Grain yield gains in three recurrent selection cycles in the CNA-IRAT 4 irrigated rice population

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ABSTRACT

One line of research on irrigated rice genetic breeding programs at Embrapa consists of synthesizing wide genetic base populations followed by recurrent selection. This strategy ensures systematic continuous gains for grain yield and other traits of interest. To estimate the gains observed in three recurrent selection cycles in the CNA-IRAT 4 population, the grain yield data from 924 $S_{0:2}$ families in 14 experiments carried out in various Brazilian states in the 1992/93, 1994/95 and 1997/98 growing seasons were analyzed. A triple lattice (two 10 x 10 and two 8 x 8 lattices) experimental design was used in the first cycle and Federer augmented blocks in the two subsequent cycles. A non -significant gain was observed in the first cycle (only 15.7 kg/ha (0.28%). The gain observed in the second cycle and the mean gain observed due the selection in the first and second cycles were significante and of high magnitude (369.9 kg/ha (6.65%) and 259.9 kg/ha (4.67%), respectively). Results showed that recurrent selection applied to genetically divergent populations can result in considerable gains for grain yield.

KEY WORDS: *Oryza sativa*, genetic gain, genetic breeding.

INTRODUCTION

The International Rice Research Institute (IRRI) released IR8 for cultivation in 1966, the first modern irrigated rice cultivar and the precursor of the 'Green Revolution´ that had a strong impact on world rice cultivation. Since then, breeders have used this cultivar, or lines derived from it, intensively as parents in crosses, a strategy that has limited the genetic variability of populations used in breeding programs, contributing to the establishment of a yield plateau. Studies by Peng et al. (1999) showed that the yield potential of new bred rice cultivars, *indica* subspecies, have remained the same over 30 years, since the release of IR8.

Brazil re-organized its agricultural research structure in the mid 1970s, and irrigated rice researchers were able to take advantage of all the advances achieved by international research groups, which helped them meet their goals in a shorter period of time (Morais and Rangel, 1997). All the effort was rewarded in the beginning of the 1980s when the traditional high stand varieties were substituted with modern low stand varieties, practically doubling the irrigated rice yield in several states in Brazil. In Rio Grande do Sul, yield in the field increased by 30% (Carmona et al., 1994) due to modern cultivars and better crop management. After this great advance, irrigated rice yield has remained the same, and efforts to increase yield potential in cultivar populations have not resulted in expressive gains (Rangel et al., 2000a). Two factors may account for the stagnation of the yield potential of the irrigated rice cultivars in Brazil: a) prioritization of grain quality and disease resistance in detriment to yield; and b) the use of a few repeated parents in the formation of breeding populations.

Recently researchers involved in the development of irrigated rice cultivars have tried to increase the yield potential through various strategies. Two lines of research are used in the IRRI: a) development of a new type of plant using the *japonica tropical* germplasm, whose results have not been encouraging up to now (Peng et al., 1999) and b) development of *indica* rice hybrids for tropical environments using Chinese technology. It is unlikely that these hybrids will be cultivated in Brazil because the seeds are very expensive and a highly elaborate and therefore costly cultivation system is required.

In Brazil, one of the research lines used by the irrigated rice genetic breeding program at the Brazilian Agricultural Research Corporation - EMBRAPA to increase the yield potential consists of synthesizing populations of wide genetic base, followed by recurrent selection breeding. This strategy ensures the systematic obtainment of continuous gains, especially for grain yield, besides other characteristics of interest, including grain quality, disease and pest resistance (Rangel and Neves, 1997, Rangel et al., 2000a).

In addition to estimating the expected gains, the breeder should also assess the gains observed in the program during a determined period, to analyze the efficiency of the procedures adopted and to plan corrective actions if necessary.

The objective of this study was to estimate the grain yield gains in three recurrent selection cycles in the CNA IRAT 4 irrigated rice population.

