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Phenotypic stability of forty advanced lines of rice at Babahoyo, Ecuador

Estabilidad fenotípica de cuarenta líneas avanzadas de arroz en Babahoyo, Ecuador

Estabilidade fenotípica de quarenta linhagens avançadas de arroz na área de Babahoyo, Ecuador

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Abstract

The crosses between *Oryza sativa* L. and *O. rufipogon* Griff., create a high genetic diversity to develop rice varieties with high yield and phenotypic stability. In the present investigation, forty advanced lines of rice were evaluated in subsidiaries F_5 (dry season) and F_6 (rainy season), together with three commercial controls in the town of Babahoyo, Ecuador. A Randomized Complete Block Design (DBCA) was applied with three repetitions, recording morphoagronomic and productive characters. Statistical analyzes were applied and phenotypic stability was determined using the Eberhart and Russell, AMMI, Lin and Binns, PROMVAR models. The average morphoagronomic results were: days to flowering (72), vegetative cycle (98 days), plant height (111 cm), panicle sterility (6 %); the productive variables the results were: tillers per plant (32), panicles per plant (31), panicle length (27 cm), grains per panicle (168) and yield (8,100 kg.ha^{-1}). The stable lines identified by the models: Eberhart and Russell were 1, 2, 10, 11, 13, 18, 25, 26, 30 and 37; AMMI identified lines 8 and 22; Lin and Binns to lines 2, 12, 18, 27, 37 and 40; and PROMOTE lines 2, 10, 13, 18, 25, 30, 38, 40 and 43; concluding that seven lines (2, 10, 13, 18, 25, 30 and 40) coincided with the applied models except AMMI. The average yield of the lines mentioned in the two seasons was 7,797 kg.ha^{-1}, higher than the average of the commercial controls that obtained 6,809 kg.ha^{-1}.

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Resumen

Los cruces entre *Oryza sativa* L. y *O. rufipogon* Griff., crean una alta diversidad genética para desarrollar variedades de arroz con alto rendimiento y estabilidad fenotípica. En la presente investigación se evaluó cuarenta líneas avanzadas de arroz en filiales F_5 (época seca) y F_6 (época lluviosa), junto con tres testigos comerciales en la localidad de Babahoyo, Ecuador. Se aplicó un Diseño de Bloques Completos al Azar (DBCA) con tres repeticiones, registrando caracteres morfoagronómicos y productivos. Análisis estadísticos fueron aplicados y la estabilidad fenotípica fue determinada utilizando los modelos Eberhart y Russell, AMMI, Lin y Binns, PROMVAR. Los resultados morfoagronómicos en promedios fueron: días a la floración (72), ciclo vegetativo (98 días), altura de planta (111 cm), esterilidad de panícula (6 %); las variables productivas los resultados fueron: macollos por planta (32), panículas por planta (31), longitud de panícula (27 cm), granos por panícula (168) y rendimiento (8.100 $kg.ha^{-1}$). Las líneas estables identificadas por los modelos: Eberhart y Russell fueron 1, 2, 10, 11, 13, 18, 25, 26, 30 y 37; AMMI identificó las líneas 8 y 22; Lin y Binns a las líneas 2, 12, 18, 27, 37 y 40; y PROMVAR las líneas 2, 10, 13, 18, 25, 30, 38, 40 y 43; concluyéndose que siete líneas (2, 10, 13, 18, 25, 30 y 40) coincidieron con los modelos aplicados excepto AMMI. El rendimiento promedio de las líneas mencionadas en las dos épocas fue de 7.797 $kg.ha^{-1}$, superior al promedio de los testigos comerciales que obtuvieron 6.809 $kg.ha^{-1}$.

Palabras clave: cruces interespecíficos, estabilidad fenotípica, adaptabilidad.

