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Performance of a breeding program for irrigated rice in Southeast Brazil

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ABSTRACT. Estimating the performance of a rice breeding program is possible by means of indexes such as the replacement rate, which quantifies the dynamism of the breeding program and provides the rate of included, excluded, maintained and renewed genotypes year after year. We evaluated the performance of the irrigated rice breeding program in the state of Minas Gerais, conducted by the EPAMIG/UFV/EMBRAPA consortium. A total of 210 lines were evaluated in the municipalities of Janaúba, Leopoldina and Lambari from 1993 to 2016. The average number of genotypes included, maintained and excluded in each year were calculated, along with the replacement rate percentage. The average genotype replacement rate was 44% for Lambari and Janaúba, and 43% for Leopoldina. The average maintenance in Lambari was 39%, and in Janaúba and Leopoldina it was 40%. In all localities, the mean rate of inclusion of genotypes was higher than the average exclusion rate, indicating good efficiency in the irrigated rice breeding program. However, new strategies should be used in the irrigated rice breeding program to increase the genetic basis of lines and increase the replacement rate.

Key words: *Oryza sativa*; Biometry; Genetic Progress; Breeding Program

INTRODUCTION

The breeding program for flooded rice in Minas Gerais is carried out by the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) in partnership with the Embrapa - National Center for Research on Rice and Beans (CNPAF) and the Federal University of Lavras (UFLA) (Santos et al., 1999). As a result of this partnership, 31 rice cultivars were made available in Minas Gerais, of which 18 are suitable for irrigated crops in floodplains and 13 for rainfed conditions.

The strategy for this success is to obtain, gradually, genetic gains while preserving the genetic variability for continuous improvement of yield, grain quality, resistance to diseases and other agronomic traits (Breseghello et al., 2011; Colombari Filho et al., 2013; Martínez et al., 2014; Morais Júnior et al., 2017; Barros et al., 2018). Another important impact of the program is the high rate of adoption of new rice cultivars by farmers, which in itself demonstrates the efficiency of the breeding program (Soares et al., 1999). However, it is of utmost importance to monitor the breeding program efficiency over time, providing quantitative indicators to correct directions and point out new strategies (Breseghello et al., 2011).

One way of quantifying the efficiency of a breeding program is by assessing the genotypic replacement rate, which expresses the dynamics of the breeding program by providing the percentage of genotype taxa included, excluded, maintained and renewed from year to year (Cruz, 2014). The dynamics established by the inclusion, exclusion and renewal of cultivars is the most efficient way to evaluate the performance of the breeding program (Federizzi et al., 2012; Ceccarelli, 2015).

We can summarize the dynamics of a breeding program through an indicator that expresses genetic progress. This information, in addition to verifying the success of the breeding program, quantifies the impact of favorable allele transfer strategies during selection process, guides future research and re-evaluates the methods used to obtain new varieties (Soares et al., 2005; Menezes Júnior et al., 2008; Streck et al., 2018). Finally, global gain estimates are useful as indicators of the effectiveness of the choice and conduct of the methodology used, as well as the potential of the exploited germplasm (Breseghello et al., 2011).

In evaluating the performance of the breeding program it should be considered that it involves large investments, financial, physical and human, in the long term, and that the decisions taken periodically will have consequences years later in the performance of the resulting cultivars. However, achievements can help predict trends and plan future breeding program adjustments.

There are few studies related to the genotypic substitution rate in cereals; these include wheat (Carginin et al., 2008; Follmann et al., 2017) and rice (Atroch et al., 2000; Reis et al., 2015) studies. To further this line of research, we examined the performance of the irrigated rice breeding program in the state of Minas Gerais, administered by the EPAMIG/UFV/EMBRAPA consortium.

