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ARTICLE

Genetic gain prediction for wheat with different selection criteria

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ABSTRACT - *The objective of this study was to compare different criteria of simultaneous environment selection based on estimated gains to identify the most appropriate ones. Two hundred and forty $F_{2:4}$ families derived from eight segregating wheat populations were evaluated. The experiments were conducted on the field, with sowings in the summer and the winter, in 2004. The highest gains were estimated by direct selection in each cultivation environment, with negative gain estimates for the indirect response in the other environment. All indices were more adequate for simultaneous selection of environments since the total gains were higher and more evenly distributed in the two environments. The index based on "desired gains" obtained the highest gains in the three situations. Selection indices are advantageous, since the selection efficiency in wheat breeding programs is improved.*

Key words: *Triticum aestivum* L., selection indices, improvement, environment.

INTRODUCTION

The diversity in wheat cultivation areas may hold a solution to reduce the variations in total yields, since climate-induced divergences of one region rarely coincide with those of other regions. According to Souza and Ramalho (2001), the cultivation of this grass is also an option for crop rotation, to maintain the high yields of summer crops in the central region of Brazil. In this region wheat production is actually quite successful, although the continuity depends on a better adaptation of cultivars to regions and/or sowing times that would make higher gains for the yield potential of this crop possible (Cargnin et al 2006).

The selection and recommendation of more productive genotypes are basic objectives of the genetic breeding programs of any cultivated species. Selection is frequently based on evaluations of genotype performance in different environments (year, location, sowing date). It is however not easy to select superior progenies, since the relevant traits (grain yield) are mostly quantitative due to the strong environmental influence, so that selection in one environment triggers changes in another (Cruz and Regazzi 1997).

Simultaneous selection in different environments raises the chances of success of improvement programs. Nevertheless, during selection that targets a particular environment, modifications can occur in another, whose sense and magnitude depend on the considered trait and the association between these environments (Cargnin et al 2006). The theory of selection index exploits the combination of the multiple information contained in the experimental unit, which makes selection possible based on more than one environment

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of interest. The selection index represents an additional trait, established by the optimal linear combination, which allows effective simultaneous selection in several distinct environments (Cruz and Regazzi 1997).

According to Cruz et al. (1993) the selection index has been most widely used in breeding programs of animals and perennial and semi-perennial plant species such as eucalypt (Paula et al. 2002) very unlike the restricted use in annual and short-cycle species. Similar studies were however recently conducted with maize (Garcia and Souza Junior 1999, Granate et al. 2002), rice (Rodrigues et al. 1998), potato (Barbosa and Pinto 1998) and soybean (Oliveira et al. 1999, Costa et al. 2004).

The objective of this study was to compare and determine the most adequate of different criteria of simultaneous progeny selection for different environments based on their estimated gains.

MATERIAL AND METHODS

The field experiments were conducted in 2004, at an experimental station of the Universidade Federal de Viçosa (UFV), in Coimbra, state of Minas Gerais (lat 20°45'S; long 42°51'W; 720 m asl).

Two hundred and forty $F_{2:4}$ families derived from eight populations of the crosses BH1146/BR24, BR24/Aliança, Aliança/EP93541, EP93541/CPAC9662, CPAC9662/IVI931009, IVI931009/BRS207, BRS207/Anahuac, Anahuac/BH1146 were evaluated in a circulant diallel, according to Bearzoti (1996), cited by Ramalho (1997).

Two sowing dates (environments) were considered, one for each experiment. The first sowing, termed summer, (stress condition) occurred at the end of January (day 30) when high temperatures prevail during the crop cycle. The second, termed winter (favourable condition), was sown in the beginning of May (day 02), which is the time when milder temperatures prevail during most part of the crop cycle.

The crop management practices were the same in both experiments to minimize the influence of biotic and/or abiotic factors on crop growth and development. To reduce the heat stress in the genotype expression caused by the high temperature, both experiments were irrigated whenever needed.

