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Potential of $F_{3:4}$ segregating wheat populations for tolerance to heat stress

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ABSTRACT

Heat is one of the major abiotic stresses that affect wheat yield and quality in many parts of the world. To overcome this problem, the development of heat tolerant cultivars has been shown to be one of the main targets of breeding programs, especially for the conditions of Central Brazil. The present study was developed with objective of identifying promising populations for tolerance to heat stress, in order to obtain lines adapted to the conditions of Central Brazil. The experiment was carried out in the summer of 2011 in Coimbra/MG where 36 segregating populations with different numbers of families per population were evaluated in an augmented block design, determining the cycle, plant height and grain yield. Genetic variability for heat tolerance was observed among the wheat populations. The vegetative development stage of wheat was more sensitive to the effect of heat stress. The most promising segregating populations were IAC364/BRS207, IAC24/Aliança IAC24/Pioneiro that associated high yield with a large number of families selected among the most productive, demonstrating the possibility of selecting heat stress-tolerant lines.

Keywords: *Triticum aestivum* L., abiotic stress, temperature, selection gains.

Potencial de populações segregantes $F_{3:4}$ de trigo quanto à tolerância ao estresse de calor

RESUMO

O calor é um dos principais estresses abióticos que afetam o rendimento e qualidade do trigo em muitas partes do mundo. Para contornar este problema, o desenvolvimento de cultivares tolerantes ao calor vem sendo uma das principais metas dos programas de melhoramento, especialmente para as condições do Brasil Central. O presente trabalho foi desenvolvido com o objetivo de identificar populações promissoras para tolerância ao estresse de calor, visando obtenção de linhagens adaptadas às condições do Brasil Central. O experimento foi conduzido no verão de 2011 em Coimbra/MG, onde foram avaliadas 36 populações segregantes com número variado de famílias por população em delineamento de blocos aumentados, determinando o ciclo, a estatura de planta e o rendimento de grãos. Foi verificada a presença de variabilidade genética para tolerância ao calor entre as populações de trigo. O estádio vegetativo de desenvolvimento do trigo foi mais sensível ao efeito do estresse térmico. As populações segregantes mais promissoras foram IAC364/BRS207, IAC24/Aliança e IAC24/Pioneiro, associando alta produtividade com grande número de famílias selecionadas entre as mais produtivas, demonstrando possibilidade de seleção de linhagens tolerantes ao estresse de calor.

Palavras-chave: *Triticum aestivum* L., estresse abiótico, temperatura, ganho de seleção.

1. Introduction

The average wheat production (*Triticum aestivum* L.) over the last five years in Brazil represents about 51% of the national consumption, that is, 5,6 million tons (Conab, 2019). The main wheat producing states, Paraná and Rio Grande do Sul, account for more than 85% of the Brazilian production with mean yields of 2.400 kg ha^{-1}. According to Pasinato et al. (2018), there is great potential to expand the production in the tropical zone, in the Southern and Midwestern regions, especially in the Cerrado biome.

Another viable alternative for central Brazil is sowing at the end of the summer, that is, the crop called upland. This type of crop is an option in succession to early soybean that complements the producers' income, increases land-use efficiency and decreases machine idleness (Cargnin et al., 2009). In the upland crop the rainfall at the end of the wet season is used that coincides with the complete development of the crop that helps to reduce the crop production cost.

Heat stress is one of the main abiotic stresses that limit yield in the wheat (Reynolds et al., 2001; Ali et al., 2010). Thus, the development of heat stress tolerant genotypes with high grain yield is one of the objectives of wheat genetic breeding programs (Reynolds et al., 2007; Ortiz et al., 2008; Oliveira et al., 2011; Al-Karaki, 2012), in addition to adaption to the conditions of central Brazil (Machado et al., 2010). According to Coelho et al. (2010) upland wheat production in Minas Gerais is around 2.000 kg ha^{-1}, where heat stresses are present.

Several studies report a negative effect of high temperatures on the wheat crop (Viswanathan and Khanna-Chopra, 2001; Ayeneh et al., 2002; Cargnin et al., 2006; Dhanda and Munjal, 2006; Dias et al., 2010; Ali et al., 2010; Machado et al., 2010; Oliveira et al., 2011; Kumari et al., 2013; Kaushal et al., 2016; Akter and Islam, 2017). In this context, obtaining information on genetic variability for heat tolerance, together with segregating population performance, is important to make wheat breeding programs more efficient.

