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Use of nonparametric selection indexes in studies of adaptability and stability of oat cultivars

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ABSTRACT - *In Brazil, oat is cultivated over a vast area. There are, however, no reports on the use of the different traits of importance measured simultaneously in different environments for cultivar classification. The objective of our study was to compare nonparametric selection indexes for cultivar classification in their average performance in six environments, with and without fungicide application. The indexes used in the present study were classification sum index, modified classification sum index (using the standard deviation in the separation of means) and index of distance to the ideotype. Cultivar UPFA22 stood out with its classification as best genotype for all indexes. Moreover, the cultivar was well classified for grain yield and hectoliter weight. These indexes are efficient; the weights of the traits should however be modified according to the importance of the traits and/or an environmental stratification.*

Key words: white oat, nonparametric selection indexes, cultivar classification.

INTRODUCTION

In Brazil, hexaploid oat (*Avena sativa* L.) has been discussed as one of the alternatives for winter crop systems in succession to wheat, in the formation of sole or joint cultivated winter pastures for hey, silage and green cover, which have a well-known effect on soil recovery and conservation (Carvalho et al. 1987). The cereal is most intensely cultivated in the southern states of Brazil, but it is grown from Mato Grosso (Central Region) to the extreme south of Rio Grande do Sul, which requires adaptation to different environmental conditions and leads to a considerable difference in genotype reactions to this broad range of conditions.

Annually, experiments with recommended oat cultivars are conducted in different environments, where many important traits are measured in conditions with and without fungicide application. Studies using the trait grain yield have observed the presence of significant genotype interaction regarding environmental variations and fungicide application (Benin et al. 2003), but also the possibility of selecting genotypes with higher adaptability and stability in favorable and unfavorable environments (Lorencetti et al. 2004). There are however no reports on the use of information from simultaneous evaluations of different important agronomic traits in different environments,

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in the ranking of oat cultivars. The adoption of an efficient index for ranking cultivars would enable the application of an impartial criterion for genotype classification, based on the simultaneous combination of a large number of traits of agronomic importance, evaluated in different environments, all summed up into one value; which would enable the comparison and order of genetic constitutions based on their average performance in different environments.

Nevertheless, oat cultivars can not be compared through the selection indexes developed for recurrent selection programs such as those of Brin et al. (1959), Kempthorne and Nordskog (1959), Pesek and Baker (1969), Tai (1977) and Smith et al. (1981), which aim at an increase of the genotypic value of a population (genetic gain), since in this case it is desirable to identify only the best genotypes for a given group of traits. In our case, there is no recombination of superior genotypes, as in recurrent selection, and higher ranked individuals should meet the minimal patterns for the crop for all measured traits (Garcia-Júnior and Souza Júnior 1999). This requirement makes methods that aim at an evaluation of the population's genotypic value (genetic gain) inadequate for the ranking of cultivars.

Besides these selection indexes, there are non linear indexes, also called nonparametric, that rank genotypes according to their average performance in diverse environments, and not according to an increase in the populational genotypic value (genetic gain). The most suitable of these indexes is the one that uses measures of distance such as the Euclidian or Mahalanobis to simultaneously rank genotypes according to many characters, as a function of its similarity to an ideal genotype defined by the breeder (Garcia-Júnior and Souza Júnior 1999). On the other hand, Mulamba and Mock (1978) proposed an index based on the sum of ranks for each one of the measured characters, so the smaller the value, the better the ranking of the genotype. To estimate these indexes, genetic parameter estimates are not necessary, as they are for the linear indexes, which make their use as a criterion for cultivar ranking possible.

Therefore, the objective of the present study was to evaluate the efficiency of nonparametric selection indexes to classify oat cultivars that had been indicated for commercial use in Brazil in the 2002 crop season based on the average performance, in six different environments, in experiments with and without fungicide application.

MATERIAL AND METHODS

The experimental data used in the present work were originated from the Brazilian Recommended Oat Cultivar Trial (Ensaio Brasileiro de Cultivares Recomendados de Aveia - EBCRA), coordinated by the Brazilian Oat Research Commission (Comissão Brasileira de Pesquisa de Aveia - CBPA). The trials were conducted in the crop season of 2002 in the states of Paraná, Rio Grande do Sul, São Paulo, Minas Gerais, and Mato Grosso, making up a total of 17 distinct environments. However, only data from six sites were used in this study, because only at these locations all evaluated characters were measured. The locations and institutes in charge of the experiments for each location were: i) Pelotas-RS (UFPel); ii) Lavras-MG (UFLA); iii) Pato Branco-PR (CEFET); iv) Entre Rios-PR (FAPA); v) Lages-SC (UDESC) and vi) São Carlos-SP (EMBRAPA).