MATERIAL AND METHODS

The CNA-IRAT 4 population used in this study has the IR36 mutant gene for male genetic sterility obtained by chemical mutation (Singh and Ikehashi, 1981). This mutant has a recessive allele (ms) that in homozygosis (msms) produces sterility in the pollen grains so that the selected families can be recombined in the field without manual crosses. This population was synthesized by EMBRAPA and the Institut de Recherches Agonomique Tropicales (IRAT) by the intercrossing of ten varieties/lines of the *indica* subspecies (Rangel and Neves, 1997). Nine varieties/lines were used as male parents in crosses with the IR36 mutant. F_1 plants were backcrossed as male parents with the nine varieties/lines, so that the nine cytoplasms were represented in the population and the participation of the IR36 mutant in the final composition could be reduced. The F_2 seeds of the heterozygot plants for the male-sterility gene were mixed in equal quantities and intercrossed three times in the field, giving rise to the CNA-IRAT 4 population (Table 1). Later this population underwent three recurrent selection cycles using the breeding method based on the $S_{O:2}$ family assessment, by Rangel and Neves (1997). In this method, each selection cycle is completed in two years, fostering the advancement of the $S_{0:1}$ families to $S_{0:2}$ and going through recombinations during the winter period.

A total of 924 $S_{0:2}$ families derived from the CNA-IRAT 4 population was assessed in 14 experiments, namely: five experiments carried out in the 1992/93 growing season in the states of Goiás, Minas Gerais, Paraná, Roraima and Tocantins, where 326 families from the first recurrent selection cycle plus two controls (Cica 8 and BR-IRGA 409) were assessed; six experiments carried out in the 1994/95 growing season in the states of Goiás, Piauí, Paraná, Roraima and Tocantins, where 400 families of the second recurrent selection cycle plus four controls (Cica 8, BR-IRGA 409, Metica 1 and Javaé) were assessed; and three experiments carried out in the 1997/98 growing season in Goiás, Pará and Roraima to assess 200 families of the third recurrent selection cycle and the controls Cica 8, BR-IRGA 409, Metica 1 and Javaé.

A triple lattice experimental design was used in the first cycle (two 10x10 and two 8x8 lattices) and the Federer augmented block (Federer, 1956) in the two subsequent cycles. The plot consisted of four 5.0m long rows and the grain yield data were obtained in the two central 4.0m drills.

The adjusted mean method (Breseghello et al., 1998) was used to estimate the observed gains for grain yield, adapted by Morais et al. (2000) for the specific case of recurrent selection that is more advantageous especially when the data are unbalanced, as is the case in this study. Thus the whole set of treatments assessed in the n selection cycles can be separated in *n+1* groups: the control group and the n groups of assessed families in each selection cycle. The means of the *n+1* groups, adjusted for year effects (in function of the common control group), locations/year and blocks/locations/year, are estimated. The restriction that all the interactions, treatment x year and treatment x location/year are components of experimental error, has to be accepted.

The gains observed due to the selection in the cycle *i* ($\hat{G}_i$) is given by:

$$\hat{G}_i = \hat{m}_{i+1} - \hat{m}_i ,$$

where $\hat{m}_i$ and $\hat{m}_{i+1}$ are the adjusted means of the assessed families of the cycles *i* and *i+1*, respectively.

As the different gains estimates are not independent and do not have homogeneous variances, the mean gain should be estimated by the generalized least squares method (Hoffman and Vieira, 1987). To estimate the matrix of covariance of the observed gains, the matrix of the covariance of the adjusted means of *n + 1* groups of treatments assessed should be obtained.

RESULTS AND DISCUSSION

The mean control yield of 6810kg/ha was significantly higher than the means of the families for all the recurrent selection cycles assessed (Table 2). The mean is one of the main genetic parameters to be considered in populational breeding. When the population mean is low, it can take a long time to raise it to a reasonable level, thus the effort may not be worthwhile for this population breeding. In the case of CNA-IRAT 4, the lower mean yield of the families compared to the controls may be due to the following factors: a) high among and within family genetic variability; b) presence of the gene for genetic male sterility in the families and c) reduced number of recurrent selection cycles.

Whenever the ten best families in each selection cycle are considered, the mean yield was greater than 7000 kg/ha and the families of the second cycle (7275 kg/ha) and the third cycle (7283 kg/ha) were significantly more productive than the control group by the Dunnett test (Dunnett, 1955; 1964) at 5% probability (Table 3). These results show the genetic potential of the CNA-IRAT 4 population for high yielding line extraction.

