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Methods of adaptability and stability analysis in irrigated rice genotypes in Minas Gerais, Brazil

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ABSTRACT - *The objective of this study was to compare different estimation methods of adaptability and stability in nine genotypes of irrigated rice. The experiment was conducted at three sites in the state of Minas Gerais in the growing seasons from 2000/2001 to 2005/2006, totaling 11 environments. The adaptability and stability were analyzed by the methods proposed by Eberhart and Russel (1966), Cruz et al. (1989), Carneiro (1998) and Annicchiarico (1992). The methods proposed by Carneiro (1998) and by Annicchiarico (1992) were more satisfactory due to the measure of behavioral adaptability and stability, which combined adaptation, adaptability and stability concepts in just one parameter. General adaptability was observed in the lines CNAi 8872 and CNAi 8874 and specific adaptability to favorable conditions in cultivar Rio Grande.*

Key words: *Oryza sativa*, genotype-environment interaction, genetic breeding, cultivar recommendation.

INTRODUCTION

Every year, numerous crosses are performed by the genetic breeding program of irrigated rice of Minas Gerais, based on an agreement between the Agriculture and Livestock Research Institute EPAMIG and the Brazilian Agricultural Research Corporation EMBRAPA Arroz e Feijão, resulting in a high number of segregating populations. Thereafter, a large number of lines is selected in the preliminary comparative trials and tested for a specific regional scope in so-called trials Value for Cultivation and Use (VCU). The greatest challenge for breeders is therefore the identification of genotypes with an ideal performance and stability under different environmental conditions, which is particularly difficult due to the genotype-environment interaction (Cargnin et al. 2006). Several studies in Asian countries showed that the genotype-environment interaction, for the trait grain yield in irrigated rice, is relatively high (Cooper et al. 1999 a,b; Inthapanya et al. 2000; Ouk et al. 2007).

Studies regarding the genotype-environment interaction, despite highly important for breeding, provide no detailed information about the performance of each genotype in response to environmental variations. The adaptability and stability were therefore analyzed to identify genotypes with predictable performance and responsive to environmental

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variations, be it in narrow or wide conditions (Cruz et al. 2004).

A series of methods are nowadays available to identify the responses of genotypes to environmental variations (Cruz et al. 2004; Cruz and Carneiro 2006). Among the methodologies of adaptability and stability, the one proposed by Eberhart and Russell (1966) is one of the most commonly used in the recommendation of cultivars. It evaluates the performance of each genotype to environmental variations by simple linear regression analysis, which estimates the regression coefficient of the traits of one genotype compared to an environmental index. The underlying concept of stability of this methodology is predictability, interpreted by the deviations from linear regression (Cruz et al. 2004).

Silva and Barreto (1985) proposed an adjustment for each genotype of a single regression equation composed of two straight-line segments to estimate the performance adaptability and stability of genotypes. Cruz et al. (1989) proposed an extension of the cited methodology, by simplifying operations and including more appropriate statistical properties for the breeding objective. Cruz et al. (2004) stated that this method provides non-correlated estimates of the regression coefficients; it is based on the concept that the ideal genotype has relatively high and stable yields in unfavorable environments, but is able to respond to favorable environments; and assumes the same concept of stability as used by Eberhart and Russell (1966).

Since the cultivars are recommended based on different parameters estimated by these methodologies, it is rather difficult to make more specific recommendations for particular environmental conditions. Carneiro (1998) thus proposed some non-parametric methodologies, modifying the methods proposed by Hernandez et al. (1993) and Lin and Binns (1988), which tend to express, in one or few parameters, the performance and behavior of one genotype in terms of yield and response capacity to environmental variations and fluctuations, which involves concepts of adaptation, adaptability and stability of performance (Oliveira et al. 2006). One of these, the methodology of the square trapeze weighted by the residual coefficient of variation takes the fluctuation in the genotype response to environmental variations into consideration, that is, it is sensitive to the variation of genotype performance in different environments (Cruz and Carneiro 2006).

Another non-parametric method that facilitates the interpretation of results for cultivar recommendation for different environmental conditions was proposed by Annicchiarico (1992). It measures the stability based on the superiority of a genotype compared to the mean of each environment.

This study aimed to compare different estimation methods of adaptability and stability of genotypes for the recommendation of irrigated rice cultivars.

