A useful 1.8m^2 area per plot was marked and included the three central rows, with the elimination of 0.5 m at each end line. The fertilization was made with 350 kg ha^{-1} NPK (8-28-16) before planting, and 80 kg ha^{-1} N as urea were applied at 25 days after sowing. Plots were weekly irrigated at a 10-mm depth, except when rainfall occurred. Experiments were harvested from 77 until 140 days after sowing for date 1, from 90 until 143 days after sowing for date 2, and from 94 until 142 days after sowing for date 3.

Table 1: Wheat (*Triticum aestivum*) genotypes analyzed in this study

Wheat genotype	2NS/2AS translocation	Heading time (days)	Cycle	Pedigree	Year of release	Country of origin
Resistant						
BR 18	absent	61	early	No information	1986	Brazil
BRS 229	absent	72	medium	Embrapa 27*3//BR 35/Buck Poncho	2004	Brazil
BRS Angico	absent	68	medium	PF 87107/2*IAC 13	2002	Brazil
CBFusarium ENT014	present	73	medium	No information	-	Mexico
CPAC 07340	absent	63	early	CPAC 96306/CPAC 9985	-	Brazil
CPAC 07434	present	60	early	Taurum/BRS 254	-	Brazil
Embrapa 27	absent	67	medium	PF 83743/5/PF 83182/4/CNT 10*4//Lagoa Vermelha*5/ Agatha/3/Londrina*4/Agent// Londrina*3/Nyu Bay	1994	Brazil
Huanca	absent	55	early	Frocor/3/McMurachy/Kenta-na// Yaqui-50/4/Maria-Esco-bar/MN2698/5/Maria-Escobar	1973	Peru
PF 909	absent	60	early	PF 83743/PF 82252//PF 84433/ BR 35	-	Brazil
Safira	absent	74	medium	PF9099/OR-1//Granito	2003	Brazil
Thatcher	absent	83	late	Marquis/Iumillo(durum)// Marquis/ Kanred	1934	United States of America
Trigo Chapéu	absent	86	late	No information	-	-
Susceptible						
Anahuac 75	absent	62	early	II-12300//Lerma-Rojo-64/II-8156/3/ Norteno-67	1975	Mexico
BRS 209	absent	71	medium	Jupateco 73/Embrapa 16	2002	Brazil

The experimental design was a randomized complete block with 14 genotypes and three replicates. Blast incidence, severity, disease index and grain yield were evaluated. For each wheat genotype, 100 spikes were randomly collected from the useful area per plot. Blast incidence was calculated as the proportion of spikes with bleaching symptoms and blast severity was calculated as the average percentage of bleached spikelets, including spikes with zero severity. Thereafter spikes with no symptoms were also accounted to the final severity of the plot. The incidence and severity values were then used to estimate the blast index, which is the product of incidence and severity (Juliana *et al.*, 2020). Spikes were threshed, grains were weighed, and plot yield was estimated in g m^{-2} and then converted to kg ha^{-1}. Data obtained in 2014 and 2015 were analyzed considering cycle and sowing date as sources of variation, and means were compared by Tukey´s test at 5% significance. Subsequently, wheat genotypes cultivated in the first sowing date of all three years (2014, 2015 and 2017) were compared by Scott-Knott procedure at 5% significance to evaluate their resistance to the disease. For each wheat genotype, yield losses of the first sowing date were estimated in terms of percent yield reduction relative to the highest yielding sowing date. Pearson correlation analysis was used to evaluate relationships between disease variables, yield and yield losses during the first sowing date experiments. Statistical analyses were performed using the SAEG software (Universidade Federal de Viçosa, Viçosa, MG, Brazil).

