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RESEARCH ARTICLE

Multi-information analysis for recommendation of flooded-irrigated rice for adaptability and phenotypic stability

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ABSTRACT

The GxE interaction is one of the major difficulties of plant breeding programs, both in the selection phase and in the recommendation of cultivars. To assess adaptability and stability, various statistical methods are used. The simultaneous use of some methodologies, using multi-information criteria for cultivar's recommendation, can extract information that cannot be observed using each methodology separately. The aim of this work was to perform a large description of the behavior of flooded-irrigated rice genotypes, responding to environmental variations, using methods already established in the literature, but exploring the particularities of each methodology that together establish an information criterion for cultivar recommendation. To this end, 18 rice genotypes belonging to flood-irrigated rice breeding program were evaluated over four agricultural years, 2012/2013 to 2015/2016, totaling 12 environments (3 sites × 4 years). Multi-information estimates were performed to adaptability and stability analysis. There was no sign for the effect of the genotypes, and there was the significance of the effects of environment and GxE interaction. The aggregation of information and the large description of the behavior of the flooded rice genotypes demonstrated to be an efficient tool for studies of adaptability and stability.

Keywords: Biometrics, information summary, *Oryza sativa* L., plant breeding, phenotypic expression, statistical methods.

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INTRODUCTION

The phenotypic expression is a result of the action of the genotype under the influence of the environment. However, when evaluating a number of environments, one not only detects genetic and environmental effects but also an additional effect, called genotype x environment interaction (GxE) (Eeuwijk et al. 2016). The GxE interaction is one of the major difficulties of plant breeding programs, both in the selection phase and in the recommendation of cultivars. If there is GxE interaction, the same genotype may express different behavior between environments due to the differential expression of its genes according to environmental influences (Cruz, Regazzi, Carneiro, & 2012). Thus, detailed studies on genotype behavior in the evaluated environments are essential for the recommendation of cultivars adapted to a specific region. Such studies are based on genotype behavior, describing its adaptability and stability (Chaves, 2001; Maia et al., 2013). Adaptability can be defined as the ability of genotypes to respond to environmental stimuli, and stability can be defined as the ability of genotypes to exhibit highly predictable behavior (Cruz, Regazzi, & Carneiro, 2014; Silva Júnior et al., 2020a).

In this context, to assess adaptability and stability, various statistical methods are used, and differ in statistical principles, biometric procedures, and interpretation of results (Eeuwijk et al. 2016). According to Cargnelutti Filho, Perecin, Malheiros and Guadagnin (2007), these methods can be arranged in several classes, such as those based on analysis of variance (Yates & Cochran, 1938; Plaisted & Peterson, 1959; Wricke, 1965), linear regression (Finlay & Wilkinson, 1963; Eberhart & Russell, 1966; Tai, 1971), bi-segmented regression (Verma, Chahal, & Murty, 1978; Cruz, Torres, & Vencovsky, 1989) in non-parametric statistics (Lin & Binns, 1988; Huehn, 1990; Annicchiarico, 1992; Rocha, Muro-Abad, Araujo, & Cruz, 2005; Nascimento et al., 2010; Nascimento et al., 2015), quantile regression (Barroso et al., 2015), bayesian statistics (Couto et al., 2015; Nascimento et al., 2011) and computational intelligence (Nascimento et al., 2013; Teodoro et al., 2015; Carneiro et al., 2018; Carneiro et al., 2019).

The diversity of methods for the study of adaptability and stability and the emergence of new methodologies is indicative that the methods presented so far, although useful for the breeder, are still insufficient to study such a complex phenomenon. However, the simultaneous use of some methodologies, through multi-information criteria for cultivar's recommendation, may be able to extract information that cannot be observed with the use of each methodology separately.

In view of the above, the aim of this work was performed a large description of the behavior of flooded-irrigated rice genotypes, in terms of responding to environmental variations, using methods already established in the literature, but exploring the particularities of each methodology that together establish an information criterion for cultivar recommendation.