MATERIAL AND METHODS

Nine irrigated rice genotypes were evaluated: four cultivars (BRSMG Predileta, Rio Grande, Jequitibá and BR IRGA-409) and five lines (CNAi 8859, CNAi 8868, CNAi 8872. CNAi 8874, and CNAi 8883), in a randomized block design with three replications. Each experimental plot consisted of six rows of 5 m, 0.30 m apart. The useful plot area consisted of the four central rows, 4 m long, totalizing a useful area of 4.8 m^2. The experiment of competition between cultivars and lines was conducted at three locations in Minas Gerais, in a total of 11 environments: in Leopoldina, in the growing seasons 2000/2001. 2001/2002. 2002/2003, 2003/2004. 2004/2005 and 2005/2006; Prudente de Morais, in 2000/2001; and, Janaúba, in the growing seasons 2001/2002. 2002/2003, 2003/2004 and 2005/2006. The experiment was set up on wetland soil and maintained constantly under flooding irrigation.

The grain yield (kg ha^{-1}) of all genotypes was evaluated. After individual analysis of variance of each environment, the homogeneity of the residual mean squares was analyzed by the test of Hartley (Ramalho et al. 2000). Results showed that the residual mean squares were homogenous; the analysis of joint variance was therefore possible. In this case, the statistical model considered the genotype effects as fixed and the effects of replication, environment and genotype-environment interaction as random (Cruz et al. 2004). The parameters of adaptability and stability were estimated by the methods of Eberhart and Russell (1966), Cruz et al. (1989), Carneiro (1998) and Annicchiarico (1992).

The linear regression model as used in the methodology of Eberhart and Russell (1966) is given by:

$$Y_{ij} = \beta_{0i} + \beta_{1i} I_j + \delta_{ij} + \varepsilon_{ij}$$

where: Y_{ij} is the mean of grain yield (kg ha^{-1}) of genotype i, in environment j; β_{0i} is the general mean; β_{1i} is the linear regression coefficient; δ_{ij} is the deviation from the regression; ε_{ij} is the mean experimental error; I_j is the codified environmental index $\left(\sum_j I_j = 0\right)$, given by:

$$I_j = \frac{1}{g}\sum_i Y_{ij} - \frac{1}{ag} Y_{..}$$

where g is the number of genotypes, a is the number of environments and $Y_{..}$ is the general mean of the environment.

By this methodology the adaptability and the stability are determined by the estimates of the parameters β_{1i} and δ_{ij} , respectively.

The methodology of Cruz et al. (1989) is based on the analysis of bisegmented regression and uses, as parameters of adaptability, the mean $\left(\hat{\beta}_{0i}\right)$ and the linear response to the unfavorable $\left(\hat{\beta}_{1i}\right)$ and to the favorable environments $\hat{\beta}_{1i}+\beta$. The genotype stability is evaluated by the deviation from regression $\left(\hat{\sigma}^2_{\delta_i}\right)$ of each genotype, due to environmental variations.

The statistical model is given by:

$$Y_{ij}=\beta_{0i} + \beta_{1i}I_j + \beta_{2i}T(I_j) + \delta_{ij} + \varepsilon_{ij}$$

where: Y_{ij}, β_{0i}, β_{1i}, δ_{ij}, ε_{ij} and were defined previously; and

$T(I_j) = 0$ if $I_j < 0$; and

$T(I_j) = I_j + \bar{I}_+$ if $I_j > 0$, where $\bar{I}_+$ the mean of the positive indices I_j.

Among the methods proposed by Carneiro (1998), the method of the square trapeze weighted by the coefficient of residual variation was chosen for this study. The performance of each genotype is given by:

$$P_i = \sum_{j=1}^{n}\left[\left(\frac{Y_{g(j+1)}+Y_{gj}}{2}\right)-\left(\frac{Y_{i(j+1)}+Y_{ij}}{2}\right)\right]^2\left(\bar{Y}_{.(j+1)}-\bar{Y}_{.j}\right)$$

where: P_i is the measure of performance adaptability and stability of genotype i; Y_{ij} is the estimated yield of genotype i in environment j; $\bar{Y}_{.j}$ is the general mean of environment j; Y_{gj} is the estimated yield of the hypothetical ideal genotype g in environment j, as defined by Cruz et al. (1989), where:

$$Y_{gj}=\beta_{0g} + \beta_{1g}I_j + \beta_{2g}T(I_j)$$

where: β_{0g} is the maximum yield of the entire trial; β_{1g} and β_{2g} are values established by Cruz and Carneiro (2006) (0.5 and 1.0, respectively). These values correspond to the genotype that has a weak response to unfavorable environments ($\beta_{1g} = 0,5$) but is responsive to favorable conditions ($\beta_{1g} + \beta_{2g} = 1.5$).