All trials were set up in a randomized complete block design with six replications, three with fungicide application and three without. One to two fungicide (tebuconazole) applications were done in the dose 0.75 L ha^{-1}, as needed at each location. The trials were fertilized according to the soil analysis of each location. The following characters were measured at each site: i) grain yield (GY), in kg ha^{-1}; ii) weight of a thousand grains (WTG), in g; iii) hectoliter weight (HW), in kg hL^{-1}; iv) plant height (PS), in cm; v) days from emergence to maturation (DEM); vi) days from emergence to flowering (DEF); and, vii) days from flowering to maturation (DFM).

The data for grain yield were subjected to analysis of variance, considering the effects of genotypes as fixed and the remaining as random, in two independent analyses: environments with and without fungicide. The adaptability and stability parameters were estimated for grain yield and by the methodology of Cruz et al. (1989), based on the segmented linear regression, which uses the adaptability parameters: mean (b_{0i}), response to unfavorable (b_{1i}) and to favorable environments (b_{1i} + b_{2i}). The stability was evaluated by the determination coefficient of each genotype (R^2) according to the model: $Y_{ij} = b_{0i} + b_{1i}I_j + b_{2i}T(I_j) + \delta_{ij} + \bar{\varepsilon}_{ij}$, where: Y_{ij} is the average yield of the ith genotype in the jth environment; b_{0i} is the overall mean yield of the ith genotype in all environments; b_{1i} is the linear regression coefficient, which expresses the response of the ith genotype to variation in unfavorable environments; I_j is the environment index; b_{2i} is the linear regression coefficient, which expresses the differential response of the ith genotype to the variation in favorable environments; $T(I_j) = 0$, if $I_j < 0$ or $T(I_j) = I_j - \bar{I}_+$, if $I_j > 0$, being $\bar{I}_+$ the average of positive I_j indexes; δ_{ij} is the standard deviation of the regression of the ith genotype in the jth environment; $\bar{\varepsilon}_{ij}$ is the average experimental error. The estimates of adaptability and stability parameters were obtained on Software Genes (Cruz 2001). Therefore, the trial had ten variables, seven of which were measured in the field and laboratory (GY, WTG, HW, PS, DEM, DEF, and DFM) plus two adaptability parameters (b_1 and b_1+b_2) and one of stability (R^2) obtained from the grain yield.

For the calculation of the proposed ideotype distance index (*IDI*), the means of the seven measured characters were estimated for each genotype at the six locations, plus the adaptability and stability parameters estimated for the character grain yield, for both conditions with and without fungicide application. Later, the ideotypes were defined for the conditions with and without fungicide as being the genotypes formed by the highest values of the characters GY, DFM, HW, WTG, b_1+b_2 and R^2 and the smallest values for the characters DEF, PS, DEM and b_1. The average Euclidian distances were estimated from the standardized data (average/standard deviation) among all 24 studied genotypes and the ideotype. The genotypes were ranked according to their distance to the ideotype, for both conditions with and without fungicide. Best cultivars were those that presented shortest distances to the ideotype.

To obtain the ranking sum indexes (*Is*) proposed by Mulamba and Mock (1978), the cultivars were ranked according to their mean for the ten analyzed variables, for both conditions with and without fungicide. The criterion used was to give number one to the best value of any given character. So genotypes with rank one presented highest means for the characters GY, DFM, HW, WTG, b_1+b_2 and R^2 and lowest for the characters DEF, PS, DEM and b_1. After obtaining the ranking numbers for each genotype, for the conditions with and without fungicide, the sum indexes were calculated as follows: $Is_j = \sum n_{ij}$, where: Is_j = index for the jth genotype; n_{ij} = number of ranking order for the ith character in the jth genotype. Cultivars that presented the lowest *Is* values were considered the best.

One of the hardest critics to the *Is* ranking index comes from the fact that it does not use any statistical criteria for ranking genotype averages. Therefore, a modification was performed in the criterion of average ranking cultivars in order to correct the method's limitation. At first, means of the 24 cultivars for each studied character and the standard deviation for the ten evaluated characters in the conditions with and without fungicide were estimated. The standard deviation was used to rank the cultivars in four classes for the characters GY, DFM, HW and WTG, b_1+b_2 and R^2, in which the interesting genotypes are those with higher values, ranked as follows: i) in group one the genotypes which presented values superior to the overall mean (mean of the means) plus one standard deviation; ii) in group two the genotypes that presented values between the overall mean and the overall mean plus one standard deviation; iii) in group three genotypes with values between the overall mean and the overall mean minus one standard deviation and iv) in group four the genotypes that presented values inferior to the overall mean minus one standard deviation. The characters DEF, PS, DEM and b_1, in which the interesting genotypes are those with the lowest values, were ranked in the opposite direction, with the best group now being called group four and vice-versa. This ranking was obtained for the conditions with and without fungicide. After the ranking for each genotype, for both conditions, the modified sum index (Is_{DP}) was estimated as follows: $Is_{DP_j} = \sum n_{ij}$, where: Is_{DPj} = índex for the jth genotype; n_{ij} = number of ranking order for the ith character in the jth genotype. Cultivars with lowest Is_{DP} values were considered the best.