Resumo

Os cruzamentos entre *Oryza sativa* L. e *O. rufipogon* Griff., criam uma alta diversidade genética para desenvolver variedades de arroz com alto rendimento e estabilidade fenotípica. Na presente investigação, foram avaliadas quarenta linhas avançadas de arroz nas subsidiárias F_5 (estação seca) e F_6 (estação chuvosa), juntamente com três controles comerciais na cidade de Babahoyo, Equador. Foi aplicado o Delineamento em Blocos Completos Randomizados (DBCA) com três repetições, registrando-se os caracteres morfoagronômicos e produtivos. Análises estatísticas foram aplicadas e a estabilidade fenotípica foi determinada usando os modelos Eberhart e Russell, AMMI, Lin e Binns, PROMVAR. Os resultados morfoagronômicos médios foram: dias para floração (72), ciclo vegetativo (98 dias), altura da planta (111 cm), esterilidade da panícula (6 %); nas variáveis produtivas os resultados foram: perfilhos por planta (32), panículas por planta (31), comprimento da panícula (27 cm), grãos por panícula (168) e produtividade (8.100 $kg.ha^{-1}$). As linhas estáveis identificadas pelos modelos: Eberhart e Russell foram 1, 2, 10, 11, 13, 18, 25, 26, 30 e 37; A AMMI identificou as linhas 8 e 22; Lin e Binns para as linhas 2, 12, 18, 27, 37 e 40; e PROMOVER as linhas 2, 10, 13, 18, 25, 30, 38, 40 e 43; concluindo que sete linhas (2, 10, 13, 18, 25, 30 e 40) coincidiam com os modelos aplicados exceto AMMI. A produtividade média das linhagens citadas nas duas safras foi de 7.797 $kg.ha^{-1}$, superior à média das testemunhas comerciais que obtiveram 6.809 $kg.ha^{-1}$.

Palavras-chave: cruzamentos interespecíficos, estabilida de fenotípica, adaptabilidade.

Introduction

The geographical origin of rice (*Oryza sativa* L.) was probably in northeastern India, on the slopes of the Himalayas; the expansion of this crop started from Southeast Asia to China 3 000 years (B.C.); later to Korea, Japan in the first century (B.C.) (Pinciroli *et al*., 2015).

The economic importance of the agricultural sector in Ecuador is also supported by rice cultivation, as it is one of the main products of the basic food basket, with only 4 % of the production destined for export to Colombia and Peru (Poveda and Andrade, 2018).

In the selection process, stable and high-yielding genotypes should be evaluated in different locations and during several cycles, to identify those with outstanding adaptability potential, before being recommended for cultivation in any location or region (Sánchez-Ramírez *et al*., 2016).

Crosses between *Oryza sativa* L. and *O. rufipogon* Griff. generate abundant genetic diversity for the development of high-yielding rice varieties. On the other hand, the introgression of certain specific alleles of wild-type rice can contribute positively, even to increase resistance to stress (Martínez *et al*., 1998).

There are statistical models that lead to determine the genetic stability of commercial cultivars. The Eberhart and Russell Model provides estimates of stability parameters and characterizes the predictability of a genotype (Jiménez, 2006).

The Lin and Binns model describes genotype x environment interaction (GEI) effects and determines adaptability in a general sense (Acevedo *et al*., 2010).

The AMMI model (Additive main effects and multiplicative interaction method), allows a more detailed analysis of IGA, ensuring the selection of more productive genotypes, providing more accurate estimates of genotypic response (Acevedo *et al*., 2010).

The PROMVAR model is based on the relationship between genotype yield averages and their respective variances (Benítez *et al*., 1988).

Due to the low genetic diversity in rice cultivation, it is possible to create new germplasm adapted to the different agroecological conditions of Ecuador. The lines characterized in this study are derived from interspecific crosses of japonica rice (*Oryza sativa* L. ssp. japonica) with wild rice (*Oryza rufipogon* Griff.) known in Ecuador as black rice or Puyón, with potential genetic contribution in agronomic, phytosanitary and production terms. For this reason, the objective was to determine the phenotypic stability of forty advanced rice lines in Babahoyo, Ecuador.