Since the coefficient of residual variation is the measure of experimental accuracy, Cruz and Carneiro (2006) recommend that the estimator be multiplied by factor $f = \frac{CV_j}{CVT}$, where: CV_j represents the coefficient of residual variation of environment j and the sum of the coefficients of variation of j environments. Thus, the locations with higher experimental accuracy have a higher weight in the evaluation of the genotype performance, since smaller distances to the ideal cultivar indicate that the adaptability and stability of performance of a genotype are greater.

By the method proposed by Annicchiarico (1992), the stability is measured by the superiority of a genotype over the mean of each environment. The method is based on the estimation of a confidence index (ω_i) that the performance of a particular genotype would be relatively superior (Cruz and Carneiro 2006). This index is given by:

$$\omega_i = \hat{\mu}_i - z_{(1-\alpha)}\hat{\sigma}_{zi}$$

where $\hat{\mu}_i$ is the mean percentage of genotype i; $z_{(1-\alpha)}$ is the percentile of the function of normal standard distribution, for which the value of the function of accumulated distribution is $1-\alpha$, where $\alpha = 0.25$; and, $\hat{\sigma}_{zi}$ is the standard deviation from the percentage values of genotype i.

The analyses of variance, parameter estimation and significance tests were performed using Program Genes (Cruz 2006).

RESULTS AND DISCUSSION

The results of the joint analysis of variance showed that the effects of environments, genotypes and genotype-environment interaction were significant ($p \leq 0.01$) (Table 1). The coefficient of residual variation was 10.77%, considered an adequate value for rice, which, according to Lúcio et al. (1999), is classified as moderate, evidencing accuracy of the experiments and soundness of the inferences regarding the estimates. The mean yield in the trials was 6,404 kg ha^{-1} (Table 1).

Table 1. Summary of the joint analysis of variance of the 9 genotypes of irrigated rice, evaluated in 11 environments in the state of Minas Gerais

Sources of variation	df	Mean square
Blocks / environments	22	1293073.49
Environments (E)	10	23441730.73 **
Genotypes (G)	8	2979509.59 **
GxE	80	881121.85 **
Error	176	476208.68
Total	296	
Mean	6404	
CV %	10.77	

** significant ($p < 0.01$)

It was verified that the source of variation of the genotype-environment interaction effect was highly significant ($p \leq 0.01$) (Table 1), indicating differentiated responses of genotypes in distinct environments, suggesting that a superior genotype in one environment would normally not have the same performance in another. In this case, the work of breeders is hampered and adaptability and stability analyses have to be used to characterize the relative performance of the genotypes under different environmental conditions, which allow the identification of those with stable performance that respond to environmental variations (Cruz et al. 1989; Cargnin et al. 2006).

The method of Eberhart and Russell (1966) considers a genotype ideal when the mean yield is high, the regression coefficient β_{1i} is equal to 1.0, and deviations from regression are as low as possible (Table 2). Therefore, the lines CNAi 8872 and CNAi 8874 can be considered closest to the ideal genotype, with high grain yield, regression coefficient $\hat{\beta}_{1i}$ of 1, and non-significant deviations from the regression $\left(\hat{\sigma}^2_{\delta_i} = 0\right)$, together with a high coefficient of determination, which indicates high performance stability or predictability, evidencing general adaptability of these genotypes, regarding the environmental conditions. Cultivar Rio Grande stood out with $\hat{\beta}_1 > 1$ and low deviations from regression $\left(\hat{\sigma}^2_{\delta_i} = 0\right)$, together with a high coefficient of determination, conferring high performance stability or predictability, indicating that this genotype can be recommended for favorable environments and is responsive to environmental improvements. However, no suitable genotype was found for unfavorable environmental conditions. On the other hand, in the highest yielding genotype, cultivar BRSMG Predileta with 6,880 kg ha^{-1}, $\hat{\beta}_1 = 1$, while the deviation from regression was high $\left(\hat{\sigma}^2_{\delta_i} \neq 0\right)$, together with a low coefficient of determination (56.41%).