MATERIAL AND METHODS

Description of the experiments

The experiments were conducted in the state of Minas Gerais - Brazil, in the experimental field of the Minas Gerais Agricultural Research Corporation (EPAMIG), in the municipalities of Leopoldina (latitude 21° 31 '48.01'' S, longitude 42° 38' 24 ''W), Lambari (latitude 21° 58 '11.24'' S, longitude 45° 20' 59.6 '' W) and Janaúba (latitude 15° 48 '77''S, longitude 43° 17' 59.09 '' W).

Eighteen rice genotypes belonging to the flood-irrigated rice breeding program of the Southeast region of the state of Minas Gerais were evaluated, and five of these genotypes were used as experimental controls (Rubelita, Seleta, Ourominas, Predileta, and Rio Grande). These genotypes were evaluated in comparative trials after multiple generations of selection, and in addition, these genotypes are known for their high yield, uniform growth rate and plant growth, resistance to major diseases, and for their excellent grain quality. Grain yield (kg.ha–1) was evaluated in the agricultural years 2012/2013, 2013/2014, 2014/2015, and 2015/2016, totaling 12 environments (3 sites × 4 years). The design used in all experiments was a randomized complete block design with three replications. The experiments were conducted in floodplain soils with continuous flood irrigation. Management practices were carried out according to recommendations for flood-irrigated rice in the relevant regions (Soares, Melo, Melo, & Soares, 2005).

Each plot consisted of three rows of 4 m length (4 m × 0.9 m, totaling 3.60 m^2). The soil was prepared by plowing and harrowing approximately 30 days before sowing and harrowing again on the eve of the sowing tests. A fertilizer of a mixture of 100 $kg.ha^{-1}$ ammonium sulfate, 300 $kg.ha^{-1}$ simple superphosphate and 100 $kg.ha^{-1}$ of potassium chloride was incorporated in the soil before sowing. Top-dressing was applied approximately 60 days after the beginning of the experiments, using 200 $kg.ha^{-1}$ of ammonium sulfate. Weeds were controlled using herbicides and manual weeding. The fields were irrigated around 10-15 days after the start of the experiments, and water was removed shortly before grain maturation. Grain was manually harvested at a moisture content of 20%–22%. And the grain yield data were obtained by weighing all grains harvested in each plot, after cleaning and uniform drying in the sun until they had reached 13% humidity.

Recommendation based on multi-information analysis

Individual variance analyzes were performed, and then the joint ANOVA, according to the statistical model described in the equation below:

$$Y_{ijk} = \mu + B/E_{jk} + G_i + E_j + GE_{ij} + \varepsilon_{ijk},$$

where: Y_{ijk} is the observation on the k^{th} block, evaluated on the i^{th} genotype and j^{th} environment; μ is the general mean of the experiments; B/E_{jk} is the effect of block k within environment j; G_i is the effect of the i^{th} genotype considered to be fixed; E_j is the effect of the j^{th} environment considered to be random; GE_{ij} is the random effect of the interaction between genotype i and environment j; ε_{ijk} is the random error associated with observation Y_{ijk}. We also performed the Scott-Knott clustering test at the 5% probability level to indicate homogeneous groups with mean potential.

Multi-information estimates were performed to adaptability and stability analysis, the following parameters were considered:

General mean

The general mean of each genotype was estimated according to the equation $m_i = Y_i/e$, where Y_i is the grain yield of the i^{th} genotype in all environments and " e ", the number of environments.

Mean potential in different environmental conditions

The mean potential expresses the productive capacity of the genotype particularizing the environmental conditions as general, favorable, or unfavorable. The favorable environment is that representative of regions with edaphic and climatic conditions appropriate to the suitability of the crop. The unfavorable environment is associated with regions of adverse weather or soil conditions or low-tech areas and the general environment corresponds to both favorable and unfavorable.

Plasticity

This refers to the ability of the genotype to alter its physiology or morphology according to the exposed environmental conditions, to express different phenotypes when exposed under different environmental conditions. The estimation of the plasticity of each genotype can be quantified from the joint analysis of the experiments and the subsequent unfolding of the sum of the squares of the effects of the environment and the G x E interaction on the environment effect of each genotype.