Materials and methods

The research was conducted in the project area of the Study Commission for the Development of the Guayas River Basin (CEDEGE), Babahoyo, Los Ríos province, Ecuador (01º50'1.85" South Latitude and 79º26'47.26" West Longitude, 7 masl), with an annual average precipitation of 1,909 mm; 85 % relative humidity; 590.9 hours of heliophany and maximum and minimum temperature of 30 and 21.9 °C, respectively [Instituto Nacional de Meteorología e Hidrología (INAMHI, 2017)].

In table 1, the advanced line codes in F_5 (dry season) and F_6 (rainy season) subsidiaries and commercial cultivars (controls) studied are detailed.

Table 1. Codes of advanced lines F_5 and F_6 and commercial cultivars (controls) of rice. Babahoyo 2018-2019.

N°	Line/cultivar codes	Nº	Line/cultivar codes
1	PUYÓN/JP002 P8-30-P55-2	23	PUYÓN/JP002 P8-31-P41-4
2	PUYÓN/JP002 P8-30-P23-12	24	PUYÓN/JP002 P8-31-P7-4
3	PUYÓN/JP002 P8-30-P84-19	25	PUYÓN/JP002 P8-31-P7-27
4	PUYÓN/JP002 P8-30-P94-1	26	PUYÓN/JP002 P8-32-P97-5
5	PUYÓN/JP002 P8-30-P60-25	27	PUYÓN/JP002 P8-32-P97-13
6	PUYÓN/JP002 P8-30-P68-1	28	PUYÓN/JP002 P8-32-P8-16
7	PUYÓN/JP002 P8-30-P13-24	29	PUYÓN/JP002 P8-32-P87-26
8	PUYÓN/JP002 P11-10-P87-11	30	PUYÓN/JP002 P8-32-P35-20
9	PUYÓN/JP002 P11-10-P40-24	31	PUYÓN/JP002 P8-32-P109-24
10	PUYÓN/JP003 P11-10-P62-32	32	PUYÓN/JP002 P8-32-P40-22
11	PUYÓN/JP002 P8-28-P7-7	33	PUYÓN/JP002 P8-29-P60-1
12	PUYÓN/JP002 P8-28-P81-32	34	PUYÓN/JP002 P8-29-P60-6
13	PUYÓN/JP002 P8-28-P47-6	35	PUYÓN/JP002 P8-29-P8-16
14	PUYÓN/JP002 P8-20-P1-6	36	PUYÓN/JP002 P8-29-P8-5
15	PUYÓN/JP002 P8-20-P94-27	37	PUYÓN/JP002 P8-29-P49-30
16	PUYÓN/JP002 P8-20-P61-3	38	PUYÓN/JP002 P8-29-P32-1
17	PUYÓN/JP002 P8-20-P72-4	39	PUYÓN/JP002 P8-29-P65-5
18	PUYÓN/JP002 P8-31-P25-2	40	PUYÓN/JP002 P8-29-P66-30
19	PUYÓN/JP002 P8-31-P45-1	41	INIAP FL1480 Cristalino (testigo 1)
20	PUYÓN/JP002 P8-31-P45-28	42	SFL-11(testigo 2)
21	PUYÓN/JP002 P8-31-P30-18	43	INIAP FL-Arenillas (testigo 3)
22	PUYÓN/JP002 P8-31-P63-5		

The experimental unit consisted of a useful area of 1 m^2, excluding the borders, where the 16 central plants were evaluated.

Morphoagronomic variables

Days to flowering (DTF), when there were more than 50 % of flowering plants in the useful plot. Vegetative cycle (VC), days from transplanting to physiological maturity of the plants (harvest). Plant height (PH), evaluated one week before harvest by measuring from the ground to the apex of the most protruding panicle. Number of tillers per plant (NTP), recorded at harvest.

Production variables

Number of panicles per plant (NPP), the number of panicles per plant was counted at the time of harvest. Panicle length (PL), considered from the ciliate node to the panicle apex. Grains per panicle (NGP), the total number of grains per panicle was recorded from three random panicles per plant of the 16 plants in the useful area. Shelled kernel length (SKL), the length in millimeters was measured in ten randomly shelled kernels with a vernier caliper using the CIAT shelling category scale (CIAT, 1993). Sterility (PEP), sterile kernels were counted and the percentage of sterility was determined from the total number of kernels. Yield in $kg.ha^{-1}$, the weight of the grains from the useful plot was determined, adjusted to 13 % moisture; to uniformize the weight, the formula used by Cedeño *et al*. (2018) was used.