Later, Pearson's correlations were estimated among all characters and the indexes *Is*, Is_{DP} and *IDI* for the conditions with and without fungicide, as well as among all estimated indexes.

RESULTS AND DISCUSSION

The results of analysis of variance for the character grain yield of the experiments with and without fungicide are presented in Table 1. The results showed highly significant differences (P < 0.01) for the factor location in both conditions with and without fungicide application, indicating large differences between the evaluated environments. In the present study, the factor location showed the highest mean square, suggesting its importance for genotype performance. Similar results had been reported earlier for oat (Federizzi et al. 1993, Benin et al. 2003, Lorencetti et al. 2004). Another noteworthy fact is that the magnitude of the mean square for location was inferior under fungicide application compared to the condition without, demonstrating that fungicide application tended to reduce the discrepancies between environments. The reason seems to be the control of crown rust, the main oat crop pathogen, which presents distinct damage levels in the locations, since some locations are more prone to disease development than others. A similar situation was reported for oat by Doehlert et al. (2001).

The significance of genotype effects evidenced the existence of genetic variability in the evaluated genotypes at 5% error probability under fungicide application and at 1% error probability without fungicide application (Table 1). Once more it was noticed that fungicide application contributed more to the reduction of existing differences among genotypes. Results indicated that there are differences among genotypes regarding grain yield, in the presence as well as absence of fungicide treatment. However, the differences were greater in the absence of fungicide, since in this situation the genotype differences are amplified, mainly as a function of the different resistance levels they present. Similar results had been reported by Benin et al. (2003) and Lorencetti et al. (2004).

Table 1. Summary of analyses of variation for grain yield, in kg ha^{-1}, obtained in six locations for the Brazilian Recommended Oat Cultivar Trial (EBCRA)

Sources of variation	with fungicide		without fungicide	
	df	MS	df	MS
Genotypes (G)	23	856297*	23	2065642**
Locations (L)	5	68308785**	5	113248579**
Interaction (G x L)	115	556094**	15	771556**
C.V. (%)		19.84		22.68

*P < 0.05; **P < 0.01

The analysis of variance also showed the presence of a highly significant (P < 0.01) location x genotype interaction (Table 1), evidencing the presence of genotypes regarding their response to environmental variations. This agrees with the results obtained by Federizzi et al. (1993), Doehlert et al. (2001), Benin et al. (2003) and, Lorencetti et al. (2004). Thus, the occurrence of crown rust contributed decisively to the detection of differences among genotypes or environments. Besides, the disease was one of the main factors causing the interaction G x L, once it is known that the fungi resistance of the genotypes varies in different environments. The presence of a highly significant interaction G x L justified the need to estimate parameters of adaptability and stability proposed in this study, and, placed them as extremely important for genotype ranking as a function of their average performance in many locations.

After the parameter estimates of adaptability and stability and the calculation of cultivar averages for the seven measured characters in the six locations were performed, the genotype ranking indexes were estimated. Tables 2 and 3 show the cultivar means and values of different indexes as well as the cultivar ranking order for these indexes, without (Table 2) and with (Table 3) fungicide application.

In both experimental conditions (with and without fungicide), cultivar UPFA 22 was ranked first of the genotypes for all indexes. In the condition without fungicide application, this genotype ranked among the five first in eight out of ten studied characters, among them GY and HW, which are the most important characters for oat. On the other hand, this genotype was not well placed for PS and R^2. For the condition with fungicide application, UPFA 22 obtained a position among the top five ranks in six out of ten evaluated characters. In this condition the genotype was also top ranked for GY and HW and once again presented high height and low yield stability as main problems. This shows that the main problems with this cultivar are in fact plant height and yield stability, independent of fungicide application. However, genotype UPFA 22 grown under fungicide application was ranked a bit inferior for traits WTG and b_1 when compared to plants obtained in the condition without fungicide. This shows that UPFA 22, despite a medium high performance under fungicide application, obtained an inferior increase in

Table 2. Means of 24 genotypes evaluated in six locations in the EBCRA in the year 2002, without fungicide application