Table 4 shows the gains observed for grain yield in the first and in the second recurrent selection cycle, in kg/ha and in family mean percentiles for the first cycle. The gain observed in the first cycle was not significant, only 15.7 kg/ha (0.28%). The gain observed in the second cycle and the mean of the two cycles were significant (more than twice the value of the respective standard deviation), 369.9 kg/ha (6.65%) and 259.9 kg/ha (4.67%), respectively. These values are greater than those estimated for the conventional breeding programs carried out in Brazil. Santos et al. (1999) analyzed the irrigated rice breeding program in Minas Gerais and acquired a non-significant grain yield gain of only 15 kg/ha/year (0.25%). Breseghello et al. (1999) and Rangel et al. (2000b) estimated the genetic gains for grain yield at 54.9 kg/ha/year (0.8%) and 18.0 kg/ha/year (0.3%), respectively, obtained by breeding programs in the Northeast and Mid North of Brazil.

Results obtained from this study showed that considerable gains for grain yield could be obtained by the use of recurrent selection applied to genetically divergent populations. However, maintaining the gains over the recurrent selection cycles will only be possible if some procedures are adopted, such as a) assessing a larger number of families (250 to 300 families) of the population, b) conducting experiments more carefully to improve accuracy of the family assessments and c) using a selection intensity which allows short term gains without genetic variability reduction.

CONCLUSIONS

Three recurrent selection cycles are efficient in increasing the productive potential of the CNA-IRAT 4 population.

RESUMO

Ganhos observados para produtividade de grãos em três ciclos de seleção recorrente na população de arroz irrigado CNA-IRAT 4

Uma das linhas de pesquisa usadas pela Embrapa em seu programa de melhoramento genético do arroz irrigado consiste na sintetização de populações de ampla base genética, seguida de sua condução através de seleção recorrente. Esta estratégia permite assegurar uma forma sistemática de obtenção contínua de ganhos, principalmente para produção de grãos, além de outras características de interesse.

Table 1. Parents and relative contribution of the component varieties/lines of the CNA-IRAT 4 population.

Varieties/Lines	Parents	Relative contribution
BG 90-2	IR 262/Remadja	8.33
CNA 7	T 141/IR 665-1-1-75-3	8.33
CNA 3815	Cica 4/BG 90-2//SML 1517	8.33
CNA 3848	IR 36/Cica 7//5461	8.33
CNA 3887	BG 90-2/Tetep//4440	8.33
Colombia1	Napal/Takao Iku 18	8.33
Eloni	IR 454/SML Kapuri//SML 66410	8.33
Nanicão	Variedade tradicional Brasil	8.33
UPR 103-80-1-2	IR 24/Cauvery	8.33
IR 36 (msms)	Mutante de IR 36	25.00

Table 2. Grain yield mean of the controls and the families in each recurrent selection cycle.

Groups	Grain yield (kg/ha)
Control	6,810
Firt cycle families	5,560 [1/]
Second cycle families	5,576 [1/]
Third cycles families	5,945 [1/]
CV (%)	18.12

[1/] Significantly less productive than the control group, by the Dunnett test at 5% probability.

Table 3. Mean grain yield of the controls and the ten best families in each recurrent selection cycle.

Groups	Grain yield (kg/ha)
Controls	6,810
Ten best families from the first cycle	7,131
Ten best families from the second cycle	7,275 [1/]
Ten best families from the third cycle	7,283 [1/]
CV(%)	18.12

[1/] Significantly higher than the mean of the control group by the Dunnett test at 5% probability.

Table 4. Estimates of gains observed for grain yield for the first cycle (G12), for the second cycle (G23) and mean gain (Gmean) in kg/ha and in percentage of the mean of the families of the first cycle [1/].

Discrimination	Gain in kg/ha	Standard deviation	Gain in % of the mean.
G12	15.7	± 207.7	0.28
G23	369.5	± 129.0	6.65
Gmean	259.9	± 101.3	4.67

[1/] Significant gain, when the value is greater than twice the respective standard deviation.