The methodology of Cruz et al. (1989) defines an ideal genotype as one with high mean, $\hat{\beta}_1 > 1$ and $\hat{\beta}_1 + \hat{\beta}_2 > 1$. However, no such genotype was found here (Table 3). Nevertheless, by this methodology cultivar BRSMG Predileta was closest due to its response to environmental improvements ($\hat{\beta}_1 + \hat{\beta}_2 > 1$). Still, the high value of deviation from regression and the low coefficient of determination show that the stability of this cultivar was low in the environments evaluated, limiting its recommendation (Table 3). By this methodology no genotype was identified for the unfavorable environments either, since all ,$\hat{\beta}_1 \geq 1$. This fact evidences that the genetic breeding program of irrigated rice in Minas Gerais performs the selection of lines in favorable environmental conditions, since in adverse conditions they do not adapt well.

The regression coefficient of cultivar BRSMG Predileta was ($\hat{\beta}_1 + \hat{\beta}_2 > 1$) by the method of Cruz et al. (1989), statistically superior to the unit, and higher than the regression coefficient (0.91) estimated by the method of Eberhart and Russell (1966). Oliveira et al. (2006) claim that this result indicates the method of Cruz et al. (1989) as more specific in the cultivar recommendation for favorable and unfavorable environmental conditions, compared to the method proposed by Eberhart and Russell (1966).

However, the results obtained by the methodologies of Eberhart and Russell (1966) and of Cruz et al. (1989) show that none of the evaluated genotypes had an ideal performance. Therefore, it is necessary to determine the genotypes that are closest to the ideotype. For this purpose, the methodology of the weighted square trapeze by the coefficient of residual variation (Carneiro 1998), expresses, in one or few parameters, the performance and behavior of a genotype compared to the ideal genotype and environmental variations. This analysis showed that the three closest genotypes to the ideotype for unfavorable conditions were lines CNAi 8872, CNAi 8874 and CNAi 8883 (Table 4). For favorable conditions and the general environment condition, the three genotypes closest to

Table 2. Estimates of the mean grain yield $\left(\hat{\beta}_{0i}\right)$, of the regression coefficient $\left(\hat{\beta}_{1i}\right)$, of the deviation from regression $\left(\hat{\sigma}^2_{\delta_i}=0\right)$ and the coefficient of determination (R^2) for 9 genotypes of irrigated rice evaluated in 11 environments in the state of Minas Gerais, by the methodology of Eberhart and Russell (1966).

Genotype	$\left(\hat{\beta}_{0i}\right)$	$\left(\hat{\beta}_{1i}\right)$	$\left(\hat{\sigma}^2_{\delta_i}=0\right)$ (10^3)	**R^2** (%)
BRSMG Predileta	6,880	0.91^{ns}	452.21^{**}	56.41
BR IRGA-409	6,041	0.88^{ns}	163.16^{*}	69.69
Jequitibá	6,189	0.79^{ns}	92.81^{ns}	70.39
Rio Grande	6,494	1.35^{*}	-1.56^{ns}	91.76
CNAi 8859	6,093	0.83^{ns}	-72.03^{ns}	88.34
CNAi 8868	6,227	0.96^{ns}	-16.28^{ns}	86.21
CNAi 8872	6,728	1.07^{ns}	85.10^{ns}	81.92
CNAi 8874	6,667	1.16^{ns}	33.81^{ns}	87.09
CNAi 8883	6,318	1.07^{ns}	196.74^{*}	75.59

** significant ($p < 0.01$); * significant ($p < 0.05$); ^{ns} non-significant

Table 3. Estimates of the mean grain yield $\left(\hat{\beta}_0\right)$, of the regression coefficients $\left(\hat{\beta}_1,\hat{\beta}_1,\hat{\beta}_2\right)$, of the deviation from regression $\left(\hat{\sigma}^2_{\delta_i}\right)$ and the coefficient of determination (R^2), for 9 genotypes of irrigated rice evaluated in 11 environments in the state of Minas Gerais, by the methodology of Cruz et al. (1989)