RESULTS AND DISCUSSION

All variables - blast incidence, severity, disease index and grain yield were affected by the length of the cycle and sowing date, as well as their interaction. Despite the interaction observed, the results show the occurrence of disease with the same magnitude regardless of the cultivar cycle. In late sowing dates, reduction of disease and yield losses were observed. For all classes of crop cycle, blast incidence was highest at the earliest sowing date (Table 2). Blast incidence observed in sowing date 2 was significantly higher than that of sowing date 3 for early genotypes, but not for medium and late ones. Considering blast severity values, there was no difference between sowing date 1 and 2 for genotypes with early heading time. For medium and late cycle genotypes, significant differences were observed among blast severity of sowing dates 1, 2 and 3. Blast disease index varied similarly to observed for blast incidence with higher values in sowing date 1. For a different group of wheat genotypes, higher disease intensities were also observed upon earlier sowing (Coelho *et al.*, 2016). Grain yield was higher at sowing date 3 for genotypes with early and medium cycles. For the latter, there was no difference between dates 2 and 3. For late genotypes, productivity at date 2 was higher but not significantly different to date 3, and means of date 3 and 1 did not differ statistically. Differences in grain yield upon different sowing dates are the result of disease intensity influence and of adaptability of wheat genotypes analyzed to this region of cultivation in Brazil.

Table 2: Mean blast incidence, blast severity, disease index, and grain yield for wheat (*Triticum aestivum*) genotypes with different cycles in three sowing dates in 2014 and 2015

Variable	Sowing date	Cycle		
		Early	Medium	Late
Incidence (%)	1	25.0 a A	18.4 a B	30.4 a A
	2	6.4 b A	3.2 b A	6.1 b A
	3	1.1 c A	0.3 b A	0.9 b A
Severity (%)	1	48.9 a B	46.2 a B	59.0 a A
	2	46.8 a A	36.3 b B	45.1 b A
	3	18.3 b B	5.8 c C	26.3 c A
Disease Index (%)	1	12.2 a B	8.6 a C	17.5 a A
	2	2.9 b A	1.5 b A	2.7 b A
	3	0.6 c A	0.1 b A	0.5 b A
Grain Yield (kg ha^{-1})	1	1,706.3 c A	2,152.3 b A	824.4 b B
	2	3,697.3 b A	3,721.8 a A	2,053.8 a B
	3	4,416.3 a A	4,120.2 a A	1,423.8 ab B

Means followed by equal capital letters in the rows and equal lowercase letters in the columns, for each trait, do not differ by the Tukey´s test, at 5% significance.

In the sowing date 1, blast incidence of wheat genotypes with medium cycle was significantly lower than that of early and late ones (Table 2). The establishment of the disease depends on temperature and wetting period (Cardoso *et al.*, 2008). It is possible that weather conditions less favorable for the disease occurred during the period comprised between 66 and 73 days after sowing date 1 (the heading time for genotypes with medium cycle). On the other hand, for sowing dates 2 and 3, blast incidences are similar between genotypes with different heading classes. During sowing dates 1 and 3, the highest blast severities were observed for wheat genotypes with late heading. This could be explained by the longer exposure time of these genotypes to field conditions, allowing greater progress of the spike bleaching and also new infections on non-infected heads. Considering blast disease index, wheat genotypes with different cycles could be clearly discriminated only in sowing date 1; significantly greater values were observed for genotypes with late heading > early heading > medium heading. For all three sowing dates, grain yield data of early and medium heading wheat genotypes were significantly higher than that observed for late heading genotypes. Based on these results, it can be recommended for this region the use of wheat genotypes with early or medium heading that have globally lower blast intensity and higher grain yields.

Data from sowing date 1 of the three years of evaluation (2014, 2015 and 2017) were considered for joint ANOVA. For all variables analyzed, there was a significant effect of the wheat genotype ($p \leq 0.01$). The comparison of means of genotypes by the Scott-Knott test at 5% significance is presented in Table 3. Anahuac 75 presented the highest blast incidence (63.5%), blast severity (65.8%) and disease index (43.9). This wheat cultivar is widely known to be susceptible to a large number of isolates of the pathogen (Arruda *et al.*, 2005). Its cultivation in Brazil was abandoned in 90s due to wheat blast. BRS 209, Thatcher and Huanca, presenting blast incidences values of 52.6%, 48.7% and 38.4%, respectively, formed a second group of wheat cultivars (group b). The former is also highly susceptible to wheat blast (Ferreira *et al.*, 2020). Thatcher and Huanca did not confirm in Patos de Minas-MG the resistance pattern observed in previous experiments under hotspots conditions. These two groups (a and b) of susceptible genotypes had blast incidence means from 38.4 to 63.5%, contrasting to experiments carried out in Dourados and in Indápolis (MS, Brazil) where for the most susceptible genotypes blast incidence was around 95-98% (Goulart *et al.*, 2007). In the present work, blast incidences ranging from 9.3 to 27.4% were observed for the remaining 10 wheat genotypes. This group (c) encompass important sources of field resistance to wheat blast.