The objective of the present study was to identify promising wheat segregating populations for heat stress tolerance to obtain lines adapted to the conditions of central Brazil.

2. Material and Methods

The experiment was carried out in 2011 in the Quartéis Experimental Station belonging to the Federal University of Viçosa (UFV), in Coimbra/MG, latitude 20º45'S, longitude 42º51'W and at 720 m altitude.

Sowing took place in March, known as summer, corresponding to the season with high temperatures throughout the crop cycle, that is, presence of heat stress. Thirty-six segregating populations were sown with a varied number of progenies ($F_{3:4}$) per population, together with three controls: Aliança, a cultivar recommended for upland cropping in Central Brazil with medium heat stress tolerance, BRS254 and Pioneiro, cultivars recommended for irrigated cultivation in Central Brazil with low heat stress tolerance.

The seeds of each progeny were obtained from an ear selected in the F_3 hybrid populations conducted in the summer of 2010 in the Prof. Diogo Alves de Melo experimental area belonging to the UFV, in Viçosa, MG, latitude 20º45'S, longitude 42º52'W and 649 m de altitude.

The populations were assessed using a Federer (1956) augmented block design. The controls were intercalated at every 50 families and each block consisted of three populations totaling 12 blocks. The plots consisted of one 1 m long row with 0.2 m between-row spacing.

Sprinkler irrigation was carried out whenever necessary to prevent water shortage interfering in crop growth and development. Fertilization consisted of applying 300 kg ha^{-1} NPK of the 08-28-16 formula in the sowing drill and 50 kg ha^{-1} N were applied with 0.65 kg ha^{-1} boron (male sterility control) as dressing at the start of tillering. The other crop treatments were carried out according to the technical recommendations for the wheat crop (RCBPTT, 2014).

Minimum temperature (*Tmin*) and maximum temperature (*Tmax*) data were collected daily from the air during the experimental period, in a conventional meteorological station belonging to UFV, located approximately 30 m from the experimental area. In order to improve characterization of the effects of temperature, the heat sum or accumulated degree day (ADD) was determined in the development phase of the crop. The following expression was used for this calculation: ADD: $\sum_{i=1}^{n}\left(\frac{(Tmax+Tmin)}{2}\right) - Tbase$, where *Tmax* is the maximum temperature in the day in ºC; *Tmin* is the minimum temperature of the day in ºC; *Tbase* is the base temperature for the wheat crop and n is the number of days assessed in the period. Was adopted the value of 4.5 °C, as the base temperature of wheat (Oliveira et al., 2011).

The following traits were evaluated: days from emergence to flowering (DEF), determined by the interval, in days, between plant emergence and the emission of 50% of the ears of each plot; days from emergence to ear maturity (DEM), determined by the interval, in days, between plant emergence and physiological maturity of the plants; plant height (PH), determined 21 days after grain filling using a ruler and expressed in centimeters and grain yield determined

(GY) defined by weighing the total production of each plot.

The control data were first corrected for later correction of families, following the methodology proposed by Cruz and Carneiro (2006). After estimating the means of the families of each population, these were submitted to analysis of variance by the augmented block methodology. The means of the treatments were analyzed using the Scott and Knott test at 5% probability. The heritability and the ratio between the genetic and environmental coefficients were estimated using the Genes computer program Genes (Cruz, 2013). The mean of the 36 segregating populations was estimated for the grain yield trait and the number of families with each population after, a selection index of 10% and 25% was obtained.

3. Results and Discussion

Significant differences (p≤0.05) were detected between populations and between families within populations exception for the variable days between emergence and flowering (DEF) (Table 1). The heritability values were 70.7%, 81.5% and 93.2% for grain yield (GY), plant height (PH) and days from emergence to maturity (DEM), respectively. From these results there is evidence that direct selection for these traits reveals favorable conditions in terms of immediate genetic gain for the next crop cycle. According to Silveira et al. (2010) results with a high heritability magnitude result from genetic variability for the traits assessed. The CVg/CVe ratio presented higher values than the unit for all the traits, that is, 1.92 (GY), 2.41 (PH) and 4.12 (DEM), indicating that direct selection for these traits may be promising in obtaining superior genotypes.