The maintenance fertilization was tuned to the results of soil analyses performed at the Laboratory of Soil Analyses of the UFV; 250 kg ha^{-1} of the formula 08-28-16 was applied in the sowing furrow and 50 kg ha^{-1} N as sidedress at the beginning of tillering. The other crop treatments followed the technical recommendations for wheat cultivation (Comissão Centro Brasileira de Pesquisa de Trigo - Comission of the Brazilian Center of Wheat Research of 2003).

The 240 families and eight parents were evaluated using the lattice design with two replicates plus eight additional wheat genotypes to complete the lattice scheme. Each plot consisted of three 3.0 m long rows, in a spacing of 0.30 m between rows, with 65 viable seeds per meter, (useful area 2.7 m^2). Grain yield data (g plot^{-1}) were collected.

After the individual analyses of variance the homogeneity of the residual variances was verified by the F maximum test, which considers the residual homogenous variances when the ratio between residual mean squares does not exceed 7. The joint analysis of variance was performed when there was homogeneity of the residual variances.

The selection was simulated, as described by Cruz and Regazzi (1997), based on three selection criteria: direct and indirect selection on the trait grain yield evaluated in each of the two environments; based on the classic selection index (Smith 1936, Hazel 1943); selection through the base index (Williams 1962) and selection through the desired gains index (Pesek and Baker 1969). These indices were evaluated in three situations: I - grain yield considered most important in both environments; II - grain yield considered most important in the summer environment and; III - grain yield considered most important in the winter environment.

In the analysis of genetic gain, the economic weights and desired gains were established based on the experimental data, following recommendations of Cruz et al. (1993). In the cases where the environment was considered principal, value 1 (one) and the estimates of genetic variation coefficient (CVg) were adopted as economic weights and the equivalent of standard genetic deviation (SDg) as desired gain, and value zero was assumed where the environment was not principal. In all cases the selection intensity was 20%. The family coincidence selected by the three indices in all situations was also estimated through the relation of the family occurrence. The software package Genes (Cruz 2001) was used for all analyses.

RESULTS AND DISCUSSION

The individual analyses of variances of the four evaluated traits of both sowing times showed that the genotype effects presented highly significant variations ($P \leq 0.01$) (Table 1). The variation coefficients between 12.64 and 13.31% expressed good accuracy, which are classified as intermediate values, considered normal for agricultural trials according to Lúcio et al. (1999).

Once the homogeneity of the residual variances of the two sowing times was verified by the F maximum test (ratio of 4.24), and based on the uniformity of management of the two trials, the joint variance analysis of the experiments was performed. The F test indicated significant effects of genotypes, environments (sowing time) and also of the genotype-by-environment interaction for the four traits. The variation coefficient of 13.77% for this analysis also expressed good data reliability (Lúcio et al. 1999) (Table 1).

The ratio CVg/CVe presented values that were superior to the unit, which according to Cruz and Regazzi (1997) are considered ideal for selection. Table 1 further shows high heritability values in the families, which is in agreement with results obtained for the same environmental conditions by Cargnin et al (2006). This author ascribed the high values to the great existing genetic variability and the high number of evaluated families to the fact that the heritability estimates were in the broad sense. The difference between the values of genetic variation coefficients of 21.33% in the environment summer and of 27.51 % in the winter and the mean grain yield of 447.03 g $plot^{-1}$ and 840.98 g $plot^{-1}$ respectively for the environments summer and winter are also noteworthy. According to Cargnin et al (2006) this difference can be explained by the heat stress in the summer environment.

The gain estimates obtained by direct and indirect selection for both sowing dates are presented in Table 2. The gains achieved by direct selection were always higher than the indirect response, evidencing the influence of the genotype-by-environment interaction on the genetic gain in one environment (j) and response to selection in the other environment (j'). For Cruz and Regazzi (1997), this value of direct response is partly consequence of the expression itself used to estimate these values.

The gains obtained by the three indices used for the trait grain yield, considered as principal and separately in each one of the two environments (situation II and III) were very similar to the gains with direct and indirect selection for these environments, with a small advantage in the first case (Table 2), principally for the summer environment, independently of the economic weight used. Similar results were obtained by Costa et al. (2004), who worked with segregating soybean families and used these same selection indices in a comparison of response to direct selection.