Table 3: Mean blast incidence, blast severity, disease index, grain yield and yield losses for fourteen wheat (*Triticum aestivum*) genotypes in the first sowing date in three years of cultivation (2014, 2015 and 2017)

Wheat genotype	**Incidence (%)**	**Severity (%)**	**Disease index (%)**	**Grain yield (kg ha^{-1})**	**Yield losses (%)**
Trigo Chapéu	27.0 c	57.7 a	14.5 c	1,588.5 b	33.3 b
Huanca	38.4 b	50.9 a	19.0 c	1,610.2 b	43.1 b
BRS Angico	16.4 c	50.4 a	8.1 c	2,789.3 a	44.3 b
PF 909	14.2 c	51.7 a	7.4 c	2,917.8 a	45.3 b
BRS 229	9.4 c	49.1 a	5.0 c	2,567.6 a	45.7 b
CBFusarium ENT014	14.7 c	41.2 b	5.7 c	2,104.7 a	48.6 b
CPAC 07434	27.4 c	47.8 a	12.9 c	2,681.1 a	48.8 b
Embrapa 27	14.7 c	48.6 a	7.7 c	2,584.0 a	48.9 b
CPAC 07340	20.8 c	42.8 b	9.8 c	2,527.7 a	54.4 b
BR 18	20.6 c	53.8 a	10.7 c	2,347.6 a	54.8 b
Safira	9.3 c	32.3 b	4.1 c	1,953.4 a	62.9 a
Anahuac 75	63.5 a	65.8 a	43.9 a	1,220.9 b	69.7 a
BRS 209	52.6 b	43.8 b	24.5 b	701.3 c	76.9 a
Thatcher	48.7 b	55.5 a	26.9 b	392.7 c	79.2 a

Means followed by equal letters, in the columns, belong to the same group by the Scott-Knott test, at 5% significance.

Greater differences among genotypes were observed for blast incidence rather than for blast severity to which two groups of means were identified (Table 3). Ten genotypes had higher values of severity ranging from 47.8 to 65.8% (group a). Both susceptible (Anahuac 75) and resistant (BR 18) checks were in this same group. Therefore, we postulate that despite the reduced incidence BR 18 presents lower resistance to spread of the pathogen in the spike tissues. After a successful infection, further colonization (and probably progress of blast severity) can continue even in conditions above or below the optimum for the pathogen (Cardoso *et al.*, 2008). In contrast to our observation, Rios *et al.* (2016) reported that the genetic resistance of BR 18 likely affected disease severity.

Under the conditions of the present work, lower blast severities were observed for four genotypes: Safira (32.3%), CBFusarium ENT014 (41,2%), CPAC 07340 (42.8%) and BRS 209 (43.8%). In contrast, under controlled environmental conditions, CBFusarium ENT014 showed significantly lower blast severity than BRS 209 (Ferreira *et al.*, 2020). Upon inoculation, the differential reaction of wheat genotypes cannot be evaluated through incidence because every inoculated spike showed bleaching symptoms. On the other hand, severity levels reveal which genotypes present mechanisms to restrain pathogen colonization (Ferreira *et al.*, 2020). Dianese *et al.* (2021) infer that upon field prone conditions to wheat blast, once a spike is infected by MoT blast severity on that spike will generally be very high.

Anahuac 75 showed the highest blast disease index (43.9) which was significantly different from all other genotypes. The lowest disease indexes were observed for eleven genotypes: Safira (4.1), BRS 229 (5.0), CBFusarium ENT014 (5.7), PF 909 (7.4), Embrapa 27 (7.7), BRS Angico (8.1), CPAC 07340 (9.8), BR 18 (10.7), CPAC 07434 (12.9), Trigo Chapéu (14.5) and Huanca (19.0) (Table 3). Juliana *et al.* (2020) considered highly resistant wheat lines having mean blast indices less than 10. This is the case for seven of the cited eleven genotypes. Interestingly, six (Safira, BRS 229, PF 909, Embrapa 27, BRS Angico and CPAC 07340) out of these 11 genotypes (54.5%) are non-2NS carriers while in field trials in Bolivia and Bangladesh, 93.8% of the lines without the 2NS translocation had mean blast indices greater than 30 (Juliana *et al.*, 2020).