The wheat cycle can be divided into two stages, vegetative and reproductive, and the vegetative phase begins from emergence to flowering or anthesis, while the reproductive stage begins at the end of the vegetative phase until physiological maturity. Based on this criterion, the average duration of the treatments for the total cycle was 114 days, presenting an accumulation of 1683.41 ºC-day (ADD).

The development phases were similar among the treatments, with a mean of 60 days for DEF (vegetative phase) and 54 days for DFM (reproductive phase). However, when the ADD is considered, the vegetative phase presented 996.58 ºC-day, while in the reproductive phase there was a total of 686.83 ºC-day, with a difference of more than 300 ADD between phases. It was evident from these results that in the vegetative phase the mean temperatures were higher than in the reproductive phase, because the duration of the two phases, in days, was close in values (Table 2). One of the methods most used to relate air temperature to plant development and/or growth is the heat stress sum or accumulated degrees day because it does not depend on the sowing time or location (Prela and Ribeiro, 2002)

Oliveira et al. (2011) assessed parents and the families in the second cycle of recurrent selection, sown during the summer and winter cropping and observed that the emergence to flowering period took more than 43 days in the presence of heat stress while for the winter crop the duration was 67 days. Considering the reproductive period there was similarity in both the crops, 50 days for the winter and 52 days for the summer crop, a result very close to that reported in the present study (Table 2).

The duration of the total development cycle of wheat cultivars is directly related to the duration of the vegetative phase rather than the reproductive phase (Walter et al., 2009). This finding was also reported by Machado et al. (2010), who did not observe differences among the temperature means in the reproductive phase, considering two sowing periods (summer and winter).

Heat stress is defined as increase in temperature above the critical value, for a period long enough to cause irreversible damage to plant growth and development (Souza et al., 2011). Plants exposed to temperatures above >24°C results in significant losses in grain yield (Kaushal et al., 2016; Akter and Islam, 2017). It was found higher occurrence of high temperatures (> 24ºC) during the vegetative phase in relation to the reproductive phase, being 54 in 60 days in relation to the vegetative phase and 35 days in 54 days in the reproductive phase (Table 2).

Table 1 - Summary of the analysis of variance for the traits plant height (PH), in cm; days from emergence to flowering (DEF), in days; days between emergence and maturity (DEM), in days and grain yield (GY), in kg ha^{-1}, and estimates of the coefficient of variation (CV), heritability (h^2) and ratio between the genetic and environmental coefficients of variation (CVg/CVe) in wheat.

Sources of variation	DF	Mean squares			
		PH	DEF	DEM	GY
Block	11	532.55	698.96	195.21	1213.62
Adjusted Treatment	2009	130.41**	89.82^{ns}	52.47**	284.80*
Residual	22	25.24	50.25	3.90	123.80
CV (%)		6.95	10.63	1.54	24.09
h^2 (%)		81.50	66.41	93.17	70.69
CVg/CVe		2.40	1.40	4.12	1.92

** and * significant at 1 and 5 % probability of error, respectively by the F test. ^{ns} not significant.

Table 2 - Mean maximum and minimum temperatures, number of days with maximum temperature above 24ºC (NDTmax > 24ºC) in the experimental period and accumulated degrees day (ADD) in the general mean of the vegetative phase (DEF), reproductive phase (DFM) and throughout the cycle, from emergence to maturity (DEM) of wheat summer 2011.

Period	Temperature (ºC)		NDTmax > 24 ºC
	Maximum	Minimum	
28 to 31 March	30.15	19.58	4 days
April	27.78	16.63	29 days
May	25.30	12.69	22 days
June	24.15	10.55	18 days
1 to 26 July	24.69	9.20	19 days

Accumulated degrees day (ADD)		
Stages of development	Days	ADD (ºC)
DEF	60	996.58
DFM	54	686.83
DEM	114	1683.41

The reproductive phase does not start with the extrusion of the anthers in the wheat ear, but rather when the plants present 2 to 4 visible leaves, characterized by the stage of the start of the terminal spikelet (Rodrigues et al., 2011). This stage is extremely sensitive to high temperatures (Farooq et al., 2011), affecting the formation of the number of spikelets and consequently the number of grains per ear, reducing the final yield.