Statistical analyses were performed using the following computer programs INFOSTAT (UNC, 2018), INFOGEN (Balzarini and Di Rienzo, 2016), and Microsoft Office EXCEL. The experimental design used was randomized complete blocks (DBCA) with three replications. The linear analysis of variance model was applied in DBCA with the following equation:

Y_{ijk} (Phenotypic value of genotype i, evaluated in k replicates and j environments) = μ (Overall mean) + g_i (Genotype effect) + $b(a)_{k(j)}$ (Within-environment repeat effect) + a_j (Environment effect) + $(ga)_{ij}$ (Genotype-environment interaction effect) + E_{ijk} (Experimental error associated with the ijk-th observation).

The scheme of the combined variance analysis was also determined: lines by epoch: Sum of squares (SC), Degrees of freedom (DF), Mean squares (MS) and calculated F. In the analysis process, parametric tests were applied based on the verification of compliance with the assumptions of normality and homoscedasticity of the data (Corral, 2019).

In addition, the following statistics were determined: mean ($\bar{Y}$), median (Md), variance (S^2), standard deviation (S), standard or typical error (EE = $S\bar{Y}$), coefficient of variation (CV %), confidence interval of μ (95 %) (LIC and LSC).

The “Bigger is better” trait differentiation criterion was used for the variables number of tillers per plant (TPP), number of panicle per plant (NPP), panicle length (PL), number of grains per panicle (NGP), yield (kg), shelled grain length (SGL), and the “Smaller is better” criterion for the variables days to flowering (DTF), life cycle in days (LCD), plant height (PH), and percent sterility (PEP). In addition, a bivariate linear *r* correlation analysis was performed.

The stability of the lines was determined by applying four models: The Eberhart and Russell Model (1966), AMMI (Additive main effects and multiplicative interaction method) proposed by Zobel *et al*. (1988), Lin and Binns (1988), as well as PROMVAR (ratio of averages and relative variability) proposed by Benítez *et al*. (1988). As for the Eberhart and Russell model, the stability parameters (b, β and S^2) were determined. The selection priority (∑MS) for the most stable lines, according to this model, taking the yield variable ($kg.ha^{-1}$), was determined with the following parameters: $\bar{G}i$ ($k.ha^{-1}$) and was transformed by assigning the value of 1 to those lines that presented yields below the general mean and the value of 3 to those lines that presented values above the general mean; the coefficient of determination R^2 was transformed, qualifying with 1 the values observed below the general mean and with 2 the values above the general mean; for the variance of the deviations (S^2d) was qualified with 3 the values below the general mean and 1 to the values above the general mean. The sum of the three parameters described ($\bar{G}i$, R^2, S^2d) allowed the calculation of the selection priority, where the lines with higher scores were determined as priority 1 of higher stability.

Results and discussion

The general average of the traits by dry (E1) and rainy (E2) seasons in the rice lines/varieties, differentiated with the criterion “Less is better”, were the variables DTF, VC, AP and PEP. The best performance was in the rainy season DAF (E2)= 72 days, VC (E2)= 98 days, PH (E2)= 111 cm, PEP (E1)= 6 %. The criterion “Bigger is better” was observed in the variables NTP, NPP, PL, NGP, kg and SGL; however, the best performance was observed in the rainy season in the variables, NTP (E2)= 32, NPP (E2)= 31 and PL (E2)= 27 cm, in contrast to the dry season, where the best results were presented by the variables NGP (E1)= 168 and yield (E1)= 8,100 $kg.ha^{-1}$ (table 2).

Table 2. Descriptive statistics of morpho agronomic and productive characteristics in Babahoyo during the dry (E1) and rainy (E2) seasons.