Nine of the 14 genotypes evaluated, including BR 18, presented the highest yields varying between 1,953.4 (Safira) and 2,917.8 kg ha^{-1} (PF 909). These values are close to the averages obtained in 2021 in the state of Minas Gerais (2,342 kg ha^{-1}) and in Brazil (2,803 kg ha^{-1}) (Conab, 2022). Under favorable climatic conditions to blast occurrence, similar mean yield (2,208 kg ha^{-1}) was found for BR 18 (Rios *et al.*, 2016).

Crop losses may be expressed in absolute terms (kg ha^{-1}) or in relative terms (loss in %). The FAO definition of yield loss is the difference between the attainable yield (determined by the genotype in a specific environment) and the actual yield, which is actually harvested (Savary *et al.*, 2012). In the present study, yield losses were estimated in terms of percent yield reduction relative to sowing date with the highest yield, for each wheat genotype. Although few results are described comparing yield losses of varieties with different resistance levels, this trait is important to identify tolerance mechanisms (Shankar *et al.*, 2021). The lowest yield losses varied between 33.3 and 54.8% and were observed for BR 18 and other nine genotypes (group b, Table 3). In Mato Grosso do Sul damages to yield oscillated from 10.5 to 13% under natural infection (Goulart *et al.*, 2007). However, considering a highly susceptible wheat cultivar in the same region, yield reduction attained 51% (Goulart & Paiva, 2000). We can conclude that environmental conditions in Patos de Minas were more favorable for the development of the disease than they were in Mato Grosso do Sul.

The highest yield losses varied between 62.9 and 79.2% (group a, mean of 72.2%, Table 3) and are similar to that ranging from 62.8 and 80.1% found for a different set of wheat genotypes evaluated (Coelho *et al.*, 2016). For localities where blast is not endemic, the occurrence of the disease depends on inoculations (Rios *et al.*, 2016). The analysis of four wheat genotypes with different levels of resistance, upon inoculation, revealed yield reductions from 19 to 42% (Gomes *et al.*, 2017). In the present work, most (71.4%) of the wheat genotypes evaluated (Trigo Chapéu, Huanca, BRS Angico, PF 909, BRS 229, CBFusarium ENT014, CPAC 07434, Embrapa 27, CPAC 07340, and BR 18) presented lower reductions of productivity (mean of 46.7%, Table 3). It is possible to estimate that their cultivation accounts to prevent a mean of 25.5% of yield losses. In the present work, no fungicide was applied to the experiments. However, based on Rios *et al.* (2017) we can infer obtaining even higher yields with the use of fungicide applications to control the disease on these resistant wheat cultivars. The authors reported both strategies combined reducing the negative effects of the disease on wheat physiology and increasing photosynthetic performance (Rios *et al.*, 2017).

Correlation between blast incidence and severity was moderate but significant (0.55) (Table 4). The calculation of a blast disease index search to estimate the effect of both parameters of quantification of the disease, incidence and severity. Blast index showed moderate to high correlations with severity (0.66) and with incidence (0.97). Grain yield was negatively correlated to incidence (-0.81) and disease index (-0.73). In their turn, yield losses were positively correlated to blast incidence (0.63) and disease index (0.59) but negatively to grain yield (-0.70). In the same municipality, similar results were obtained by Coelho *et al.* (2016). Under blast hotspot conditions, a positive correlation between yield losses and blast incidence was also observed for early cycle genotypes (Dianese *et al.*, 2021). Actually, yield impacts due to the disease depend on the resistance of the host plant, on the environmental conditions and even on the pathogen populations, which tend to be diverse in different regions (Maciel *et al.*, 2014). Mean disease index values varied with similar ranges in Brazil and Bolivia (Cruz *et al.*, 2019). Nonetheless, under high pressure of disease, penalties to yields are higher in Brazil (Cruz *et al.*, 2019). The significance of these correlations varied with different wheat genotypes (Gomes *et al.*, 2017) but they are proven to be significant for wheat genotypes with different heading timing under the conditions of the present work (Table 4). In field trials, besides being laborious the estimation of blast severity is dispensable since as incidence as disease index showed significant negative correlations to yield losses. Therefore, blast incidence can be used as the parameter for evaluation of wheat reaction to the disease.