Cultivar	DEF[1]	PS	DEM	DFM	GY	HW	WTG	b_1	b_1+b_2	R^2	*Is*	OrderI_S	Is_{DP}	OrderIs_{DP}	*IDI*	Order*IDI*
UPF 15	94.11	104.64	128.17	34.06	1583.45	40.37	30.92	1.04	0.37	98.39	163	20	31	22	2.41	22
	(22[2]-4[3])	(18-3)	(21-4)	(19-3)	(13-3)	(20-3)	(10-2)	(12-3)	(24-4)	(4-2)						
UPF 16	90.94	90.71	125.89	34.94	1384.36	40.42	27.72	1.13	1.24	92.59	159	19	27	14	2.20	15
	(18-3)	(5-1)	(18-3)	(16-3)	(22-4)	(19-3)	(21-3)	(18-3)	(8-2)	(14-2)						
UPF 17	88.78	89.24	123.94	35.22	1238.52	39.80	33.92	1.02	0.89	95.31	129	12	26	12	2.01	12
	(13-3)	(4-1)	(15-3)	(15-3)	(24-4)	(21-3)	(4-1)	(10-3)	(15-3)	(8-2)						
UPF 18	91.61	113.17	123.72	32.11	2001.61	41.33	29.86	1.03	0.51	86.76	170	24	32	24	2.34	21
	(20-3)	(24-4)	(14-3)	(23-4)	(6-2)	(15-3)	(15-3)	(11-3)	(22-4)	(20-3)						
UPF 19	89.06	101.97	123.44	34.33	1414.94	40.59	30.28	1.04	0.52	88.74	165	21	30	19	2.21	16
	(14-3)	(14-3)	(13-2)	(18-3)	(21-3)	(18-3)	(14-3)	(13-3)	(21-4)	(19-3)						
UPFA 20	83.22	99.72	123.33	40.22	1946.72	42.35	35.07	0.79	0.85	68.08	99	8	22	7	1.65	6
	(6-2)	(10-3)	(12-2)	(3-1)	(8-2)	(12-3)	(3-1)	(5-1)	(17-3)	(23-4)						
UPFA 22	75.50	105.11	116.44	40.94	2138.11	47.70	33.29	0.64	1.52	69.14	63	1	16	1	1.27	1
	(2-1)	(19-3)	(2-1)	(2-1)	(5-1)	(2-1)	(5-2)	(2-1)	(2-1)	(22-4)						
UFRGS 14	91.22	93.45	121.67	30.50	1528.86	39.04	32.78	1.17	1.13	94.47	140	15	27	15	2.21	17
	(19-3)	(7-2)	(7-2)	(24-4)	(15-3)	(22-4)	(6-2)	(21-3)	(10-2)	(9-2)						
UFRGS 15	99.06	86.10	132.00	32.89	1273.69	38.83	30.51	0.90	0.90	90.46	167	22	31	23	2.56	24
	(24-4)	(2-1)	(24-4)	(21-4)	(23-4)	(23-4)	(13-3)	(7-2)	(14-3)	(16-2)						
UFRGS 1	693.67	110.62	131.72	38.06	1764.64	40.95	30.66	0.96	0.58	99.32	144	16	30	20	2.34	20
	(21-4)	(23-4)	(23-4)	(8-2)	(12-2)	(16-3)	(12-3)	(8-2)	(20-4)	(1-2)						
UFRGS 17	90.17	97.43	126.94	36.89	1503.50	41.40	31.49	1.15	1.00	94.42	136	14	25	11	2.04	14
	(17-3)	(9-2)	(19-3)	(11-2)	(16-3)	(14-3)	(9-2)	(20-3)	(11-2)	(10-2)						
UFRGS 1	895.94	91.17	130.56	34.67	1529.31	38.42	29.34	1.12	0.86	92.72	169	23	30	21	2.46	23
	(23-4)	(6-1)	(22-4)	(17-3)	(14-3)	(24-4)	(17-3)	(17-3)	(16-3)	(13-2)						
UFRGS 1	989.89	85.26	127.00	37.17	1463.36	43.05	27.21	1.29	0.73	90.82	155	18	27	16	2.25	18
	(16-3)	(1-1)	(20-3)	(10-2)	(19-3)	(10-2)	(22-4)	(24-4)	(18-3)	(15-2)						
URS 20	82.89	101.11	124.06	41.17	1971.63	46.74	31.72	0.88	1.53	95.62	66	2	19	4	1.27	2
	(5-2)	(12-3)	(16-3)	(1-1)	(7-2)	(3-1)	(8-2)	(6-2)	(1-1)	(7-2)						
URS 21	79.67	109.24	118.61	38.94	2235.86	48.05	30.88	0.59	1.44	60.24	81	3	18	2	1.66	8
	(4-1)	(22-4)	(4-1)	(6-2)	(2-1)	(1-1)	(11-2)	(1-1)	(6-1)	(24-4)						
URS 22	78.33	87.54	118.28	39.94	1492.70	43.74	27.75	1.13	1.52	89.17	97	6	19	5	1.64	5
	(3-1)	(3-1)	(3-1)	(4-1)	(17-3)	(7-2)	(20-3)	(19-3)	(3-1)	(18-3)						
OR 2	86.00	101.77	124.06	37.94	2182.59	44.81	25.47	1.18	0.59	94.26	132	13	26	13	2.02	13
	(9-2)	(13-3)	(17-3)	(9-2)	(3-1)	(5-2)	(24-4)	(22-3)	(19-4)	(11-2)						
OR 3	86.50	104.08	123.22	36.72	1793.53	43.73	37.33	1.11	0.95	99.31	98	7	22	8	1.68	9
	(10-2)	(16-3)	(11-2)	(12-2)	(11-2)	(8-2)	(1-1)	(15-3)	(12-3)	(2-2)						
OR 4	87.17	102.58	122.50	35.33	1838.27	43.66	37.28	1.19	0.38	98.86	120	10	24	10	1.92	10
	(11-2)	(15-3)	(10-2)	(14-3)	(10-2)	(9-2)	(2-1)	(23-3)	(23-4)	(3-2)						
FAPA 4	84.61	96.74	120.78	36.22	2456.01	46.65	25.76	0.97	0.94	89.58	101	9	22	9	1.65	7
	(8-2)	(8-2)	(5-2)	(13-3)	(1-1)	(4-1)	(23-4)	(9-2)	(13-3)	(17-2)						
FAPA 5	83.78	107.58	122.11	38.33	2149.29	43.92	32.23	0.77	1.22	74.49	94	5	21	6	1.56	4
	(7-2)	(20-3)	(9-2)	(7-2)	(4-1)	(96-2)	(7-2)	(4-1)	(9-2)	(21-4)						
CFT 1	87.89	104.42	121.06	33.11	1878.01	42.00	29.12	1.11	1.38	96.45	123	11	27	17	1.94	11
	(12-3)	(17-3)	(6-2)	(20-4)	(9-2)	(13-3)	(18-3)	(16-3)	(7-2)	(5-2)						
CFT 2	89.83	108.43	121.94	32.11	1457.27	40.88	27.98	1.08	1.48	96.32	147	17	28	18	2.27	19
	(15-3)	(21-4)	(8-2)	(22-4)	(20-3)	(917-3)	(19-3)	(14-3)	(5-1)	(6-2)						
IAC 7	75.11	100.47	114.44	39.39	1468.24	43.02	29.43	0.70	1.49	93.85	82	4	18	3	1.42	3
	(1-1)	(11-3)	(1-1)	(5-1)	(18-3)	(11-2)	(16-3)	(3-1)	(4-1)	(12-2)						
Ideotype	75.11	85.26	114.44	41.17	2456.01	48.05	37.33	0.59	1.53	99.32						
Mean[4]	87.29	99.69	123.58	36.30	1737.27	42.56	30.75	1.00	1.00	89.56						
SD[5]	6.11	8.08	4.41	3.01	338.75	2.76	3.15	0.19	0.39	10.63						