Relative contribution to the interaction

It is a measure that quantifies the contribution of a given genotype to the G x E interaction. It is possible to detail this contribution to the total square sum of the interaction as proposed by Wricke (1965) or to the total pure component of the interaction denoted $\hat{\sigma}^2_{ge}$, as proposed by Plaisted and Peterson (1959).

Recommendation index associated with the ith genotype

The concept of the genotype of good performance the greatest productive potential, in terms of mean, and less environmental variability. The recommendation index estimate is based on the methodology of Annicchiarico (1992). The procedures for the calculations are initially performed with the transformation of the means of each cultivar in each environment, as the percentage of the environment mean, being the standard deviation and the mean of the percentages of each cultivar estimated later.

Adaptability or responsiveness of genotype i

It is a measure of the genotype’s ability to respond to improvements in the environment. The adaptability estimate is obtained by regression coefficients (β_{1i}) which is the linear response of genotype i to environmental variation, obtained from the following model proposed by Finlay and Wilkinson (1963), and Eberhart and Russell (1966).

Stability or predictability

It is a measure of the predictability of genotype i behavior in response to environmental variations, considering a linear regression model, as described by Eberhart and Russell (1966). The stability parameter (σ^2_{di}) is estimated by the analysis of variance method from the mean square of the regression deviation of each genotype and the mean square of the residue.

An alternative way to measure predictability is through the model determination coefficient that measures the proportion of total variation explained by the linear behavior of the genotype.

Genotype response j pattern

It is considered a favorable trait for a given genotype and expresses its ability to maintain good productivity under unfavorable conditions but to be responsive under favorable conditions. To detect this ability, the models of Finlay and Wilkinson (1963) or Eberhart and Russell (1966) would be inefficient because they only contemplate a regression coefficient. However, it is possible to quantify this genotypic trait from bi-segmented regression models, as advocated by Cruz et al. (1989).

Champion pattern

In this genotypic attribute, the good genotype is superior to all others in all environments. Most of the time, this genotype does not exist or is not present in the experiment, but it's possible to quantify the distance of the evaluated genotypes to this hypothetical, called champion pattern. You can have this information considering all environments or for those considered favorable or unfavorable, according to the methodology proposed by Lin and Binns (1988).

Recommendation index using the centroid method

It is a measure that allows characterizing each genotype by its proximity to the hypothetical genotypes considered a pattern, even beyond the one recommended by Lin and Binns (1988), and others of interest. For this characterization, the centroid method proposed by Rocha et al. (2005), consists of comparing cartesian distance values between genotypes and four pre-established references (ideotypes), created based on experimental data, whose mean values in each environment are given by: C1, ideotype 1 (maximum general productivity); C2, ideotype 2 (specific maximum productivity for favorable environments); C3, ideotype 3 (specific maximum productivity for unfavorable environments); and C4, ideotype 4 (minimum productivity).

To use the centroid method, environments should be classified as favorable and unfavorable using the environmental index proposed by Finlay and Wilkinson (1963). After the classification of the environments and creation of the representative reference points of the ideotypes (centroids), the Euclidean distance values between the points (genotypes) and each of the four centroids that allow their classification by means of a recommendation index are calculated of classification. An extension of this technique is to include three other centroids having the following recommendation classes: Class I: High general adaptability (maximum yield in favorable and unfavorable environments); Class II: Specific adaptability to favorable environments (maximum production in favorable environments and minimum in unfavorable environments); Class III: Specific adaptability to unfavorable environments (minimum production in favorable environments and maximum in unfavorable environments); Class IV: Poorly adapted (minimum production in favorable and unfavorable environments); Class V: High general adaptability (medium production in favorable and unfavorable environments); Class VI: Specific adaptability to favorable environments (maximum yield in favorable environments and mean in unfavorable environments); Class VII: Specific adaptability to unfavorable environments (mean yield in favorable environments and maximum in unfavorable environments).

After obtaining each of the parameters described above, they were organized in a table that contains the most varied information resulting from different adaptability and stability study proposals that together reveal important characteristics of each cultivar for its recommendation. Thus, allowing the simultaneous analysis of the indices characterizing the multi-information analysis. The GENES software (Cruz 2016) was used to perform the analyses.