Table 4: Coefficients of Pearson´s correlation between blast incidence, blast severity, disease index, grain yield and yield losses for fourteen wheat (*Triticum aestivum*) genotypes in the first sowing date in three years of cultivation (2014, 2015 and 2017)

	Incidence	Severity	Disease index	Grain yield	Yield losses
Incidence	-	0.55*	0.97***	-0.81***	0.63*
Severity		-	0.66*	-0.24	-0.02
Disease index			-	-0.73**	0.59*
Grain yield				-	-0.70**
Yield losses					-

*, **, *** Significant by the t test, at 5%, 1% and 1°/oo probability.

It is noteworthy that despite Safira had the lowest values for the three disease variables evaluated, it presented one of the highest yield losses (62.9%) showing no significant difference for the yield reduction of the most susceptible genotypes Anahuac 75, BRS 209 and Thatcher (Table 3). These data indicate that Safira did not show any tolerance to the disease. Unlike this result, Dianese *et al.* (2021) identified wheat tolerant genotypes with minor yield losses (mean of 1.5%) having mean blast incidence of 71.5%. There are few reports of the presence of blast tolerance mechanisms in wheat. However, these results can contribute to both new studies to unravel the genetic basis of wheat blast resistance and breeding programs, including yield losses evaluation in the selection process with traits related to disease quantification.

The 2NS/2AS translocation-based lines are currently used as sources of blast resistance in South America countries and in Bangladesh (Cruppe *et al.*, 2020). Besides the variability of resistance levels conferred by this translocation, their solely use can risk to select more aggressive races of the pathogen. Though finding novel sources of blast resistance is imperative (Cruz & Valent, 2017; Juliana *et al.*, 2020; Dianese *et al.*, 2021; Juliana *et al.*, 2022). Cruppe *et al.* (2020) evaluated over 780 accessions searching for identifying non-2NS sources of resistance to wheat blast, and only 1% of them was characterized as resistant or moderately resistant to the pathogen. However, no data about grain yield was obtained (Cruppe *et al.*, 2020). The present work identified wheat genotypes with reduced blast intensity and also reduced yield losses upon high blast pressure in Minas Gerais State (located at Cerrados region) where wheat blast is endemic. Interestingly, most of the wheat genotypes with lower losses had the highest grain yields under these conducive conditions for the disease (Table 3). Apart from CBFusarium ENT014 and CPAC 07434, that have the 2NS translocation, the group with higher grain yield and lower yield losses includes BR 18 as other five genotypes that do not carry the 2NS/2AS translocation: BRS Angico, PF 909, BRS 229, Embrapa 27, and CPAC 07340. All these wheat genotypes are good options for breeding programs to improve both reaction to the disease and grain yield performance.

CONCLUSIONS

Regardless of the heading time of the wheat genotype, blast intensity is higher and grain yield is lower in the first sowing date.

Blast incidence and disease index showed a significant negative correlation with grain yield, and a positive correlation with yield losses.

Associated with blast incidence, yield losses is an important trait to identify mechanisms of tolerance to wheat blast.

Six wheat genotypes without the 2NS translocation (BR 18, BRS Angico, PF 909, BRS 229, Embrapa 27 and CPAC 07340) showed the highest grain yields and the lowest yield losses similar to those of the two genotypes (CBFusarium ENT014 and CPAC 07434) carrying the 2NS translocation, known as the major source of wheat blast resistance.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors wish to thank the Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG) and the Empresa Brasileira de Pesquisa Agropecuária (Embrapa, projects 02.08.01.006.00.00 and 02.11.08.004.00.00) for financial support, and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) by the scholarship awarded to NFW (88887.372512/2019-00).

The authors declare there is no conflict of interest in the execution and publishing this study.