[1] days from emergence to flowering (DEF); plant height (PS); days from emergence to maturation (DEM); days from flowering to maturation (DFM); grain yield (GY); hectoliter weight (HW); weight of a thousand grains (WTG); response in unfavorable environments (b_1); response in favorable environments ($b_1 + b_2$); stability (R^2); ranking sum index (*Is*); ranking order for the ranking sum index (order *Is*); modified sum index (Is_{DP}); ranking order for the modified ranking sum index (order Is_{DP}); ideotype distance index (*IDI*); order for ideotype distance index (order *IDI*); [2] ranking order for the ranking sum; [3] ranking order for the modified ranking sum index; [4] overall mean; [5] standard deviation

Table 3. Means of 24 genotypes evaluated in six locations in the EBCRA in the year 2002, with fungicide application

Cultivar	DEF[1]	PS	DEM	DFM	GY	HW	WTG	*b1*	b_1+b_2	R^2	I_S	OrderI_S	Is_{DP}	OrderIs_{DP}	*IDI*	Order*IDI*
UPF 15	95.00	107.84	130.11	35.11	2103.86	42.65	34.36	1.01	0.78	95.94	166	23	32	23	2.45	22
	(2[2]-4[3])	(18-3)	(21-4)	(19-3)	(21-4)	(24-4)	(9-2)	(11-3)	(16-3)	(5-2)						
UPF 16	90.56	100.93	128.17	37.65	2296.66	45.14	30.88	0.92	1.27	91.42	136	18	26	16	1.94	14
	(17-3)	(9-2)	(18-3)	(13-3)	(14-3)	(16-3)	(19-3)	(9-2)	(8-2)	(13-2)						
UPF 17	89.39	96.99	126.06	36.72	2056.12	43.91	37.12	1.00	1.95	88.16	125	13	26	17	1.91	13
	(16-3)	(4-1)	(16-3)	(15-3)	(24-4)	(19-4)	(4-1)	(10-3)	(2-1)	(15-3)						
UPF 18	91.39	112.10	124.89	33.44	2491.87	43.84	29.52	1.24	1.27	94.42	162	22	31	21	2.39	21
	(18-3)	(24-4)	(9-2)	(23-4)	(7-2)	(20-4)	(21-4)	(23-4)	(9-2)	(8-2)						
UPF 19	89.11	110.97	125.50	36.44	2486.03	46.72	33.99	1.16	2.06	93.37	125	14	25	14	1.88	12
	(14-3)	(22-4)	(13-3)	(16-3)	(8-2)	(13-2)	(10-2)	(18-3)	(1-1)	(10-2)						
UPFA 20	83.94	101.20	125.56	41.56	2418.88	46.28	39.48	1.12	1.13	87.78	100	4	22	3	1.52	2
	(5-2)	(10-2)	(14-3)	(3-1)	(11-2)	(14-3)	(2-1)	(15-3)	(10-2)	(16-3)						
UPFA 22	75.50	106.35	116.67	41.44	2555.95	51.10	35.18	1.01	1.81	87.47	65	1	18	1	1.13	1
	(1-1)	(13-3)	(2-1)	(4-1)	(5-2)	(1-1)	(7-2)	(12-3)	(3-1)	(17-3)						
UFRGS 14	91.44	100.73	125.11	33.78	2667.33	43.65	36.18	1.20	0.30	97.15	133	17	28	18	2.12	17
	(19-3)	(7-2)	(11-2)	(21-4)	(4-1)	(21-4)	(5-2)	(21-4)	(21-4)	(3-2)						
UFRGS 15	100.17	94.64	133.44	33.17	2264.90	44.04	32.48	1.16	1.46	89.63	160	21	30	20	2.52	23
	(24-4)	(2-1)	(24-4)	(24-4)	(16-3)	(18-4)	(13-3)	(19-3)	(6-2)	(14-2)						
UFRGS 16	92.78	111.57	132.44	39.22	2366.05	43.00	32.45	1.24	1.57	97.47	157	20	31	22	2.38	20