MATERIAL AND METHODS

Description of the field experiments

The experiments were carried out in the state of Minas Gerais, Brazil, in the experimental fields of the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) in the municipalities of Leopoldina (latitude 21°31'48.01" S, longitude 42°38'24.00" W), Lambari (latitude 21°58'11.24" S, longitude 4520'59.60" W) and Janaúba (latitude 15°48'0.77" S, longitude 43°17'59.09" W). A total of 210 lines were evaluated for grain yield between 1993 and 2016. In each experiment, 25 lines were evaluated, with the exception of the years 1994, 1995 and 1999, during which 12, 24 and 26 lines were evaluated, respectively (Table 1).

Table 1. Experimental information, including number of replications, spacing, total area and useful area of the plots of Value and Cultivation and Use (VCU's) trials of rice cultivars conducted from 1993/94 to 2015/16 in Minas Gerais, Brazil.

Years Agricultural	Repetitions	Size of the Plots (m)	Total area of Plots (m^2)	Useful Area of Plots (m^2)
1993/94	4	5 x 1.50	7.5	3.6
1994/95	4	5 x 1.50	7.5	3.6
1995/96	4	5 x 1.50	7.5	3.6
1996/97	4	5 x 1.50	7.5	3.6
1997/98	4	5 x 1.50	7.5	3.6
1998/99	4	5 x 1.50	7.5	3.6
1999/00	4	5 x 1.50	7.5	3.6
2001/02	4	5 x 1.80	9.0	4.8
2002/03	3	5 x 1.80	9.0	4.8
2003/04	3	5 x 1.80	9.0	4.8
2004/05	3	5 x 1.80	9.0	4.8
2005/06	3	5 x 1.80	9.0	4.8
2006/07	3	5 x 1.50	9.0	4.8
2007/08	3	5 x 1.50	7.5	3.6
2008/09	3	5 x 1.50	7.5	3.6
2009/10	3	5 x 1.50	7.5	3.6
2010/11	3	5 x 1.50	7.5	3.6
2012/13	3	5 x 1.50	7.5	3.6
2013/14	3	5 x 1.50	7.5	3.6
2014/15	3	5 x 1.50	7.5	3.6
2015/16	3	5 x 1.50	7.5	3.6

All experiments were carried out in randomized blocks, with four replications each until 2002. From that year on, the same design was adopted using three replications. The experimental plots from 1993 to 1999 and from 2000 to 2016 consisted of five meter rows. The plots were composed of five rows with 0.30 m spacing between rows. The harvest area was composed of the three internal rows to exclude any border effects. From 2001 to 2007, the plots were composed of six rows, and the four central meters of the five internal rows were considered. The irrigation rate was gradually increased as the plants developed. The experiments were conducted in agreement with the technical recommendations for the crop (Embrapa,1997).

Emphasis was given to the grain yield in $kg.ha^{-1}$, since this is the main trait evaluated in breeding programs. For the analysis of genotype performance, the GENES software (Cruz, 2016) was used.

Number and average of genotypes included, maintained and excluded each year

From a set of information related to the performance of a genotype group evaluated in a given period of time, the following information is obtained:

I: number of new genotypes in relation to the previous year. For year 1 we have I equal to zero. For the next years, I is determined as follows:

$$I_i = n_{ij}\text{-}n_{i,j-1} \quad \text{(Eq. 1)}$$

where: n_{ij}: number of genotypes evaluated in year i; n_{ij} = $n_{j,i}$:, i: number of genotypes evaluated in year i and j.

M: number of genotypes kept for evaluation in the following year:

$$M_i = n_{i,j+1} \quad \text{(Eq. 2)}$$

For the last year (i = a) we have: $M_a = n_{aa}$.

E: number of genotypes excluded from the evaluation in the following year:

$$E_i = n_{ii} - n_{i,i+1} \quad \text{(Eq. 3)}$$

For the last year (i = a) we have: $E_a = 0$.

T: number of genotypes evaluated in the year in which Ti = n_{ii}; MI: mean of new (renewed) genotypes in relation to the previous year. For the first year, $MI_a = 0$; MM: mean of the genotypes kept for evaluation in the subsequent year; ME: mean of the genotypes excluded from the evaluation in the subsequent year. For the last year, $ME_a = 0$; and MT: mean of all genotypes evaluated in the year.