Genotypes	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_1+\hat{\beta}_2$	$\hat{\sigma}^2_{\delta_i}$ (10^3)	**R^2** (%)
BRSMG Predileta	6,880	0.79^{ns}	2.91^{**}	128.51^{**}	72.84
BR IRGA-409	6,041	0.94^{n}	^{s}-0.18*	87.20^{ns}	75.67
Jequitibá	6,189	0.84^{ns}	-0.08^{ns}	70.25^{ns}	75.49
Rio Grande	6,494	1.33^{*}	1.55^{ns}	52.25^{ns}	91.88
CNAi 8859	6,093	0.85^{ns}	0.43^{ns}	26.26^{ns}	89.53
CNAi 8868	6,227	0.92^{ns}	1.69^{ns}	37.90^{ns}	89.13
CNAi 8872	6,728	1.03^{ns}	1.78^{ns}	72.54^{ns}	84.06
CNAi 8874	6,667	1.19^{ns}	0.72^{ns}	61.25^{n}	^{s}87.83
CNAi 8883	6,318	1.12^{n}	^{s}0.18^{ns}	104.80	*78.68

** significant (p d" 0.01); * significant (p d" 0.05); ^{ns} non-significant.

the ideal genotype were lines CNAi 8872, CNAi 8874 and cultivar Rio Grande. The adaptability of line CNAi 8883 was therefore identified as specific to unfavorable environments and of cultivar Rio Grande specific to favorable environments while the lines CNAi 8872 and CNAi 8874 have wide adaptability (general adaptability).

The use of the method proposed by Carneiro (1998) overcomes the difficulty of using the methods of Eberhart and Russell (1966) and Cruz et al. (1989), since the recommendation of genotypes by these methods in based on numerous parameters (β_0; β_1; $\beta_1+\beta_2$; $\sigma^2_{\delta i}$ and R^2). Oliveira et al. (2006) report that the recommendation by the method of Carneiro (1998) is immediate, due to the unicity of the statistical Pi.

In the methodology proposed by Annicchiarico (1992), the measure of stability is given by the superiority of a genotype compared to the mean of each environment (see Table 5). For the general environment conditions it was verified that cultivar BRSMG Predileta and the lines CNAi 8872 and CNAi 8874 would have a 4.61, 2.94 and 1.87% higher performance, respectively, than the environmental mean (with 75% probability), with the highest confidence indices (ω_i), which are therefore the genotypes with best performances. For the favorable environmental conditions the ω_i values were highest for lines CNAi 8872, CNAi 8874 and cultivar Rio Grande (102.84, 104.79 and 103.64%, respectively). For the unfavorable environmental

Table 4. Grain yield, estimates of the statistical Pi for the general (Pi_g), favorable (Pi_f) and unfavorable environmental conditions (Pi_d) for 9 genotypes of irrigated rice, evaluated in 11 environments in the state of Minas Gerais, by the methodology of the square trapeze, weighted by the coefficient of residual variation (Carneiro 1998)

Genotype	Grain yield (kg ha^{-1})	Pi_g (10^6)	Class.	Pi_f (10^6)	Class.	Pi_d (10^6)	Class.
BRSMG Predileta	6,880	1676	5	433	4	1242	8
BR IRGA-409	6,041	1901	7	776	9	1125	5
Jequitibá	6,189	1876	6	731	8	1145	6
Rio Grande	6,494	1461	3	394	3	1067	4
CNAi 8859	6,093	1951	8	728	7	1223	7
CNAi 8868	6,227	2091	9	671	6	1420	9
CNAi 8872	6,728	1194	1	390	1	805	1
CNAi 8874	6,667	1285	2	391	2	894	2
CNAi 8883	6,318	1531	4	628	5	903	3

conditions cultivar BRSMG Predileta and line CNAi 8872 stood out with values of 109.03 and 102.88%, respectively.

Summing up, by the results obtained by the methodology of Annicchiarico (1992), it was verified that line CNAi 8872 has a wide adaptation to environmental fluctuations; cultivar BRSMG Predileta has specific adaptability to unfavorable environments, while cultivar Rio Grande and line CNAi 8874 have a specific adaptability to favorable environments. Therefore, the great advantage of this methodology is the ease of result interpretation since it estimates the risk of success in the recommendation of a particular cultivar for different environmental conditions by the confidence index ω_i.