	(21-3)	(23-4)	(23-4)	(11-2)	(12-3)	(22-4)	(14-3)	(24-4)	(5-2)	(2-2)						
UFRGS 17	92.44	109.94	128.17	35.50	2452.61	47.67	34.56	0.87	1.65	91.90	126	15	23	6	1.88	11
	(20-3)	(19-3)	(19-3)	(18-3)	(9-2)	(10-2)	(8-2)	(7-2)	(4-1)	(12-2)						
UFRGS 18	97.83	97.39	131.56	33.50	2128.70	42.97	30.95	1.22	0.84	93.66	179	24	33	24	2.63	24
	(23-4)	(5-1)	(22-4)	(22-4)	(20-4)	(23-4)	(18-3)	(22-4)	(15-3)	(9-2)						
UFRGS 19	89.33	97.70	129.83	40.50	2274.86	48.69	31.77	1.06	1.06	85.21	129	16	25	15	1.87	10
	(15-3)	(6-1)	(20-3)	(7-2)	(15-3)	(5-2)	(17-3)	(13-3)	(12-2)	(19-3)						
URS 20	84.33	104.96	125.06	40.67	2209.17	49.47	32.90	0.89	1.04	96.22	91	3	22	4	1.58	4
	(6-2)	(11-3)	(10-2)	(6-2)	(19-3)	(2-1)	(12-3)	(8-2)	(13-2)	(4-2)						
URS 21	79.33	110.74	120.22	41.28	2242.09	48.30	32.23	0.72	0.59	61.99	118	10	23	7	2.17	18
	(3-1)	(20-4)	(4-1)	(5-1)	(17-3)	(7-2)	(16-3)	(4-1)	(18-3)	(24-4)						
URS 22	80.28	92.13	120.11	41.82	2060.26	49.35	33.09	0.68	1.03	77.78	84	2	19	2	1.58	3
	(4-1)	(1-1)	(3-1)	(2-1)	(22-4)	(3-1)	(11-3)	(1-1)	(14-2)	(23-4)						
OR 2	85.28	100.89	125.72	40.33	2711.84	48.18	27.70	1.18	0.03	98.45	117	9	24	10	2.00	16
	(8-2)	(8-2)	(15-3)	(8-2)	(2-1)	(8-2)	(24-4)	(20-3)	(23-4)	(1-1)						
OR 3	86.72	106.54	126.83	39.89	2437.83	48.82	39.93	1.14	0.54	81.66	123	11	24	11	1.82	8
	(10-2)	(14-3)	(17-3)	(10-2)	(10-2)	(4-2)	(1-1)	(17-3)	(19-3)	(21-3)						
OR 4	87.39	107.10	125.39	37.74	2674.99	48.69	38.66	1.09	0.32	95.30	104	6	23	8	1.71	7
	(12-2)	(16-3)	(12-2)	(12-3)	(3-1)	(6-2)	(3-1)	(14-3)	(20-4)	(6-2)						
FAPA 4	86.44	95.70	123.78	37.17	2793.92	47.48	28.36	1.12	0.00	94.91	115	8	24	12	1.96	15
	(9-2)	(3-1)	(7-2)	(14-3)	(1-1)	(11-2)	(23-4)	(16-3)	(24-4)	(7-2)						
FAPA 5	84.44	107.09	124.50	40.00	2335.23	44.94	35.26	0.79	1.36	86.37	106	7	23	9	1.64	5
	(7-2)	(15-3)	(8-2)	(9-2)	(13-3)	(17-3)	(6-2)	(6-1)	(7-2)	(18-3)						
CFT 1	87.06	107.11	122.94	36.44	2530.55	47.28	30.70	0.68	0.24	93.13	123	12	24	13	1.86	9
	(11-2)	(17-3)	(5-2)	(17-3)	(6-2)	(12-2)	(20-3)	(2-1)	(22-4)	(11-2)						
CFT 2	88.78	110.82	123.50	35.00	2215.98	45.74	29.52	0.70	0.62	81.87	155	19	29	19	2.25	19
	(13-3)	(21-4)	(6-2)	(20-3)	(18-3)	(15-3)	(22-4)	(3-1)	(17-3)	(20-3)						
IAC 7	76.50	105.59	115.89	42.76	2057.33	47.76	32.37	0.77	1.11	80.11	101	5	22	5	1.69	6
	(2-1)	(12-3)	(1-1)	(1-1)	(23-4)	(9-2)	(15-3)	(5-1)	(11-2)	(22-4)						
Ideotype	75.50	92.13	115.89	42.76	2794.00	51.10	39.93	0.68	2.06	98.45						
Mean[4]	87.73	104.04	125.48	37.96	2368.04	46.49	33.32	1.00	1.00	89.22						
SD[5]	6.07	5.99	4.41	3.05	218.13	2.43	3.31	0.19	0.59	8.26						

