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Recurrent selection as breeding strategy for heat tolerance in wheat

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ABSTRACT - *The development of heat-tolerant varieties is an important goal of wheat breeding programs, requiring efficient selection methods. In the present study the use of recurrent selection was evaluated as a strategy to improve heat stress tolerance in wheat. Two cycles of recurrent selection were performed in experiments conducted in research areas of the Universidade Federal de Viçosa, located in Coimbra-MG and Viçosa-MG, in 2004 and 2007, in two growing seasons (summer and winter). The genetic gain and the existence of variability show the possibility of successful recurrent selection for heat-tolerance in wheat.*

Key words: selection gains, temperature, *Triticum aestivum* L.

INTRODUCTION

In the late 1980s, the Brazilian government eliminated subsidies to wheat producers and liberalized marketing (Rossi and Neves 2004). Thereafter, there was a decline in the area growing wheat, with an annual production of less than four million tons of grain, which is insufficient to meet the domestic demand of around 10 million tons. This scenario resulted in several proposals from public institutions and representatives of the production chain of alternatives to increase and stabilize wheat production in Brazil.

The vastness of the Cerrado in Central Brazil indicates the region as a strategic area for wheat cultivation. However, the extreme heat in this region is a drawback, cutting back the agronomic potential of the varieties (Souza and Ramalho 2001, Cargnin et al. 2006a).

An important goal in wheat breeding is the development of new lines with tolerance to high temperature stress (Reynolds et al. 2007, Ortiz et al. 2008), especially for the conditions in Central Brazil, which requires efficient selection methods. In this context, we highlight the recurrent selection method, which consists of a dynamic and continuous process of progeny production, evaluation and selection, followed by intercrossing of the best. The primary purpose of a recurrent selection program is to increase the frequency of favorable alleles for traits of interest, without exhausting the variability (Ramalho et al. 2001).

The periodic estimation of genetic parameters in a recurrent selection program is essential to inform plant breeders about the selection techniques and alternatives that could increase the efficiency. Detailed

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knowledge of these estimates and of implications of environmental effects are therefore fundamental for breeding programs and decisions on the most suitable strategies.

This paper was developed to evaluate the use of recurrent selection as a strategy to improve heat stress tolerance in wheat.

MATERIAL AND METHODS

The recurrent selection program was initiated with eight wheat lines from different sources: BH 1146, BR 24, EP 93541, CPAC 9662, BRS 207, UFVT-Pioneiro, MGS-Aliança and Anahuac, which were chosen in view of their variability in heat tolerance and desirable agronomic traits.

The lines above were crossed in a similar scheme as described by Ramalho et al. (2001). In the first cycle (cycle I) of recurrent selection, 240 $S_{0:2}$ families were evaluated, derived from the eight segregating populations generated by the cited scheme. The experiments were conducted in 2004 at an experimental station of the Universidade Federal de Viçosa, in Coimbra-MG (lat 20º 45'S, long 42º 51'W , 720 m asl). Two sowing dates were used, one for each experiment. The first, called summer sowing (stress condition), was performed at the end of January 2004, with prevailing high temperatures (> 20 ºC) during most of the crop cycle. The second, called winter sowing (favorable condition) was performed at the beginning of May 2004, a period in which temperatures are mild (< 20 ºC) during most of the cycle.

The 240 families, with 30 families of each segregating population, and the eight parents were evaluated in a 16 x 16 lattice design, with two replications. Eight wheat genotypes were added to complete the lattice. Each plot consisted of three 3.0 -m long rows, spaced 0.186 m apart, with an evaluation area of 1.67 m^2.

Families of the second cycle (cycle II) were derived from intercrossing the best family of each population of the first recurrent selection cycle, similar to the scheme described by Ramalho et al. (2001), so that each family consisted of four unrepeated parents. The experiments were conducted in 2007 in an experimental area of the Universidade Federal de Viçosa, in Viçosa-MG, (lat 20º 45'S, long 42º 52'W, 649 m asl). The experimental design and plot arrangement were the same as in the first selection cycle. Two sowing dates were used, one for each experiment, the first in February 2007 (heat stress) and the second in June 2007 (favorable condition).

In the experiment with heat stress, sown in February, 240 $S_{0:2}$ families were evaluated. Seeds ($S_{0:3}$) from these families were used to sow the winter experiment. This strategy was adopted because there were not enough $S_{0:2}$ seeds for both experiments.