Populations with the highest grain yield (GY) means were IAC364/BRS207 (population 33), EMB42/BRS207 (population 9), EMB22/VI98053 (population 4), EMB42/Anahuac (population 7) and BRS264/Aliança (population 20), that were shown to be tolerant to heat stress, with superior performance to that of the controls (Table 3).

The Aliança and Pioneiro, cultivars that are well accepted by rural producers in summer planting in central Brazil, together with 14 populations, showed intermediary performance for grain yield, presenting relative tolerance to heat stress. Seventeen populations and the BRS254 showed low productive potential due to low heat stress tolerance. Three classes were formed for plant height (PH) and populations BRS264/Pioneiro, BRS254/VI98053, BRS254/BRS207 and BRS264/VI98053 as having the lowest means (Table 3). High values were found in the populations EMB42/BRS207, EMB42/Anahuac, BRS264/Aliança, IAC364/BRS207 and IAC24/Pioneiro and the control Aliança. It is pointed out that these populations presented the highest GY means, except for the IAC24/Pioneiro population and the control Aliança.

The controls are classified as early cycle (Aliança and BRS 254) and medium cycle (Pioneiro) and the results of the present study showed 130 days for “Aliança” and a 112 day cycle for “BRS254” and “Pioneiro” (Table 3). Regarding the populations, 19 populations presented cycle like the controls, 12 populations were classified as late and five populataions, EMB42/IVI10041, EMB42/Anahuac, BRS254/VI98053, BRS264/IVI010041 and BRS264/Pioneiro presented a short cycle. The short-cycle populations have low grain yield potential and were shown to be highly sensitive to heat stress. In some studies, the wheat development cycle was 88 days in heat stress environments (Yildirim and Bahar, 2010), 95 days (Oliveira et al., 2011), 106 and 104 days (Ayeneh et al., 2002).

Breeding is an adaptive response to crop change, therefore, the breeding for heat tolerance is still in a preliminary stage (Akter and Islam, 2017), requiring the direct selection of stress tolerant individuals. In order to identify promising families, truncated selection was carried out on grain yield, identifying the 10 and 25% of individuals with best mean phenotypic performance. Considering the 25% selection, superior families were identified in almost all the populations, except for the populations EMB22/Anahuac, EMB22/Aliança, BRS254/Aliança and BRS254/VI98053 where no families were selected (Table 4).

When the 10% most productive families are considered, they were derived from 18 of the 36 populations, highlighting the IAC364/BRS207 population with 21 families, showing again the superiority of this population (Table 3).

Populations EMB22/VI98053, EMB42/Anahuac, EMB42/BRS207 and BRS264/Aliança, that presented high population means (Table 3), did not show superiority in relation to the number of superior families, with 1, 2, 4 and 6 selected families, respectively (Table 4). On the other hand, populations IAC24/Aliança, IAC24/BRS207, IAC24/IVI010041 and IAC24/Pioneiro presented contrary performance, with low population means for GY (Table 3), but with a high number of superior families selected, 19, 8, 9 and 13, respectively (Table 4).

Table 3 - Mean for the traits plant height (PH), in cm; days from emergence to maturity (DEM), in days and grain yield (GY) in kg ha^{-1}, 436 populations and three controls (Aliança, BRS254, Pioneiro) of wheat cropped in the summer 2011.