RESULTS AND DISCUSSION

Table 1 presents the results of the joint analysis of variance regarding grain yield (Kg.ha^{-1}) of the 18 rice genotypes evaluated in the 12 environments. The individual analysis was performed for each environment and found a significant effect for all genotypes. Subsequently, there was no significance for the effect of the genotypes, through the joint ANOVA, being justified by the advanced stage of reproduction of these genotypes, making it difficult to detect differences between the general means of these genotypes (Silva et al., 2019; Silva Júnior et al., 2020a). There was significance (P <0.01) for the effects of environment and for GxE interaction, another fact that may have masked the existence of variation between the general means of the studied genotypes. Thus, genotype behavior was influenced by environmental conditions, justifying the use of methodologies that can classify genotypes according to their adaptability and stability. The estimated coefficient of variation for grain yield (19.21%) was consistent with those obtained in other rice studies (Streck, Aguiar, Magalhães Júnior, Facchinello, & Oliveira, 2017; Santos, Carneiro, Silva Júnior, Cruz, & Soares, 2019; Silva et al., 2019; Silva Júnior et al., 2020a; Silva Júnior et al., 2020b).

Table 1. Summary of joint variance analysis regarding grain yield (Kg.ha^{-1}) of 18 rice genotypes evaluated in 12 environments of Minas Gerais State.

FV	DF	Mean Square	F test	*p-value*
Block/Environments	24	3214399.58	-	
Genotypes (G)	17	1954786.78	1.28	0.207
Environments (E)	11	128702466.86	40.04	0.010
GxE	148	1516798.35	1.69	0.001
Residue	317	894726.77		
Mean	4.925			
CV (%)	19.21			

FV: Source of Variation; DF: Degree of freedom; CV: Coefficient of variation in %.

Regarding the 18 rice genotypes evaluated in this study (Table 2), the means followed by the same letter provide homogeneous groups by the Scott-Knott test, at a 5% probability level. In this work, from the results of Table 2, that the breeder has only the interest of characterizing the genotype that has great recommendation potential based on the grouping test of means, which in this case is the genotype BRA02691. Other criteria for keeping information on all cultivars or excluding some of them in the analysis, may be adopted by the breeder.

Table 2. Mean grain yield (Kg.ha^{-1}) of the 18 rice genotypes evaluated in 12 environments of Minas Gerais State.

Genotypes	$\overline{X}$	**Genotypes**	$\overline{X}$	**Genotypes**	$\overline{X}$
BRA 031001	4976[a]	Seleta	4909[a]	BRA 02708	5028[a]
BRA 041099	4834[b]	Ourominas	5228[a]	BRA 031006	4987[a]
BRA 02691	5302[a]	CNAI 9091	4799[b]	BRA 01330	4965[a]
Rubelita	4618[b]	BRA041230	5008[a]	BRA 041236	4631[b]
MGI 0607-1	5130[a]	Predileta	4562[b]	BRA 031018	4980[a]
BRA 02706	456[b]	MGI 0717-18	5299[a]	Rio Grande	4831[b]

The means followed by the same letter in each column indicate homogeneous groups at the 5% probability level by the Scott-Knott test.

Table 3 we illustrate the strategy of analysis of the multi-information technique that contains the most varied information resulting from different adaptability and stability study proposals that together reveal important characteristics of each cultivar for its recommendation. As an illustration, we will consider the individual information of genotype BRA02691.

Table 3. Recommendation based on multi-information analysis of BRA 02691 genotype for rice grain yield trait.