Cultural practices were uniform in the crops of both sowing dates and both selection cycles to minimize the influence of biotic and/or abiotic factors on crop growth and development, apart from the stress factor of high temperatures. The experiments were irrigated as necessary.

At sowing, 300 kg ha^{-1} NPK fertilizer (8-28-16) and 250 kg ha^{-1} ammonium sulfate were used as top dressing, at the beginning of tillering. The other cultural practices were performed following technical recommendations for the crop (Reunião 2003).

Data of the following traits were measured: flowering (days), plant height (cm) and grain yield (g/ 1.67 m^2), which were subjected to separate analysis of variance using software MSTAT 1983. After the analysis of variance of each experiment and confirming the homoscedasticity of residual variances between the seasons (Pimentel Gomes 1990), a combined analysis of the experiments was performed, as described by Ramalho et al. (2005).

The effect of families and of the interaction of families with environments was considered random and the effect of environment as fixed. Based on the mathematical expectation of the mean squares, genetic parameters were estimated in the environments summer, winter and environment mean (combined analysis). The lower (LL) and upper limits (UL) of the heritability estimates were calculated by the expressions proposed by Knapp et al. (1985), with $\alpha = 0.05$.

Estimates of realized heritability (h^2_R) were computed by the expression $h^2_R = \dfrac{GS/mi}{ds/mj}$, where: *GS* is the gain from selection in the summer environment considering the families evaluated in the winter environment; *ds* is the selection differential, which is the mean of the selected families (20%) minus the overall family mean, considering the winter environment; *mi* and *mj* are the means of the families in the summer and winter environments, respectively.

The genetic progress from recurrent selection was estimated based on the family performance in the different experiments. Since the cycles were evaluated under different conditions and there were effects of environments and of interaction on the trait expression, the performance of the common controls, used in all evaluations, was consulted as a measure of this effect. The deviation of the family mean and of the best 48 families (20%) was calculated in this way in comparison to the common controls, to indicate the genetic progress.

RESULTS AND DISCUSSION

The occurrence of high temperatures in the summer (Table 1) influenced the plant cycle (Table 2), reducing the number of days needed to achieve the heat sum requirements in both recurrent selection cycles.

Table 1. Means of the temperatures (minimum, mean and maximum), in different development stages of wheat plants in the summer and winter of 2004, in Coimbra–MG (cycle I), and in the summer and winter of 2007, in Viçosa–MG (cycle II)

	CYCLE I		
Cycle stages	**Summer (a)**	**Winter (b)**	**b - a**
Emergence – Beginning of tillering			
Temperature (°C): Mean	22.1	17.4	-4.7
Minimum	19.0	14.0	-5.0
Maximum	27.4	23.1	-4.3
Beginning of tillering - Flowering			
Temperature (°C): Mean	21.7	16.8	-4.8
Minimum	18.3	13.1	-5.2
Maximum	27.6	23.1	-4.4
Flowering - Maturation			
Temperature (°C): Mean	21.2	16.5	-4.7
Minimum	17.6	12.3	-5.4
Maximum	27.1	23.4	-3.8
Total cycle			
Temperature (°C): Mean	21.6	16.9	-4.8
Minimum	18.3	13.1	-5.2
Maximum	27.4	23.2	-4.2
	CYCLE II		
Cycle stages	**Summer (a)**	**Winter (b)**	**b – a**
Emergence - Beginning of tillering			
Temperature (°C): Mean	22.3	16.2	-6.1
Minimum	17.6	10.7	-7.0
Maximum	29.7	25.0	-4.7
Beginning of tillering - Flowering			
Temperature (°C): Mean	22.4	17.1	-5.3
Minimum	18.1	11.2	-6.9
Maximum	29.6	25.9	-3.7
Flowering - Maturation			
Temperature (°C): Mean	18.7	20.1	1.4
Minimum	14.2	14.3	0.1
Maximum	26.0	27.9	1.9
Total cycle			
Temperature (°C): Mean	21.1	17.8	-3.3
Minimum	16.6	12.1	-4.5
Maximum	28.4	26.3	-2.1

The analysis of variance of the first recurrent selection cycle showed significant differences among families for all traits (P≤0.01), both for the summer as for the winter environment, which evidences genetic variability for the traits in both environments.