Variables	Statistics											
	Ȳ	Md	S^2	S	SE	CV	RV	Min	Max	N	LIC	LSC
DTF (E1)	74	74	3,69	1,92	0,29	2,60	0,39	70	79	43	74	75
DTF (E2)	72	72	0,94	0,97	0,15	1,30	0,20	70	75	43	72	73
VC (E1)	114	114	3,69	1,92	0,29	1,70	0,26	110	119	43	114	115
VC (E2)	98	98	0,94	0,97	0,15	0,99	0,15	96	101	43	98	99
PH (E1)	113	112	22,85	4,78	0,73	4,20	0,64	109	137	43	112	115
PH (E2)	111	111	28,02	5,29	0,81	4,75	0,72	104	130	43	110	113
NTP (E1)	26	26	2,15	1,46	0,22	5,70	0,86	23	29	43	25	26
NTP (E2)	32	32	2,58	1,60	0,24	5,03	0,77	27	35	43	31	32
NPP (E1)	25	25	2,27	1,51	0,23	6,00	0,91	22	28	43	25	26
NPP (E2)	31	31	2,73	1,65	0,25	5,30	0,81	26	35	43	31	32
PL (E1)	26,00	26,00	0	0	0,06	1,40	0,22	26	28	43	26	27
PL (E2)	26,50	26,40	0,58	0,76	0,12	2,88	0,44	25	29	43	26	27
NGP (E1)	168	168	23	4,80	0,73	2,90	0,44	152	177	43	166	169
NGP (E2)	140	139	22,18	4,71	0,72	3,37	0,51	133	154	43	139	141
PEP (E1)	6,20	6,30	0,87	0,93	0,14	15	2,28	4,00	9,00	43	6,00	7,00
PEP (E2)	5,70	5,80	0,44	0,66	0,10	11,60	1,77	4,00	7,00	43	5,53	5,93
$kg.ha^{-1}$ (E1)	8100	8105	755106	869	133	10,73	1,64	6271	9884	43	7840	8359
$kg.ha^{-1}$ (E2)	6608	6593	278854	528	81	7,99	1,22	5440	7777	43	6450	6766
SGL (E1)	7,20	7,10	0,01	0,11	0,02	1,59	0,24	7,00	8,00	43	7,00	7,00
SGL (E2)	7,23	7,21	0,01	0,12	0,02	1,66	0,25	6,94	7,58	43	7,20	7,30

DTF: Days to flowering. VC: Vegetative cycle. PH: Plant height. NTP: Number of tillers per plant. NPP: Number of panicles per plant. PL: Panicle length. NGP: Number of grains per panicle. PEP: percent sterility. $kg.ha^{-1}$= Yield. SGL: shelled grain length. Ȳ= Mean; Md= Median; S^2= Variance; S= Standard deviation; SE= Standard error; CV= Coefficient of variation %; RV= Relative variability %; Min= Minimum; Max= Maximum; n= Number of observations; LIC= Lower confidence limit; LSC= Upper confidence limit.

According to the mentioned criteria "Higher is better" and "Lower is better" in the two seasons studied, the traits that stood out in each season were differentiated, where it was observed that there is an effect of the environment on the lines and varieties, through the evaluated traits. The best performance of the lines was observed in the dry season; these results agree with Chloupek *et al*. (2004), who mentioned that IGA is influenced by the different crop management technologies in the producing areas. The increase in yield over time is supported by genetic gains from the substitution of cultivars traditionally planted in the locality by cultivars from promising lines, in which genetic improvement programs have contributed with relevant modifications in characters of agronomic, productive and phytosanitary importance.

To decide the relevance of the parametric analysis of variance, homoscedasticity and normality tests were performed. In the first case, the F test was used and in the second case the Jarque and Bera (1987) test was used, contrasting with Chi-square. The F test for yield ($kg.ha^{-1}$) showed that most of the lines presented homoscedasticity and normality in the two periods; therefore, the assumption required for the application of parametric tests such as analysis of variance was met.

In this study it was demonstrated that most of the lines showed homoscedasticity between the season; therefore, the required assumption is fulfilled. Siegel (1990) mentioned that the conditions of normality, homoscedasticity and independence of quantitative data series in agricultural research are generally not verified; therefore, the risk of committing type I errors in statistical decisions is elevated. These selection decisions in rice lines have usually been made in descriptive analyses, mainly of means ± standard deviation.