Description		**BRA 02691**		
		Value	**Rank**	[1] **Reference (Min; Max; Average)**
Average potential	General Environment	5302	1	(4560;5302;4925) $\mu = 4925$
	Favorable Environment	6469	2	(5665;6580) $\mu = 6188$
	Unfavorable Environment	4135	2	(2919;4527) $\mu = 3661$
Plasticity QMG/A		10671218	16	(5226227;12511339)
Interaction Contribution	S^2GxA (%)	11.50	18	(1.77;11.50)
	SQGxA (%)	10.55	18	(2.37;10.55)
Recommendation Index	General Environment (%)	77.51	12	(63.63;95.99)
	Favorable Environment (%)	66.74	12	(56.97;105.84)
	Unfavorable Environment (%)	98.12	2	(83.55;98.25)
Adaptability (%)		1.09^{ns}	-	(0.76;1.24)
Stability (%)		80.43**	-	(76.31;93.71)
Answer pattern j	Adaptability β_1	1.06 ^{ns}	-	(0.69;1.28)
	Adaptability $\beta_1 + \beta_2$	1.33 ^{ns}	-	(0.37;1.52)
	Stability (%)	81.10**	-	(76.55;96.76)
Champion pattern	General Environment	514236	3	(412961;1728495)
	Favorable Environment	278778	4	135350;1048016)
	Unfavorable Environment	749695	2	(199432;3034618)
Recommendation Index	4 Centroid	I: High general adaptability		
	7 Centroid	V: Median adaptability		

**, * and ns: significant at 1%, 5% and not significant by the test of F, respectively; [(1)] Reference: Minimum (Min), Maximum (Max), and average grain yield, respectively.

For each parameter, the reference corresponds to the maximum and minimum values of all genotypes (in this experiment, equal to 18). The mean value is also provided for quantitative comparisons and the qualitative position can also be obtained by the value of the classification. Rank 1 is considered more favorable for all criteria (Table 3). Thus, if we consider the mean potential, classification 1 means that the genotype reached the highest mean, but if the statistic is the value of Pi, Lin and Binns (1988), classification 1 indicates that the genotype has the lowest value and, therefore, closest to the genotype with the best performance in all environments (Table 3). Another feature is the stability information, whose value shown in the table corresponds to the coefficient of determination, and the associated significance is related to the hypothesis that the deviation from the regression model is null (Table 3).

The breeder is interested in characterizing the genotypes with superior potential for a recommendation based on the means clustering test, which in this case are MGI0717-18, BRA041230, and BRA02691 and the control Ourominas. The summary information about the stability and adaptability attributes is presented in Table 4. For each parameter, a reference estimated that corresponds to the maximum and minimum value of all 18 rice genotypes, so it was possible to obtain the ranking and greater credibility of both genotypes according to each parameter (Table 4).

According to the description of the mean potential for favorable and unfavorable environments, recommendation index for unfavorable environments, and champion pattern for unfavorable environments, genotype BRA 02691 was ranked second about to the other genotypes. In terms of plasticity and the contribution of interaction, this genotype was ranked among the last positions, sixteenth and last place respectively. This genotype also obtained the best ranking for the mean potential to the general environment, but about the contribution of the interaction, its classification was last. In contrast, descriptions of stability and stability response pattern j for this genotype were significant ($P < 0.01$) (Table 4).

Based on the recommendation index of the four and seven centroid methodologies, the BRA02691 genotype was classified as high general adaptability and median adaptability, respectively (Table 4). Thus, this genotype in environments classified as unfavorable response significantly to environmental improvement and in environments classified as favorable does not respond much to environmental improvement (Figure 1). It’s relevant to present that this genotype was recently inserted as a new cultivar by the flooded-irrigated rice breeding program, due to its better performance compared to the other lines of the breeding program.

The BRA041230 genotype was ranked third about the other genotypes for the description of the mean potential for the favorable environment, the contribution of interaction, and champion pattern to favorable environments. When evaluating the four and seven centroid methodologies for the recommendation index, this genotype was classified as favorable environment-specific adaptability and median adaptability, respectively (Table 4). For the unfavorable environment recommendation index, this genotype obtained the best ranking. Given these results, this genotype is poorly responsive to environmental improvement for both unfavorable and favorable environments (Figure 1).

The genotype MGI0717-18 was considered the best descriptor for medium potential in unfavorable environments, recommendation index for favorable environments, and champion pattern for general and unfavorable environments (Table 4). Classified as adaptive to the unfavorable environment by four and seven centroid recommendation indices, this genotype responds greatly to unfavorable environments as well as favorable environments indicating that it's very responsive to environmental improvement (Figure 1). The Ourominas control obtained the best description for medium to favorable environment potential, interaction contribution, general environment recommendation index, and favorable environment champion pattern. According to the recommendation index of four and seven centroids, Ourominas control was classified as having high general adaptability and favorable environment specific adaptability, respectively.