REFERENCES

Albrecht JC, Ribeiro Junior WQ & Silva MS (2007) Cultivares de trigo para o Cerrado. In: Faleiro FG & De Sousa E dos S (Eds.) Pesquisa, desenvolvimento e inovação para o Cerrado. Planaltina, Embrapa Cerrados. p.61-68.

Arruda MA, Bueno CR, Zamprogno KC, Lavorenti NA & Urashima AS (2005) Reação do trigo à *Magnaporthe grisea* nos diferentes estádios de desenvolvimento. Fitopatologia Brasileira, 30:121-126.

Cardoso CAA, Reis EM & Moreira EN (2008) Development of a warning system for wheat blast caused by *Pyricularia grisea*. Summa Phytopathologica, 34:216-221.

Coelho MA de O, Torres GAM, Cecon PR & Santana FM (2016) Sowing date reduces the incidence of wheat blast disease. Pesquisa Agropecuária Brasileira, 51:631-637.

Conab - Companhia Nacional de Abastecimento (2022) Tabela de dados - Produção e balanço de oferta e demanda de grãos. Março 2022. Available at: <https://www.conab.gov.br/info-agro/safras/graos>. Accessed on: Mar 30th 2022.

Cruppe G, Cruz CD, Peterson G, Pedley K, Asif M, Fritz A, Calderon L, Da Silva CL, Todd T, Kuhnem P, Singh PK, Singh RP, Braun H-J, Barma NCD & Valent B (2020) Novel sources of wheat head blast resistance in modern breeding lines and wheat wild relatives. Plant Disease, 104:35-43.

Cruz CD & Valent B (2017) Wheat blast disease: Danger on the move. Tropical Plant Pathology, 42:210-222.

Cruz CD, Peterson GL, Bockus WW, Kankanala P, Dubcovsky J, Jordan KW, Akhunov E, Chumley F, Baldelomar FD & Valent B (2016) The 2NS translocation from *Aegilops ventricosa* confers resistance to the *Triticum* pathotype of *Magnaporthe oryzae*. Crop Science, 56:990-1000.

Cruz CD, Santana FM, Todd TC, Maciel JLN, Kiyuna J, Baldelomar DF, Cruz AP, Lau D, Seixas CS, Goulart ACP, Sussel AA, Schipanski CA, Chagas DF, Coelho M, Montecelli TDN, Utiamada C, Custódio AP, Rivadeneira MG, Bockus WW & Valent B (2019) Multi-environment assessment of fungicide performance for managing wheat head blast (WHB) in Brazil and Bolivia. Tropical Plant Pathology, 44:183-191.

Cunha GR da, Pasinato A, Pimentel MBM, Haas JC, Maluf JRT, Pires JLF, Dalmago GA & Santi A (2011) Regiões para trigo no Brasil: ensaios de VCU, zoneamento agrícola e época de semeadura. In: Pires JLF, Vargas L & Cunha GR da (Eds.) Trigo no Brasil: bases para produção competitiva e sustentável. Passo Fundo, Embrapa Trigo. p.27-40.

Dianese A de C, Zacaroni AB, Souza BCP de, Pagani APS, Pinheiro NO, Gomes EM de C, Torres GAM, Consoli L & Café-Filho AC (2021) Evaluation of wheat genotypes for field resistance to wheat blast caused by *Magnaporthe oryzae* pathotype *Triticum* (MoT) and correlation between yield loss and disease incidence in the Brazilian Cerrado. Euphytica, 217:84.

Farias AR, Mingoti R, Holler WA, Spadotto CA, Lovisi Filho E, De Mori C, Cunha GR da, Dossa AA & Só e Silva M (2016) Potencial de produção de trigo no Brasil a partir de diferentes cenários de expansão da área de cultivo. Passo Fundo, Embrapa Trigo. 40p. (Boletim de pesquisa e desenvolvimento online, 85).

Ferreira JR, Torres GAM, Consoli L, Binneck E, Camilotti GA, Scagliusi SMM, Deuner CC, Dianese A de C, Goulart ACP, Seixas CDS & Coelho MA de O (2020) Genetic and molecular basis of wheat-*Magnaporthe oryzae Triticum* interaction. In: Kumar S, Kashyap PL & Singh GP (Eds.) Wheat blast. Boca Raton, CRC Press. p.69-104.