Genotypic replacement rate

The genotypic replacement rate quantifies the breeding program dynamism and provides the rate of genotypes included, excluded, maintained and renewed from year to year. The rate estimates are:

$$\%\ M = \frac{100M}{M+E+I} \quad \text{(Eq. 4)}$$

$$\%\ E = \frac{100E}{M+E+I} \quad \text{(Eq. 5)}$$

$$\%\ I = \frac{100I}{M+E+I} \quad \text{(Eq. 6)}$$

It was considered that M was the number of genotypes maintained from year to year. For years 1 and 2, M= n_{12}; E is the number of genotypes excluded in the previous year. For years 1 and 2, E= $n_{11} - n_{21}$; I is the number of genotypes included in the subsequent year. For years 1 and 2, I= $n_{22} - n_{21}$.

The rate of new genotypes created by the breeding program compared to the previous year (%I) is also a measure of a breeding program’s dynamism. The rate of renewal (%R), expressed by the rate of new genotypes among those being tested in a given year, is given by:

$$R = \frac{100I}{M+I} \quad \text{(Eq. 7)}$$

RESULTS AND DISCUSSION

The level of cultivars' adoption by farmers is certainly the most efficient qualitative way of evaluating the performance of a plant breeding program. However, even in programs of proven success, quantitative indicators are needed. It allows, for example, evaluation of the genotypic replacement rate using experimental data, such as those available from VCU's assays. In this context, using the results of evaluation of grain yield of the network of VCU's trials, it was possible to evaluate the dynamism of the flood-irrigated rice breeding program developed in Minas Gerais from 1993/1994 to 2015/2016 (Table 2).

Table 2: Genotype replacement rate (%) in Value for Cultivation and Use testing of irrigated rice in each pair of years, from 1993 to 2016 in Minas Gerais, Brazil.

Year	Lambari				Janaúba				Leopoldina			
	I	E	M	R	I	E	M	R	I	E	M	R
1994	0.65	0.29	0.06	0.92	0.65	0.29	0.06	0.92	0.65	0.29	0.06	0.92
1995	0.31	0.31	0.37	0.46	0.31	0.31	0.37	0.46	0.31	0.31	0.37	0.46
1996	0.48	0.46	0.07	0.88	0.48	0.46	0.07	0.88	0.48	0.46	0.07	0.88
1997	0.49	0.49	0.02	0.96	0.49	0.49	0.02	0.96	0.49	0.49	0.02	0.96
1998	0.44	0.44	0.11	0.8	0.31	0.28	0.42	0.42	0.31	0.28	0.42	0.42
1999	0.42	0.42	0.16	0.72	0.41	0.43	0.16	0.72	0.41	0.43	0.16	0.72
2001	0.19	0.19	0.61	0.24	0.42	0.42	0.16	0.72	0.42	0.42	0.16	0.72
2002	0.34	0.34	0.32	0.52	0.19	0.19	0.61	0.24	0.19	0.19	0.61	0.24
2003	0.22	0.22	0.56	0.28	0.38	0.38	0.25	0.6	0.34	0.34	0.32	0.52
2004	0.34	0.34	0.32	0.52	-	-	-	-	0.22	0.22	0.56	0.28
2005	0.11	0.11	0.79	0.12	0.34	0.34	0.32	0.52	0.34	0.34	0.32	0.52
2006	0.31	0.31	0.39	0.44	0.11	0.11	0.79	0.12	0.11	0.11	0.79	0.12
2007	0.14	0.14	0.72	0.16	0.31	0.31	0.39	0.44	0.31	0.31	0.39	0.44
2008	0.29	0.29	0.43	0.4	0.14	0.14	0.72	0.16	0.14	0.14	0.72	0.16
2009	0.07	0.07	0.85	0.08	0.29	0.29	0.43	0.4	0.29	0.29	0.43	0.4
2010	0.34	0.34	0.32	0.52	0.07	0.07	0.85	0.08	0.07	0.07	0.85	0.08
2011	0.22	0.22	0.56	0.28	0.34	0.34	0.32	0.52	0.34	0.34	0.32	0.52
2013	0.19	0.19	0.61	0.24	0.22	0.22	0.56	0.28	0.22	0.22	0.56	0.28
2014	0.22	0.22	0.56	0.28	0.19	0.19	0.61	0.24	0.19	0.19	0.61	0.24
2015	-	-	-		0.22	0.22	0.56	0.28	0.22	0.22	0.56	0.28
Average	0.31	0.29	0.39	0.44	0.31	0.29	0.4	0.44	0.31	0.29	0.4	0.43