Objetivando estimar os ganhos observados em três ciclos de seleção recorrente na população CNA-IRAT 4, foram analisados os dados de produtividade de grãos de 924 famílias $S_{0:2}$ em 14 ensaios conduzidos em vários estados do Brasil, nos anos agrícolas 1992/93, 1994/95 e 1997/98. O delineamento experimental utilizado foi o látice triplo no primeiro ciclo (dois látices 10x10 e dois 8x8) e os blocos aumentados de Federer nos dois ciclos subsequentes. O ganho observado do primeiro ciclo foi de apenas 15,7 kg/ha (0,28%), não significativo. O ganho observado do segundo ciclo e ganho médio foram, respectivamente, 369,9 kg/ha (6,65%) e 259,9 kg/ha (4,67%), significativos e de elevadas magnitudes. Os resultados obtidos demonstram que através da utilização da seleção recorrente aplicada em populações geneticamente divergentes pode-se obter ganhos consideráveis para produtividade de grãos.

REFERENCES

Breseghello, F.; Rangel, P.H.N. and Morais. O P. 1999. Ganho de produtividade pelo melhoramento genético do arroz irrigado no Nordeste do Brasil. Pesquisa Agropecuária Brasileira. 34:399-407.

Breseghello, F.; Morais, O .P. and Rangel, P.H.N. 1998. A new method to estimate genetic gain in annual crops. Genetics and Molecular Biology. 21 :551-555.

Carmona, P.S.; Terres, A .L. and Schiocchet, M. 1994. Avaliação crítica dos projetos do PNP-Arroz na área de melhoramento genético, no período de 1980 a 1990: Estados do Rio Grande do Sul e Santa Catarina. p.269-285. In: Reunião Nacional De Pesquisa De Arroz , 4th, Goiânia, 1990. A pesquisa de arroz nos anos 80: avaliação crítica dos principais resultados. Embrapa-CNPAF, Goiânia.

Dunnett, C.W. 1964. A new table for multiplecomparisons with control. Biometrics. 20(3):482-491.

Dunnett, C.W. 1955. A multiple comparison procedure for comparing several treatments with control. Journal of the American Statistical Association. 50(272):1096-1121.

Federer, W.T. 1956. Augmented (or hoonuiaku) designs. Hawaii. Plant. Rec. 55:191-208.

Hoffmam, R. and Vieira, S. 1987. Análise de regressão; uma introdução à econometria. Hucitec, São Paulo.

Morais, O.P. and Rangel, P.H.N. 1997. Melhoramento de arroz no Brasil. p.148-166. In: Abreu, A .F.B.; Gonçalves, F.M.A.; Marques Jr., O G. and Ribeiro, P.H.E.(Orgs.). Simpósio sobre atualização em genética e melhoramento de plantas. Ed. UFLA, Lavras.

Morais, O.P.; Zimmermann, F.J.P. and Rangel, P.H.N. 2000. Evaluación de ganancias observadas en selección recurrente. p.21-35. In: Guimarães, E.P.

(Orgs.). Avances en el mejoramiento poblacional en arroz. Embrapa, Santo Antônio de Goiás.

Peng, S.; Cassman, K.G.; Virmani, S.S.; Sheehy, J. and Khush, G.S. 1999. Yield potential trends of tropical rice since the release of IR8 and the challenge of increasing rice yield potential. Crop Science. 39:1552-1559.

Rangel, P. H. N. and Neves, P. C. F. 1997. Selecion recurrente aplicada al arroz de riego en Brasil. p.79-97. In: Guimarães, E. P. (Org.). Selección Recurrente en Arroz. Ed CIAT, Cali.

Rangel, P.H.N.; Zimmermann, F.J.P. and Fagundes, P.R.R. 2000a. Mejoramiento poblacional del arroz de riego en Brasil. p.65-85. In: Guimarães, E.P. (Org.). Avances en el mejoramiento poblacional en arroz. Embrapa, Santo Antônio de Goiás.

Rangel, P.H.N.; Pereira, J.A .; Morais, O .P.; Guimarães, E.P. and Yokokura, T. 2000b. Ganhos para produtividade de grãos pelo melhoramento genético do arroz (*Oryza sativa* L.) irrigado no meio norte do Brasil. Pesquisa Agropecuária Brasileira. 35:1595-1604.

Santos, P.G.; Soares, P.C.; Soares, A .A .; Morais, O .P. and Cornélio, V.M. de O. 1999. Avaliação do progresso genético do obtido em 22 anos no melhoramento do arroz irrigado em Minas Gerais. Pesquisa Agropecuária Brasileira. 34:1889-1896.

Singh, R.J. and Ikehashi, H.I. 1981. Monogenic male sterelity in rice: Induction, identification and inheritance. Crop Science. 21:286-289.

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