Giraldo P, Benavente E, Manzano-Agugliaro F & Gimenez E (2019) Worldwide research trends on wheat and barley: a bibliometric comparative analysis. Agronomy, 9:352.

Gomes DP, Rocha VS, Pereira OL & Souza MAD (2017) Damage of wheat blast on the productivity and quality of seeds as a function of the initial inoculum in the field. Journal of Seed Science, 39:66-74.

Goulart ACP & Paiva FA (2000) Perdas no rendimento de grãos de trigo causadas por *Pyricularia grisea*, nos anos de 1991 e 1992, no Mato Grosso do Sul. Summa Phytopathologica, 26:279-282.

Goulart ACP, Sousa PG & Urashima AS (2007) Danos em trigo causados pela infecção de *Pyricularia grisea*. Summa Phytopathologica, 33:358-363.

Islam MT, Croll D, Gladieux P, Soanes DM, Persoons A, Bhattacharjee P, Hossain SMd, Gupta DR, Rahman MdM, Mahboob MG, Cook N, Salam MU, Surovy MZ, Sancho VB, Maciel JLN, Nhani Júnior A, Castroagudín VL, Reges JT de A, Ceresini PC, Ravel S, Kellner R, Fournier E, Tharreau D, Lebrun M-H, McDonald BA, Stitt T, Swan D, Talbot NJ, Saunders DGO, Win J & Kamoun S (2016) Emergence of wheat blast in Bangladesh was caused by a South American lineage of *Magnaporthe oryzae*. BMC Biology, 14:84.

Juliana P, He S, Kabir MR, Roy KK, Anwar MdB, Marza F, Poland J, Shretha S, Singh RP & Singh PK (2020) Genome-wide association mapping for wheat blast resistance in CIMMYT´s international screening nurseries evaluated in Bolivia and Bangladesh. Scientific Reports, 10:15972.

Juliana P, He X, Marza F, Islam R, Anwar B, Poland J, Shrestha S, Singh GP, Chawade A, Joshi AK, Singh RV & Singh PK (2022) Genomic selection for wheat blast in a diversity panel, breeding panel and full-sibs panel. Frontiers in Plant Science, 12:745379.

Kohli MM, Mehta YR, Guzman E, De Viedma L & Cubilla LE (2011) *Pyricularia* blast–a threat to wheat cultivation. Czech Journal of Genetics and Plant Breeding, 47:S130-S134.

Maciel JLN, Ceresini PC, Castroagudin VL, Zala M, Kema GH & McDonald BA (2014) Population structure and pathotype diversity of the wheat blast pathogen *Magnaporthe oryzae* 25 years after its emergence in Brazil. Phytopathology, 104:95-107.

RCBPTT - Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale (2020) Informações técnicas para trigo e triticale - safra 2020. Passo Fundo, Biotrigo Genética. 255p.

Rios JA, Rios VS, Paul PA, Souza MA, Araujo L & Rodrigues FA (2016) Fungicide and cultivar effects on the development and temporal progress of wheat blast under field conditions. Crop Protection, 89:52-160.

Rios JA, Rios VS, Paul PA, Souza MA, Neto LBMC & Rodrigues FA (2017) Effects of blast on components of wheat physiology and grain yield as influenced by fungicide treatment and host resistance. Plant Pathology, 66:877-889.

Savary S, Ficke A, Aubertot JN & Hollier C (2012) Crop losses due to diseases and their implications for global food production losses and food security. Food Security, 4:519-537.

Shankar M, Reeves K, Bradley J, Varischetti R & Loughman R (2021) Effect of varietal resistance on the yield loss function of wheat to nodorum blotch. Plant Pathology, 70:745-759.

Tembo B, Mulenga RM, Sichilima S, M'Siska KK, Mwale M, Chikoti PC, Singh PK, He X, Pedley KF, Peterson GL, Singh RP & Braun HJ (2020) Detection and characterization of fungus (*Magnaporthe oryzae* pathotype *Triticum*) causing wheat blast disease on rain-fed grown wheat (*Triticum aestivum* L.) in Zambia. PLOS ONE, 15:e0238724.