I: number of new genotypes in relation to the previous year; M: number of genotypes maintained for evaluation in the subsequent year; E: number of genotypes excluded from the evaluation in the subsequent year; T: number of genotypes evaluated in the year.

The process of indicating varieties for commercial plantations is continuous and dynamic. Thus it is recommended to periodically include new cultivars in substitution to those less productive and with less commercial acceptance. Table 2 provides indicators to quantify the dynamism of the irrigated rice breeding program in the State of Minas Gerais. The average grain yield of the genotypes evaluated in the periods from 1993 to 2016 was 3631 $kg.ha^{-1}$ in Lambari. At this location, the highest average of all evaluated genotypes was recorded in the agricultural year 2002/2003, which corresponds to 6812 $kg.ha^{-1}$ and the lowest 2465 $kg.ha^{-1}$ in the 2010/2011 agricultural year (Table 3). In Janaúba and Leopoldina, the average results of the genotypes were better than Lambari, since in Janaúba and Leopoldina the overall mean reached 6282 kg.ha^{-1} and 5790 kg.ha^{-1}, respectively (Table 3).

Table 3. Estimation of the average yield (kg.ha^{-1}) of the new strains, maintained, excluded and evaluated each year in the program for the improvement of irrigated rice, from 1993 to 2016, in Lambari - MG, Janaúba - MG and Leopoldina - MG.

YEAR	Lambari				Janaúba				Leopoldina			
	MI	**MM**	**ME**	**MT**	**MI**	**MM**	**ME**	**MT**	**MI**	**MM**	**ME**	**MT**
1994	-	2158	1863	1912	-	1009	9973	9993	-	7186	6909	6955
1995	4584	4516	4307	4420	8003	8412	7673	8073	7459	7827	7126	7506
1996	4842	5295	5027	5060	7427	7491	7624	7607	5680	5443	5656	5629
1997	3449	4069	3372	3400	6666	6336	6687	6673	5643	5668	5662	5662
1998	4492	4937	4381	4492	6253	6446	6037	6282	5318	5687	4768	5320
1999	-	-	-	3059	6391	6550	6389	6432	5689	5683	5880	5827
2001	3026	3136	3030	2903	6387	6391	6387	6388	5270	5609	5270	5365
2002	2766	3039	2471	6812	8313	8308	8191	8280	5282	5378	5585	5427
2003	7213	6655	6957	1282	6182	5937	6326	6170	6060	5538	5146	5334
2004	1429	1238	1397	2745	5191	5213	-	5213	5601	6112	4964	5790
2005	2879	3172	2351	2309	-	4115	3979	4044	6141	6532	5757	6129
2006	1940	2468	1148	4575	6978	6747	6268	6689	7007	7138	6265	7033
2007	5057	5096	3912	2189	5773	5675	5156	5447	8435	8185	7574	7916
2008	2277	2349	1345	4269	8282	8409	7812	8314	6057	6612	5294	6401
2009	4820	4239	4313	4892	3894	3443	3681	3538	4076	4039	4036	4038
2010	4885	4878	5046	2465	5465	5446	4904	5403	5814	5944	5701	5924
2011	8733	9625	8653	5468	6135	6466	6483	6475	4391	5071	4803	4932
2013	5280	5455	5500	3862	4248	4171	4251	4194	3903	4093	3700	3983
2014	3997	3966	3532	4600	5601	5427	5438	5430	2708	2647	2753	2673
2015	5043	4773	4157	2808	5352	5695	5303	5585	7744	7646	7654	7648
2016	2989	2808	-	-	6008	5990	-	5990	7085	6854	-	6854

MI: mean of new (renewed) genotypes in relation to the previous year; MM: mean of the genotypes maintained for evaluation in the subsequent year; ME: mean of the genotypes excluded from the evaluation in the subsequent year; MT: mean of the total genotypes evaluated in the year.