[1] coded as in Table 2; [2] ranking order for the ranking sum index; [3] ranking order for the modified ranking sum index; [4]overall mean; [5]standard deviation of means

performance response than the other cultivars. This can be explained by the fact that the genotype presents superior levels of resistance to crown rust, and therefore had a lower response to fungicide application.

Another genotype that ranked top in both conditions for all indexes used was URS 20 which ranked second for *Is* and *IDI* and fourth for Is_{DP} without fungicide. Under fungicide application, this genotype ranked third for *Is* and fourth for Is_{DP} and *IDI*, and was outstanding for HW in both conditions. However, this genotype was not well ranked for GY in any of the conditions evaluated in this study.

Cultivar URS 21 presented an excellent ranking for the condition without fungicide, where it was ranked third for *Is*, second for Is_{DP} and eighth for *IDI*. This genotype was ranked among the top five genotypes in five out of ten studied characters, among them GY and HW. However, its main deficiencies were a high height and low grain yield stability, similarly to cultivar UPFA 22. Nevertheless, under fungicide application, this genotype did not present a high yield and was ranked 10^{th} for *Is*, seventh for Is_{DP} and 18^{th} for *IDI*; which shows that this genotype does not respond expressively to fungicide application, compared to the other cultivars. Regarding GY, the genotype moved from second in the condition without fungicide to 10^{th} when fungicide was applied, presenting an increase of only 6.29 kg ha^{-1} in grain yield under fungicide application. This result suggests the existence of a high level of crown rust resistance in this genotype, making the application of fungicide for this genotype inadvisable, in line with results reported by Benin et al. (2003).

Cultivars UPF 19 and UFRGS 14 responded best regarding grain yield when the fungicide was applied, expressing increases of 1071.09 and 1138.47 kg ha^{-1}, respectively. Despite this expressive increase in GY, both genotypes did not rank well for any of the estimated indexes in the experimental conditions used, since they presented inferior means for most measured characters.

Great similarity was observed in a comparison of the results obtained with the different indexes and conditions (Tables 2 and 3). This fact can be proved by the high and significant correlations observed between the different indexes (Table 4). Among the evaluated indexes, the ones that presented highest correlations were *Is* and Is_{DP}, for both equivalent or contrasting conditions of fungicide application. This result can be explained by the high similarity presented by the indexes, since Is_{DP} is merely a modified version of *Is*. The use of Is_{DP} can be a good alternative (*i.e*, to group similar genotypes and separate dissimilar ones, when genotypes with similar means are used within ranking groups and large differences between groups, which would reduce the distances within groups and differentiate groups clearly). The high correlations detected between the different indexes (with *vs* without fungicide) indicate that, in general, the studied genotypes responded similarly to fungicide application, with some exceptions, e.g., URS 21. The lowest correlations were observed between *IDI* (with fungicide) and *Is* and Is_{DP} (without fungicide), which were, respectively, 0.75 and 0.78. However, even those correlations were highly increased. Garcia Júnior and Souza Júnior (1999), in a study comparing maize inbreds, also found a 0.78 correlation between the indexes *Is* and *IDI*, which is in agreement with the results of the present study.