In this experiment, the combined analysis of variance for yield ($kg.ha^{-1}$) (CV= 15.78 %), showed highly significant differences in sowing seasons (dry and rainy), lines/variety, repetition and seasons x lines (table 3).

Table 3. Combined analysis of variance of yield ($kg.ha^{-1}$) of forty lines and three commercial rice varieties in two seasons (dry and rainy) at Babahoyo location 2018-2019.

Source of variation	Degrees of freedom	Sum of squares	Mean square	F calculated	p-value
Seasons	1	143528913	143528913	106.63	<0.0001
Lines/variety	42	69126597	1645871	1.22	0.1871
Repetition	2	10108696	5054348	3.76	0.0254
Epochs x lines/variety	42	61161261	1456221	1.08	0.3543
Error	170	228824957	1346029		
Total	257	512750424			

CV (%) 15.78

The Pearson's product moment correlation analysis (r) determined the statistical association between the morphoagricultural variables as shown in table 4. The VC variable was observed correlated with greater consistency with the following variables: NTP (r = -0.751**); NPP (-0.740**); NGP (0.801**). Likewise, the variables NTP and NPP (0.988**) showed the same trend of consistency, since they approached values of 1 or -1.

Table 5 shows lines 1, 2, 10, 11, 13, 18 and 32, which were the ones that occupied selection priority 1 due to their high stability; however, the other lines/cultivars were distributed in priorities from 2 to 6.

Table 4. Linear correlation matrix r between morphological and productive characters of forty lines and three commercial rice varieties in two seasons (dry and rainy), in the locality of Babahoyo 2018-2019.

Variables	DAF	CVD	AP	LHB	NMP	NPP	LP	NGP	kg.ha-^{1}	LGD
DTF	1									
VC	0.594**	1								
PH	0.072	0.163	1							
FLL	0.108	-0.178	0.585**	1						
NTP	-0.355**	-0.751**	-0.208**	0.140	1					
NPP	-0.356**	-0.740**	-0.197	0.148	0.988**	1				
PL	0.102	0.001	0.471**	0.455**	-0.058	-0.066	1			
NGP	0.231**	0.801**	0.208 **	-0.169	-0.615**	-0.594**	0.130	1		
kg.ha^{-1}	0.113	0.484**	0.015	-0.152	-0.256**	-0.268 **	0.044	0.490**	1	
LGD	0.154	-0.066	0.285**	0.337**	0.017	0.018	0.314**	-0.106	-0.117	1

*correlation at 95 % confidence, **correlation at 99 % confidence where p<0.01, and GL=256 critical values of r 0.05 = 0.151 and r 0.01 = 0.197. DTF= Days to flowering, VC= Vegetative cycle, PH= Plant height, FLL= Flag leaf length, NTP= Number of tillers per plant, NPP= Number of panicle per plant, PL= Panicle length, NGP= Number of grains per panicle, kg.ha^{-1}= Yield, LGD= Shelled grain length.

Table 5. Results of the Eberhart and Russell model, using the variable yield (kg.ha^{-1}) with the rice lines determined as selection priority 1.

Lines	G_i					Gi	R^2	S^2d	Σ MC	Priority of
	(kg.ha^{-1})	b	β	S^2d	R^2	(1-3)	(1-2)	(1-3)		Selection
1	7357	1.86	0.86	0.506	0.832	3	2	3	8	1
2	8301	1.20	0.20	0.594	0.637	3	2	3	8	1
10	7546	1.64	0.64	0.682	0.458	3	2	3	8	1
11	7793	1.99	0.99	0.651	0.815	3	2	3	8	1
13	7605	0.99	-0.01	0.353	0.667	3	2	3	8	1
18	8240	0.80	-0.20	0.033	0.678	3	2	3	8	1
32	7388	0.85	-0.15	0.899	0.868	3	2	3	8	1
Ȳ (kg.ha^{-1})	7354	1.02	0.02	1.08	0.35					

Ḡi kg.ha^{-1}= Yield, (b= Slope, β= B prime, S^2d= Variance of deviations, R^2= Coefficient of determination)= Eberhart and Russell stability parameters, (Gi (1-3), R^2 (1-2), S^2d (1-3))= Ordinal scaled category grouping of average yield statistics of genotypes, Σ MC= Multicredit value, Selection priority.