The means of the traits flowering, plant height and grain yield were lower in the summer than the winter environment (Table 2). It can therefore be inferred that the high temperatures in the summer (stress condition) led to a reduction in the three traits, confirming results reported in the literature (Souza and Ramalho 2001, Cargnin et al. 2006c). It is presumed that the reduction in the crop cycle is likely to result in reduced plant height and lower accumulation of reserves, which reflects in lower grain yield. According to Reynolds et al. (2001), a shorter crop cycle can result in a reduced accumulation of total dry mass when growth rates are insufficient to compensate for the reduction of the cycle under heat stress.

Based on the results of combined analysis of variance of the experiments of the first selection cycle, it was found that there are significant differences between families, sowing dates and the effect of family x season interaction for all traits (P≤0.01) indicating variability among families and differentiated responses to changes in environment.

In cycle II there were no marked differences between the temperature means in the flowering-maturation stage, considering the two sowing dates (Table 1). This indicates that the thermal stress on wheat plants was similar during grain filling, so this is not the decisive stage for the differences between the two environments. Thus, the differences between the two sowing dates were due mainly to heat stress in the early stages, i.e., sowing to flowering. Some studies report that the effects of heat stress can already be observed in the stage of germination and

Table 2. Estimates of the genetic parameters of 240 wheat families for the traits flowering (FLO) in days, plant height (PHT) in cm and grain yield (YLD) in g 1,67m^{-2}, in the growing seasons summer, winter and in the mean of the growing seasons (combined), in the two cycles of recurrent selection for heat tolerance, in Coimbra-MG (cycle I) and Viçosa-MG (cycle II)

Traits	Growing seasons	Mean	CV%	$\hat{\sigma}^2_{G_F}$	$\hat{\sigma}^2_e$	$\hat{\sigma}^2_{GxE}$	h^2	LL	UL	h^2_R	D.	D.(20%+)
						CYCLE I						
	Summer	47.07	3.65	8.31	1.48	—	0.85	0.80	0.88	—	0.37	—
FLO	Winter	60.06	2.63	10.45	1.25	—	0.89	0.86	0.92	0.75	-0.82	—
	Combined	53.57	3.08	7.18	1.36	2.20	0.91	0.89	0.93	—	-0.22	—
	Summer	71.09	7.15	56.23	12.91	—	0.81	0.76	0.86	—	-5.58	—
PHT	Winter	108.75	3.97	135.54	9.31	—	0.94	0.92	0.95	0.57	-1.01	—
	Combined	89.92	5.24	81.53	11.11	14.35	0.94	0.92	0.95	—	-3.30	—
	Summer	247.48	11.68	2619.05	417.97	—	0.86	0.82	0.89	—	9.87	93.66
YLD	Winter	470.25	12.66	16753.02	1773.56	—	0.90	0.88	0.93	0.00	-83.42	114.08
	Combined	358.86	13.04	4566.16	1096.77	5119.90	0.89	0.87	0.91	—	-36.37	65.69
						CYCLE II						
	Summer	42.86	5.42	15.44	2.70	—	0.85	0.81	0.89	—	-0.81	—
FLO	Winter	66.93	1.63	3.91	0.60	—	0.87	0.83	0.90	0.35	-1.14	—
	Combined	54.89	3.30	6.18	1.65	3.49	0.88	0.85	0.91	—	-0.98	—
	Summer	73.01	7.54	55.98	15.15	—	0.79	0.72	0.84	—	0.41	—
PHT	Winter	114.01	7.48	63.67	36.32	—	0.64	0.53	0.72	0.46	3.06	—
	Combined	93.51	7.67	50.92	25.74	8.90	0.80	0.75	0.84	—	1.74	—
	Summer	268.60	25.33	4034.11	2314.94	—	0.64	0.53	0.72	—	-18.4	98.69
YLD	Winter	458.68	18.53	4506.29	3610.92	—	0.56	0.42	0.66	0.31	-14.34	116.44
	Combined	363.64	21.17	3337.67	2962.93	932.53	0.69	0.61	0.75	—	-16.39	88.01

1/ $\hat{\sigma}^2_{G_F}$: genotypic variance among families; $\hat{\sigma}^2_e$: residual variance; $\hat{\sigma}^2_{GxE}$: variance of the interaction family x growing season; h^2: broad-sense heritability; LL and UL: lower and upper limit of the heritability estimates; h^2_R : realized heritability; D.: Deviation of the family mean compared to the common control means; D. (20%+): Deviation of the means of the 48 best families (20%) compared to the means of the common controls seedling emergence (Blum and Sinmena 1994, Cargnin et al. 2006b).