Table 4. Recommendation summary based on multi-information analysis of flooded- irrigated rice genotypes with superior mean performance to grain yield.

Description		BRA 02691		Ourominas		BRA 041230		MGI 0717-18		
		Value	Rank	Value	Rank	Value	Rank	Value	Rank	[(1)] Reference (Min; Max; Average)
Average Potencial	General Environment	5302	1	5228	3	5008	6	5299	2	(4560;5302) $\mu = 4925$
	Favorable Environment	6469	2	6580	1	6432	3	6071	12	(5665;6580) $\mu = 6188$
	Unfavorable Environment	4135	2	3876	5	3585	12	4527	1	(2919;4527) $\mu = 3661$
Plasticity QMG/A		10671218	16	7421351	6	8828224	12	5409173	3	(5226227;12511339)
Interaction Contribution	S^2GxA (%)	11.49	18	1.77	1	2.42	3	8.43	14	(1.77;11.50)
	SQGxA (%)	10.55	18	2.37	1	2.92	3	7.98	14	(2.37;10.55)
Recommendation Index	General Environment	77.51	12	95.99	1	87.19	5	88.21	4	(63.63;95.99)
	Favorable Environment	66.74	12	95.80	2	79.36	9	106	1	(56.97;105.84)
	Unfavorable Environment	98.12	2	95.15	3	98.25	1	86.27	13	(83.55;98.25)
Adaptability (%)		1.09^{ns}	-	0.99^{ns}	-	1.08^{ns}	-	0.76*	-	(0.76;1.24)
Stability (%)		80.43**	-	93.51^{ns}	-	93.71^{ns}	-	77.24*	-	(76.31;93.71)
Answer pattern j	Adaptability β_1	1.06^{ns}	-	1.04^{ns}	-	1.09^{ns}	-	0.69**	-	(0.69;1.28)
	Adaptability $\beta_1 + \beta_2$	1.33^{ns}	-	0.64^{ns}	-	0.99^{ns}	-	1.17^{ns}	-	(0.37;1.52)
	Estability (%)	81.10**	-	95.47^{ns}	-	93.81^{ns}	-	80.99^{ns}	-	(76.55;96.76)
Pattern Champion	General Environment	514236	3	465610	2	905246	9	412961	1	(412961;1728495)
	Favorable Environment	278778	4	135350	1	275299	3	626490	14	135350;1048016)
	Unfavorable Environment	749695	2	795870	3	1535193	12	199432	1	(199432;3034618)
Recommendation Index	4 Centroid		I		I		II		III	
	7 Centroid		V		VI		V		VII	

**, *, ns: significant at 1%, 5% and not significant by F test; [(1)] Reference: Minimum (Min), Maximum (Max), and Average grain yield, respectively.

The major problem of the breeders is knowing which methodologies to assess adaptability and stability should be used to recommend a particular cultivar for a specific or wide region. Given this, several studies in the literature aim to compare these methodologies in different crops, such as corn (Oliveira, Moreira, & Ferreira, 2013; Bujak, Nowosad, & Warzecha, 2014; Faria et al., 2017; Oliveira, Carvalho, Costa, & Carvalho Filho, 2017), sugarcane (Paula et al., 2014), soybean (Barros et al., 2010; Batista, Hamawaki, Souza, Nogueira, & Hamawaki, 2015; Freitas Monteiro, Peluzio, Afferri, Carvalho, & Santos, 2015; Woyann et al., 2018), wheat (Roostaei, Mohammadi, & Amri, 2014), pea (Fikere, Bing, Tadesse, & Ayana, 2014), beans (Nunes, Freire Filho, Ribeiro, & Gomes, 2014) and rice (Akter et al., 2019; Silva et al., 2019; Silva Júnior et al., 2020a; Silva Júnior et al., 2020b). However, it is not pertinent to compare such methodologies, since each methodology aims to present results as answers to different questions, even though some methodologies have equal estimates.