The highest total genotypes average corresponded to 8314 kg.ha^{-1} in the crop year 2007/2008, in the municipality of Janaúba. In this same place, the lowest mean was 3538 kg.ha^{-1} in the 2008/2009 crop year. In Leopoldina, the highest average was 7916 kg.ha^{-1} agricultural year of 2006/2007 and the lowest average of 2673 kg.ha^{-1} agricultural year 2013/2014 (Table 3). In spite of the low total averages, Lambari was the site that obtained the highest average of the new genotypes in relation to the previous year (8733 kg.ha^{-1}), and also the highest average of the genotypes excluded from the evaluation in the following year (8653 kg.ha^{-1}) (Table 3).

From the point of view of rigor in the breeding of irrigated rice in Minas Gerais, the agricultural years 1993/1994 to 1999/2000, obtained a greater number of new genotypes in relation to the previous year and the smaller number of genotypes kept for evaluation in the year (Table 2), and, consequently, higher was required for the breeder's requirement in this period for the evaluation of genotypes. It was verified that the Irrigated Rice Improvement Program in the State of Minas Gerais promoted a good genotype renewal rate throughout the evaluated period (Table 2), demonstrating the program's dynamism in launching cultivars, providing new crop options for the farmer. Similar results were found in works such as Carginin et al. (2008), in wheat, who obtained 33% renewal rate and in Soares et al., (1999), Atroch and Nunes (2000), in rice, who found rates of renewal of 44% and 46%

respectively, these authors reported that the values found evidence high vitality of breeding programs.

In general, the genotype maintenance rate in this study was considered medium (Table 2). Branquinho et al. (2016) obtained a result of 25%, which was considered low. Soares et al. (1999) and Dovale et al. (2012) obtained good results (56% and 58%, respectively). Atroch and Nunes (2000) verified an average maintenance rate of 38% in the period from 1997/1998 to 2011/2012 and Reis et al. (2015) obtained a mean maintenance rate of 63% in rice. In other crops, such as cotton (Moresco, 2003) and wheat (Carginin et al., 2007), average maintenance rates of 44% and 55%, respectively, were found to be optimal.

The effectiveness of a breeding program is also related to the inclusion and exclusion rate. When the inclusion rate is higher in relation to the exclusion rate, it indicates that the breeding program is contributing to the release of varieties, allowing new cultivation options for the farmer (Cruz, 2003). In all places, the mean inclusion rate was higher than the average exclusion rate, indicating good efficiency of the irrigated rice breeding program in Minas Gerais (Table 2).

The mean maintenance rates were 39% in Lambari and 40% in Janaúba and Leopoldina (Table 2). The lowest maintenance rate in Lambari compared to other locations is due to the analysis being made with different farm years, since 20 years of agricultural production were evaluated in Lambari, while in the other locations 21 agricultural years were evaluated. This makes it possible to obtain an estimate of the variation of the environment between the years under evaluation. In this sense, the environmental effect is due to the contrast between the genotypes common to the years considered (Atroch and Nunes, 2000). The greater the number of common treatments every couple of years, the more accurate is the environmental effect estimate. Thus, the data analysis leads to greater safety in the estimation of genetic progress by the consequent reduction caused by the experimental errors and the interactions of genotypes with years.