The separate analysis of variance for the traits assessed in the summer and winter environments, in the second recurrent selection cycle, showed significant differences between families for all traits ($P \leq 0.01$), both in summer and winter, indicating genetic variability in both sowing dates.

The means of all traits were lower for the summer environment, as in the previous cycle (Table 2). The tall plant height of the families in the second cycle is noteworthy, when grown in the winter environment, since some of them were taller than 135 cm. This trait is relevant for selection, since lodging may occur, with negative effects on grain yield. Singh and Chaudhary (2006) emphasize this point, and verified that the selection of short wheat plants was more efficient under irrigation (no stress). When the selection was performed under unfavorable conditions, the most productive plants were the tallest in the environment without stress.

In the combined analysis of variance for the traits evaluated in the second selection cycle significant differences were found between seasons, between families and for the interaction between families and seasons ($P \leq 0.01$), indicating, as in the previous cycle, the existing variability among families and differentiated responses to environmental changes.

Estimates of genetic parameters are presented in Table 2. It was found that the estimates of genotypic variance among families ($\hat{\sigma}^2_{G_F}$) resulted in high values in both selection cycles. This indicates that the variability was released in each recombination cycle and, above all, that there is sufficient variability to continue recurrent selection.

The estimate of h^2 for grain yield was > 56% in all cases, a rate considered relatively high (Silva et al. 2008). For plant height, the lowest estimate was > 64%, and for flowering > 85% (Table 2). In all cases the lower limit, at 95% probability, was positive.

It is worth mentioning that the h^2 estimates are in the broad sense, however, since dominance is not significant for these traits, it appears that great part of the variance contained in the numerator of the h^2 must be additive. A comparison of heritability estimates is not always reliable because it depends on the population considered, the number of families evaluated, the environmental conditions, plot size, and experimental accuracy. However, our results were similar to those reported in the literature (Camargo et al. 2000, Kuchel et al. 2007).

The estimates of realized heritability, obtained by selection in the winter environment, and gains in the summer environment were lower than the estimates of broad-sense heritability in both environments and in both selection cycles (Table 2). This shows the effect of genotype by environment interaction for the traits evaluated. The interaction reduces the success from selection when selection is performed in an unstressed environment compared to the gain in stressful environments (Singh and Chaudhary 2006). It was further noted that the realized heritability for grain yield was higher in the second cycle, indicating the possibility of continued success with selection in the following cycles.

As an indicator of genetic progress, we calculated the deviation of the family mean in comparison to the common controls (D.) for each sowing date and the two selection cycles. It was found that the deviations were higher for cycle II, in most cases (Table 2), except for grain yield in the summer and flowering in both environment. Higher deviations in the second recurrent selection cycle indicate gains over the previous cycle. It is worth noting that the gains were in a similar range as in other studies evaluating recurrent selection as a strategy for wheat breeding (Maich et al. 2000).

It follows therefore that recurrent selection was effective for increasing grain yield considering the two environments (combined analysis), although the plants were becoming too tall.

Considering the deviation from the mean of the best families in comparison to the common control mean (D. 20% +) for grain yield, it was found that the deviations were higher in the second cycle for both sowing dates and by combined analysis (Table 2), which also shows the effectiveness of the selection process in a recurrent selection program for heat tolerance in wheat.

CONCLUSIONS

The genetic gain and the existence of variability show the possibility of successful recurrent selection for heat tolerance in wheat.

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Seleção recorrente como estratégia de melhoramento para tolerância ao calor em trigo

RESUMO - *O desenvolvimento de cultivares tolerantes ao calor é meta importante dos programas de melhoramento de trigo, necessitando de métodos de seleção eficientes. No presente trabalho estabeleceu o objetivo de avaliar a utilização da seleção recorrente como estratégia de melhoramento para tolerância ao estresse térmico em trigo. Foram realizados dois ciclos de seleção recorrente com experimentos conduzidos em áreas de pesquisa da Universidade Federal de Viçosa, localizadas em Coimbra-MG e em Viçosa-MG, nos anos de 2004 e 2007, em duas épocas (verão e inverno). O ganho genético obtido e a existência de variabilidade evidenciam a possibilidade de se obter sucesso com a seleção recorrente para tolerância ao calor em trigo.*

Palavras chave: ganhos por seleção, temperatura, *Triticum aestivum* L.

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