Regarding the correlations presented between the different indexes and the evaluated characters, Table 5 shows that the indexes presented significant correlations with the same characters under different conditions (application or not of fungicide). In the presence of fungicide, the characters that presented significant and positive correlations with the three indexes were DEF and DEM, and significant and negative correlations were DFM and HW. The correlation signal is in agreement with the expected, since for DEF and DEM the genotypes with the best means were considered the best, while the opposite was observed for the other two characters. In the absence of fungicide, the characters that showed significant correlations for the condition with fungicide, remained correlated with the indexes. Nevertheless, the adaptability parameters b_1 and b_1+b_2 also began to show significant correlations with the indexes. This fact evidences that in this condition, an increase in importance is seen for the parameters that measure the genotype responses in GY when facing environmental variations.

Table 4. Phenotypic correlations between selection indexes

Index	Condition	with fungicide			without fungicide		
		IDI[1]	*Is*	Is_{DP}	*IDI*	*Is*	Is_{DP}
IDI	WF	1.00	0.95*	0.93*	0.84*	0.75*	0.78*
Is	WF		1.00	0.97*	0.90*	0.85*	0.88*
Is_{DP}	WF			1.00	0.86*	0.81*	0.87*
IDI	SF				1.00	0.97*	0.95*
Is	SF					1.00	0.96*
Is_{DP}	SF						1.00

*P < 0.05

[1] ideotype distance index (*IDI*); ranking sum index (*Is*); modified ranking sum index (Is_{DP})

Table 5. Phenotypic correlations between 10 evaluated traits

	DEF[1]	PS	DEM	DFM	GY	WP	WTG	b_1	b_1+b_2	R^2
with fungicide										
IDI	0.79*	0.04	0.64*	-0.72*	-0.17	-0.76*	-0.41	0.35	-0.15	0.18
Is	0.86*	0.11	0.72*	-0.77*	-0.18	-0.81*	-0.32	0.38	-0.03	0.27
Is_{DP}	0.85*	0.09	0.71*	-0.76*	-0.17	-0.87*	-0.27	0.47	-0.02	0.37
without fungicide										
	DEF	PS	DEM	DFM	GY	WP	WTG	b_1	b_1+b_2	R^2
IDI	0.92*	-0.20	0.75*	-0.77*	-0.53	-0.81*	-0.24	0.57*	-0.59*	0.43
Is	0.89*	-0.22	0.71*	-0.76*	-0.55	-0.82*	-0.29	0.62*	-0.62*	0.45
Is_{DP}	0.93*	-0.07	0.75*	-0.78*	-0.45	-0.80*	-0.21	0.57*	-0.66*	0.49

*P < 0.05

[1] as coded in Table 2

However, the most important character for plant breeding (GY) did not present significant correlation with any of the indexes used, which must be considered a major flaw in the indexes. To correct this problem, it would be necessary to add a larger weight to GY, since it is the most important character for oat genotype selection. In general, the indexes used were efficient in the ranking of oat cultivars in different environments. The genotypes UPFA 22, URS 21 and URS 20 were noteworthy with all indexes.

The obtained results indicate that these indexes are viable alternatives for the ranking of cultivars in experiments performed in different environments. However, changes are due in the weight of characters, according to their agronomic importance, i.e., characters such as GY and HW should receive a higher weight, which would prevent high ranking of genotypes with low performance for these characters, as it was the case with genotype IAC 7 in both conditions and UPFA 20 and URS 22 under fungicide application (Tables 2 and 3). Another possible change would be a stratification of the environments, dividing them in favorable and unfavorable, or even regionalizing the rankings. However, such changes should be discussed by the components of Research Committees of different crops, in order to establish a more efficient cultivar ranking that is trusted with the support of the Committees. Nevertheless, for measuring the viability of the changes mentioned above, it would be necessary to evaluate the indexes in experiments conducted in a higher number of environments. After testing and validating the aforementioned changes, these indexes could even be useful for cultivar releases.

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Uso de índices de seleção não paramétricos em estudos de adaptabilidade e estabilidade de cultivares de aveia

RESUMO - *No Brasil a aveia é cultivada em uma ampla área, no entanto, não existem relatos da utilização dos diversos caracteres de importância, avaliados em diferentes ambientes, de forma simultânea, na classificação de cultivares. O objetivo do estudo foi comparar índices de seleção não paramétricos, na classificação de cultivares, através do desempenho médio destes, em seis ambientes, com e sem a aplicação de fungicida. Os índices utilizados no presente estudo foram: índice de soma de classificação, índice de soma de classificação modificado (utilizando o desvio padrão na separação de médias) e índice de distância ao ideótipo. O cultivar UPFA 22 foi classificado como melhor genótipo por todos os índices, o que o coloca em posição de destaque, mais ainda por ter sido bem classificado para rendimento de grãos e peso do hectolitro. Estes índices são eficientes, porém, são necessárias modificações nos pesos dos caracteres, de acordo com a importância e/ou uma estratificação dos ambientes.*

Palavras-chave: aveia-branca, índices de seleção não-paramétricos, classificação de cultivares.

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