This difference between sites is due to the representative effect of a complex set of factors acting at random. This involves climatic factors, incidence of pests and diseases as well as factors peculiar to certain moments in time and space. Thus, it is not expected, contrary to the directed action of the improvement, a favorable temporal action of the environment over the years. Another explanation is that the best genotype in one location may not be the best in another, that is, differentiated behavior of genotypes versus environmental variations, because of this difference between environment, which expresses the interaction genotypes by environments (Colombari Filho et al., 2013 and Kleinknecht et al., 2016). However, in addition to the productivity that the genotype-environment interaction is visible, it is worth noting that the attributes related to irrigated rice grain quality are highly related not only to genetic but also environmental factors (Cameron et al., 2008; Hakata et al., 2012; Lyman et al., 2013; Li et al., 2014; Xu et al., 2015; Streck et al., 2017; Streck et al., 2018). The physical attributes of the grains are very complex quantitative traits because they are controlled by maternal and cytoplasmic effects (Streck et al., 2018). Therefore, many genetic mechanisms and interactions with the environment are still obscure (Shi et al., 2002; Zhou et al., 2009).

It is important to note that, in all places, the averages were higher than the average in the State of Minas Gerais during the period from 1993 to 2016. Therefore, the breeding program of irrigated rice in Minas Gerais provides a great contribution of cultivars to the rice farmer. In this sense, the first cultivar recommended for the State was IR 841 in 1975 and in the agricultural year 1976/1977 the production in the State with this cultivar was 897 $kg.ha^{-1}$. The first variety of rice launched by the rice improvement program in Minas Gerais was in fact the IAC 899 variety in 1978 and in the first agricultural year after its launch the productivity obtained in the State was approximately 1300 $kg.ha^{-1}$ showing the efficiency of the rice improvement program in the State (CONAB, 2016).

Reis et al., (2015) evaluated 108 genotypes of flooded rice in the period 1997/1998 to 2011/2012 in the VCU's tests of the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) of the irrigated rice breeding program. According to these authors there was balance in the irrigated rice improvement of the EPAMIG program regarding the inclusion and exclusion of materials in this study.

An important caveat that must take into account the high maintenance rates that limit genetic gains to rice productivity, mainly due to the low exploitation of the genetic base for the crop available in germplasm banks, and also because this characteristic is quantitative (Streck et al., 2018). This restricts the potential for genotypic variability of elite materials to be explored. An ideal situation would be that replacement rates were equal to or even higher than that observed in the period 1998 to 2012, which was 26% (Reis et al., 2015). In view of these results, new strategies should be used in the breeding program of irrigated rice in Minas Gerais to increase the genetic base of the lines, as well as increase in the rate of replacement and reduction in the rate of maintenance and selection in a specific environment.

In view of these results, the gain to productivity has not been satisfactory at the present time, and the elite lineages have not exceeded the cultivars already launched. This can be justified by the importance that the program has given to the selection of other traits than grain yield (Santos et al., 1999), for example, the one focused on releasing cultivars with high productivity potential, good quality and healthy grains, resistance to biotic and abiotic factors and good adaptation to growing conditions (Streck et al., 2018). Corroborating the previous discourse, it is necessary to point out the need to establish new breeding strategies aiming at obtaining cultivars superior to those already launched, since it is known that irrigated rice still has sufficient productive potential and variability to be exploited (Santos et al., 1999).

According to Soares et al. (2008), the indication technology of rice cultivars for commercial plantations is dynamic and periodically new cultivars are recommended as substitutes for those less productive or with less commercial acceptance. In view of this, the development of new cultivars is crucial to help increase food availability and the success of breeding programs that depends on the existence of genetic variability and also, breeders recommended the formation of a population base based on the interbreeding of higher cultivars and genetically divergent (Santos et al., 2017; Rabelo et al., 2015). This is of paramount importance for the success of breeding programs (Cruz, Ferreira, & Pessoni, 2011).

CONCLUSIONS

The breeding program of irrigated rice developed in Minas Gerais in the agricultural years 1993/1994 to 2015/2016 obtained a significant increase in grain yield. Although the results are satisfactory, new strategies should be used to increase the genetic base of the lines, as well as the rate of replacement.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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