The analysis of the total gains demonstrated that the index of Pesek and Baker (PB) was superior since it was the only index that obtained indirect positive gain in situation II (summer as principal) and the lowest value of indirect negative gain for situation III (winter as principal). According to Cruz et al. (1993), the use of the indices, even when taking only one principal

Table 1. Summary of the individual and joint analyses of variance and of the parameters: mean, genetic variation coefficient (CVg), experimental variation coefficient (CVe), ratio between the genetic and experimental variation coefficient (CVg/CVe) and broad-sense heritability at the mean level (h^2) for grain yield

Source of variation	df	Mean squares		
		Joint analysis	Summer	Winter
Genotypes (G)	255	63770.56**	19016.61**	115691.62**
Environments (A)	1	40998717.40**		
Interaction GxA	255	70937.67**		
Error	450	7072.24	2697.63	11446.86
Mean (g/plot)		644.67	447.03	840.98
CVg (%)		18.53	21.33	27.51
CVe (%)		13.77	12.64	13.31
CVg/CVe		1.35	1.69	2.07
h^2 (%)		87.87	85.06	89.52

** significant at 1% probability

Table 2. Estimates of the selection gains (SG) in g plot^{-1} and in percentage (%) obtained for the trait grain yield with direct and indirect selection (SDI) by the indices proposed by Smith (1936) and Hazel (1943) (SH), Williams (1962) (BW) and Pesek and Baker (1969) (PB), with the economic weights and desired gains (EW/DG) in the respective situations of selection

Index	EW/DG	Situation	SG (g plot^{-1})		Total	SG %		Total
			Summer	Winter		Summer	Winter	
		I[(1)]	42.04	286.75	328.79	9.4	34.1	43.5
SH	1	II[(2)]	134.80	-4.30	130.50	30.15	-0.51	29.64
		III[(3)]	-23.09	317.22	294.13	-5.16	37.72	32.56
		I	34.08	293.96	328.04	7.62	34.95	42.57
SH	CVg[(4)]	II	134.80	-4.30	130.50	30.15	-0.51	29.64
		III	-23.09	317.22	294.13	-5.16	37.72	32.56
		I	47.43	281.35	328.78	10.61	33.46	44.07
BW	1	II	134.80	-4.30	130.50	30.15	-0.51	29.64
		III	-20.12	317.31	297.19	-4.5	37.73	33.23
		I	34.08	293.96	328.04	7.62	34.95	42.57
BW	CVg[(4)]	II	134.80	-4.30	130.50	30.15	-0.51	29.64
		III	-20.12	317.31	297.19	-4.5	37.73	33.23
		I	89.46	214.44	303.91	20.01	25.5	45.51
PB	SDg[(5)]	II	134.67	6.62	141.29	30.13	0.79	30.92
		III	-7.94	315.70	307.76	-1.78	37.54	35.76
SDI		II	123.08	-23.50	99.58	27.53	-2.79	24.74
SDI		III	-9.93	306.42	296.49	-2.22	36.44	34.22

(1) Grain yield considered principal in the two environments
(2) Grain yield considered principal in the summer environment
(3) Grain yield considered principal in the winter environment
(4) Genetic variation coefficient
(5) Genetic standard deviation

environment or trait into consideration, has advantages over direct selection, since the gains are more evenly distributed across all evaluated environments or traits, with higher total gains, without significant loss in the main environment.

We further emphasize that the correlated response was lower and had an opposite signal to the estimates of the other environment. Cargnin (2006) studied wheat at the same sowing dates and pointed out that the existence of negative correlation in this pair of environments explains this finding.

The gains were estimated by the indices of Smith and Hazel (SH), of Pesek and Baker (PB) and the base index of Williams (BW) when grain yield was considered main trait in both environments (situation I) (Table 2). These data illustrate the higher total gains of all studied selection indices, independent of the economic weights 1 (one) and genetic variation coefficient (CVg) or genetic standard deviation (SDg) as desired gain. Still, the indices BW and PB with the economic weights 1 (one) and SDg as desired gain, respectively, were slightly superior.