In this discussion, it was verified that practically the same irrigated rice genotypes were recommended for the state of Minas Gerais, based on the methodologies used in this study. However, the method of the square trapezium weighted by the coefficient of residual variation, as proposed by Carneiro (1998) and the method proposed by Annicchiarico (1992) were most suitable for the recommendation of cultivars, owing to the measure of behavioral adaptability and stability, which combined adaptation, adaptability and stability concepts in just one parameter, making the interpretation of results far easier.

CONCLUSIONS

1. The methodologies used here indicated practically the same irrigated rice genotypes for the state of Minas Gerais. The methods proposed by Carneiro (1998) and by Annicchiarico (1992) however proved most appropriate for the recommendation of cultivars, due to the ease of interpretation of results.

2. General adaptability was observed in the lines CNAi 8872 and CNAi 8874 and specific adaptability to favorable environmental conditions in cultivar Rio Grande.

Table 5. Measures of grain yield, of the standard deviation of the percentage values of grain yield compared to the mean of environments $\hat{\sigma}_{zi}$ and of the confidence index ω_i for 9 genotypes of irrigated rice, evaluated in 11 environments in the state of Minas Gerais, by the methodology proposed by Annicchiarico (1992)

Environments	Measure	Mean	Genotypes								
			BRSMG Predileta	BR IRGA -409	Jequitibá	Rio Grande	CNAi 8859	CNAi 8868	CNAi 8872	CNAi 8874	CNAi 8883
Geral	Grain yield (kg ha^{-1})	6,404	6,880	6,041	6,189	6,494	6,093	6,227	6,728	6,667	6,318
	Grain yield (%)	100.00	107.43	94.33	96.64	101.41	95.14	97.24	105.06	104.11	98.66
		-	11.69	8.76	8.38	8.32	1.90	5.66	7.67	7.36	8.73
		-	104.61	92.05	94.67	98.47	94.07	95.72	102.94	101.87	96.06
Favorable	Grain yield (kg ha^{-1})	7,320	7,611	6,912	6,969	7,680	6,907	7,067	7,671	7,769	7,294
	Grain yield (%)	100.00	103.97	94.43	95.20	104.92	94.36	96.54	104.79	106.13	99.64
		-	14.66	9.32	6.13	4.35	4.80	6.23	6.64	4.51	10.34
		-	99.61	92.09	93.72	103.64	93.15	94.70	102.84	104.97	96.96
Unfavorable	Grain yield (kg ha^{-1})	5,641	6,271	5,315	5,538	5,505	5,415	5,526	5,942	5,748	5,505
	Grain yield (%)	100.00	111.17	94.22	98.17	97.59	95.99	97.96	105.33	101.90	97.59
		-	8.33	9.17	10.29	9.62	5.27	5.62	9.06	9.06	7.98
		-	109.03	91.77	95.45	94.70	94.75	96.46	102.88	99.46	95.15

Métodos de análises de adaptabilidade e estabilidade em genótipos de arroz irrigado em Minas Gerais

RESUMO - *O objetivo deste trabalho foi comparar diferentes métodos de estimação da adaptabilidade e estabilidade em nove genótipos de arroz irrigado. O experimento foi instalado em três locais de Minas Gerais durante os anos agrícolas de 2000/2001 a 2005/2006, perfazendo-se um total de onze ambientes. Para a análise de adaptabilidade e estabilidade utilizaram-se os métodos propostos por Eberhart e Russel (1966), por Cruz et al. (1989), por Carneiro (1998) e por Annicchiarico (1992). O método proposto por Carneiro (1998) e o proposto por Annicchiarico (1992), destacaram-se para a recomendação de cultivares, em razão da medida de adaptabilidade e estabilidade de comportamento englobar, em um único parâmetro, os conceitos de adaptação, adaptabilidade e estabilidade, facilitando a interpretação dos resultados. As linhagens CNAi 8872 e CNAi 8874 apresentam adaptabilidade geral. A cultivar Rio Grande apresenta adaptabilidade específica às condições favoráveis de ambiente.*

Palavras-chave: *Oryza sativa;* interação genótipos x ambientes; melhoramento genético; recomendação de cultivares.

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