Through information on evaluations in many environments, the recommendation of cultivars has been of interest for many decades and, currently, there are still propositions of new methodologies to assist breeders in this activity. A detailed view shows that a great contribution was made in the concepts that were formulated, referring to production potential, relative superiority, ecovalence, invariance, predictability, plasticity, and responsiveness. Other contributions refer to different statistical modeling capable of concisely capturing these concepts for use by breeders. Thus, as an example, current computational intelligence methodologies (Nascimento et al. 2013; Teodoro et al., 2015) or logic fuzzy (Carneiro et al., 2018; Carneiro et al., 2019) are interesting because they allow for machine learning less subjective interpretations of information or concepts already presented decades ago by Eberhart and Russell (1966) or Lin and Binns (1988). Techniques such as GGE biplot and AMMI use the interaction phenomenon (GxE) and allow, through a series of graphical analyzes, interpretations of environments and genotypes simultaneously where invariance, responsiveness, and similarity of response patterns can be visualized.

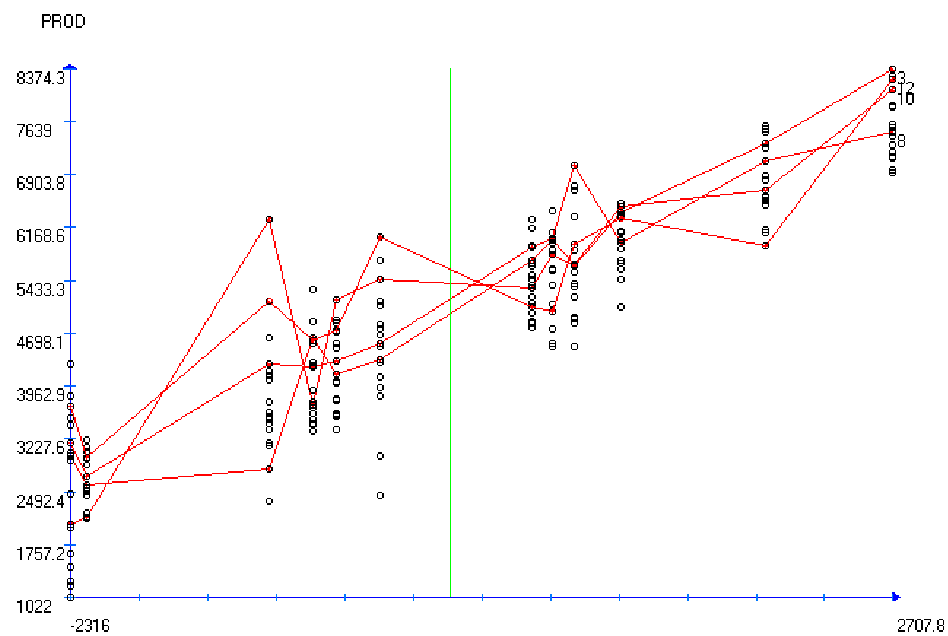

Figure 1. Representation of the behavior of 18 flooded-irrigated rice genotypes. The highlight lines represent the genotypes BRA02691 (3), BRA041230 (10), MGI0717-18 (12), and Ourominas control (8). The vertical line delimits unfavorable (left) and favorable (right) environments.

The existence of several methodologies to solve the same problem of adaptability and stability in crops or to be applied to the same data set indicates that there is not yet an ideal method. Thus, recent and well-founded methods, for example, Bayesian analysis (Couto et al., 2015; Nascimento et al., 2011) or quantile regression (Barroso et al. 2015), have in essence to capture concepts already established and desired by breeders without necessarily presenting an innovative concept but a more accurate method given experimental heterogeneities, failures, disruptions, and others. Also, was assumed that it’s not necessary to add in a single statistical model all the important concepts for the evaluation of an individual’s superiority and its recommendation. However, these concepts should be readily available to enable meta-analysis for rapid and effective decision making. Thus, it is recommended to generate information for concepts already established and available, even if separated, in a set of methodologies already proposed.

CONCLUSION

The aggregation of information and the large description of the behavior of the flooded-irrigated rice genotypes proved to be an efficient tool for studies of adaptability and stability.

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