Population		PH		DEM		GY	
1	EMB22/Anahuac	74	b[1]	115	b	1422	c
2	EMB22/Aliança	68	b	114	b	1339	c
3	EMB22/BRS207	71	b	117	c	1689	c
4	EMB22/VI98053	72	b	114	b	2090	b
5	EMB22/IVI010041	76	b	114	b	1545	c
6	EMB22/Pioneiro	72	b	118	c	1650	c
7	EMB42/Anahuac	84	c	112	b	2043	b
8	EMB42/Aliança	72	b	117	c	1186	d
9	EMB42/BRS207	89	c	118	c	2221	b
10	EMB42/VI98053	65	b	113	b	1377	c
11	EMB42/IVI010041	70	b	106	a	1126	d
12	EMB42/Pioneiro	76	b	108	a	1636	c
13	BRS254/Anahuac	68	b	110	b	1323	c
14	BRS254/Aliança	73	b	117	c	1083	d
15	BRS254/BRS207	62	a	114	b	858	d
16	BRS254/VI98053	57	a	109	a	905	d
17	BRS254/IVI010041	68	b	113	b	1271	c
18	BRS254/Pioneiro	73	b	112	b	1568	c
19	BRS264/Anahuac	69	b	111	b	780	d
20	BRS264/Aliança	83	c	113	b	1782	b
21	BRS264/BRS207	71	b	118	c	1154	d
22	BRS264/VI98053	63	a	111	b	885	d
23	BRS264/IVI010041	73	b	107	a	772	d
24	BRS264/Pioneiro	56	a	108	a	796	d
25	IAC24/Anahuac	68	b	114	b	617	e
26	IAC24/Aliança	76	b	114	b	1658	c
27	IAC24/BRS207	76	b	120	c	1180	d
28	IAC24/VI98053	76	b	120	c	888	d
29	IAC24/IVI010041	65	b	113	b	1001	d
30	IAC24/ Pioneiro	81	c	118	c	1473	c
31	IAC364/Anahuac	69	b	113	b	806	d
32	IAC364/Aliança	72	b	114	b	959	d
33	IAC364/BRS207	81	c	121	c	2764	a
34	IAC364/VI98053	68	b	114	b	1615	c
35	IAC364/IVI010041	72	b	119	c	1425	c
36	IAC364/ Pioneiro	73	b	118	c	963	d
37	Aliança	83	c	113	b	1567	c
38	BRS254	65	b	112	b	1044	d
39	Pioneiro	68	b	112	b	1244	c

[1]Means followed by the same letter in the column do not differ by the Scott-Knott test at 5% level of 5% probability.

Table 4 - Total number of families in the original population (TN) and number of families selected per population (NS) between the 25% and 10% most productive wheat families assessed in the summer 2011.

Population		Original		25%		10%	
		TN	GY[1]	NS	GY	NS	GY
1	EMB22/Anahuac	20	1421				
2	EMB22/Aliança	20	1338				
3	EMB22/BRS207	52	1688	5	2659		
4	EMB22/VI98053	64	2089	18	2529	1	3828
5	EMB22/IVI010041	54	1544	6	2524		
6	EMB22/Pioneiro	54	1649	4	2388		
7	EMB42/Anahuac	67	2043	17	2848	2	5038
8	EMB42/Aliança	41	1186	4	2269		
9	EMB42/BRS207	62	2220	23	2779	4	4148
10	EMB42/VI98053	48	1377	4	2236		
11	EMB42/IVI010041	39	1125	1	2317		
12	EMB42/Pioneiro	24	1635	3	2167		
13	BRS254/Anahuac	52	1323	5	2405		
14	BRS254/Aliança	41	1083				
15	BRS254/BRS207	46	857	1	1972		
16	BRS254/VI98053	34	905				
17	BRS254/IVI010041	42	1271	6	2454		
18	BRS254/Pioneiro	78	1567	11	2625	1	3572
19	BRS264/Anahuac	44	779	6	2585		
20	BRS264/Aliança	67	1781	31	2879	6	4059
21	BRS264/BRS207	64	1153	17	2726	1	4940
22	BRS264/VI98053	72	884	9	2589	1	4159
23	BRS264/IVI010041	48	772	6	2656	1	3612
24	BRS264/Pioneiro	72	796	6	2368		
25	IAC24/Anahuac	52	616	13	2876	2	4049
26	IAC24/Aliança	83	1658	55	3152	19	4435
27	IAC24/BRS207	70	1179	34	3006	8	4159
28	IAC24/VI98053	77	887	29	2759	3	4045
29	IAC24/IVI010041	69	1000	28	2990	9	4200
30	IAC24/ Pioneiro	85	1473	45	3163	13	4531
31	IAC364/Anahuac	43	806	3	2369		
32	IAC364/Aliança	65	959	9	2703	1	5334
33	IAC364/BRS207	77	2764	55	3626	21	4979
34	IAC364/VI98053	78	1614	27	2677	5	3791
35	IAC364/IVI010041	46	1424	13	2985	2	4849
36	IAC364/ Pioneiro	57	963	8	2649		
Means			1329		2654		4318

[1]GY: grain yield.

4. Conclusions

The genetic variability that exists among the populations has potential to derive heat stress tolerant lines, especially populations IAC364/BRS207, IAC24/Aliança and IAC24/Pioneiro.

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