Index PB, with SDg as desired gain obtained the best estimate, for total gains as much as for the most evenly distributed gains in relation to the two simultaneously evaluated environments. The use of this index in selection programs would allow higher yields under stress conditions while not affecting the performance of this trait under more ideal crop cultivation conditions.

Based on the comparisons between the selected families (Table 3) it was stated that in the same selection situation, but independent of the economic weight adopted, the indices SH and BW were very similar, and can reach up to 100% coincidence of families selected by these two indices. On the other hand, the comparisons showed a certain dissimilarity between index PB versus SH and BW, principally when the grain yield was considered main trait in the two environments (situation I), with a maximum of 77% coincidence in this

Table 3. Estimate of the number of coincidences of selected families, using the indices of Smith and Hazel (SH), Wiliams (BW) and Pesek and Baker (PB), with different economic weights and desired gain in three situations of selection

Selection index	Selection situation		
	I(1)	II(2)	III(3)
SH(4) x SH(5)	46	48	48
SH(4) x BW(4)	47	48	47
SH(4) x BW(5)	46	48	47
SH(4) x PB(6)	36	47	45
SH(5) x BW(4)	45	48	47
SH(5) x BW(5)	48	48	46
SH(5) x PB(6)	35	47	45
BW(4) x BW(5)	45	48	48
BW(4) x PB(6)	37	47	46
BW(5) x PB(6)	34	47	46

(1) Grain yield considered principal in the two environments
(2) Grain yield considered principal in the summer environment
(3) Grain yield considered principal in the winter environment
(4) Economic weight equal to 1 (one).
(5) Economic weight equal to the genetic variation coefficient
(6) Desired gain equal to the genetic standard deviation

situation, which can still be considered a relatively high value. Even in cases of less coincidence of selected families, it does not drop below 70% coincidence.

When working with these same selection indices in soybean, Costa et al. (2004) also verified that the indices SH and BW were similar in the same selection situation, reaching 99% coincidence, while the PB index was the least similar in relation to the others, in spite of up to 82% coincidence, which these authors considered a high value.

The use of these indices resulted in high and positive gains in both environments, with the highest values for the winter environment. There is therefore a possibility of progress when selecting superior genotypes for the two environments without losing gains in any environment. Cargnin et al (2006) anticipates that this may speed up the breeding programs of Central Brazil when selection is performed in summer as much as in winter wheat. Besides, the possibility of identifying specific genotypes for planting in the irrigated or non-irrigated systems would increase, which would consequently diminish the breeders' work and costs for the development, evaluation and recommendation of new cultivars for these two cultivation systems.

Summing up, the use of these selection indices in wheat improvement programs would allow a yield increase under specific conditions through the identification of genotypes with specific adaptability to heat stress, without affecting the yield performance, or even achieving gains, in favorable wheat cultivation conditions.

CONCLUSIONS

The use of simultaneous selection indices resulted in high total gains that were more evenly distributed across the environments.

The desired gains index allowed the highest gains in the three situations studied.

The use of selection indices is advantageous, improving selection efficiency in wheat breeding programs for heat tolerance for cultivation in central Brazil.

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Predição de ganho genético por diferentes critérios de seleção em trigo

RESUMO - *O objetivo deste trabalho foi comparar diferentes critérios de seleção simultânea de ambientes, por meio de seus ganhos estimados, determinando os mais adequados. Foram avaliadas 240 famílias $F_{2:4}$ oriundas de oito populações segregantes de trigo. Os experimentos foram conduzidos a campo, com as semeaduras realizadas no verão e no inverno, em 2004. As maiores estimativas de ganhos foram obtidas pela seleção direta em cada ambiente de cultivo, sempre com estimativas de ganho negativo para a resposta indireta no outro ambiente. Com a seleção simultânea de ambientes, todos os índices apresentaram se mais adequados para a seleção, por registrarem maiores ganhos totais, os quais foram melhores* *distribuídos entre os dois ambientes. O índice baseado em "ganhos desejados" permitiu os maiores ganhos nas três situações. O uso de índices de seleção é vantajoso, tornando a seleção mais eficiente nos programas de melhoramento de trigo.*

Palavras-chave: *Triticum aestivum* L., índices de seleção, melhoramento, ambiente.

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