The AMMI model combines additive components for the main effects (ANDEVA) and multiplicative components for the genotype x environment interaction (IGA), using principal components analysis (PCA) (Jiménez, 2006).

The results of the application of the AMMI model, classify and determine the magnitude of the interaction of the lines with the environment using the production variable, where CP1 represented 100% of the total variance in the two periods evaluated in Babahoyo. The most stable lines were: 3, 6, 8, 10, 13, 13, 16, 17, 18, 22, 25, 29, 31 and 32. The most stable and highest yielding lines were 8 and 22. The lines with the highest IGA were: 1, 5, 11, 12, 14, 24, 26, 27, 35, 36 and 37 (figure 1).

Lozano-del Río *et al.* (2009), using the AMMI model, identified the locations of high IGA in 14 environments, where the production of twenty-two forage genotypes of triticale (x *triticosecale* Wittm.) was evaluated. This same situation was evidenced for the highest IGA with lines 37, 24, 11 and 35 in the dry season at the Babahoyo locality.

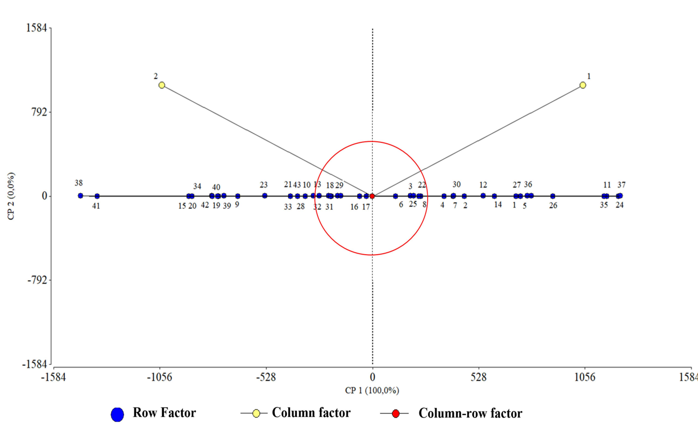

Figure 1. Results of the AMMI model on yield stability (kg.ha^{-1}) of forty lines and three commercial rice cultivars in two seasons (dry and rainy), in the locality of Babahoyo 2018-2019.

Acevedo *et al*. (2010), applying the AMMI analysis to establish the magnitude of IGA in yield (t.ha^{-1}) and to evaluate the adaptability and phenotypic stability of rice genotypes, stated that the relative stability values depend fundamentally on the representativeness of the available environments and the number of locations evaluated.

The environmental index determined by the Lin and Binns model (1988), allowed the identification of rice lines 2, 12, 18, 27, 37 and 40 of high adaptability (figure 2). The results of the Lin and Binns model in the present research, corroborate what was studied by Regitano *et al*. (2013), who evaluated the behavior of rainfed rice genotypes in the state of Sao Paulo, to determine the stability and adaptability of the yield variable, using the methodologies proposed by Eberhart and Russel (1966) and Lin and Binns (1988), where they identified three genotypes that showed the lowest values of environmental index Pi, which indicated that they were the closest to maximum productivity.

In this experiment, four models (Eberhart and Russel, Lin and Binns, AMMI and PROMVAR) were used to determine the phenotypic stability of forty lines and three commercial controls, with only seven lines coinciding in the three models applied. This study corroborates the data obtained by Vargas *et al*. (2016), who using the Eberhart and Russel, Lin and Binns, and AMMI models evaluated maize hybrids developed by the National Federation of Cereal and Legume Growers (Fenalce) with germplasm provided by the International Maize and Wheat Improvement Center (CIMMYT), in 17 environments in six agroecological zones of Colombia.

As for the PROMVAR model, the values were located in the lower right grid (figure 3), showing general average values in yield and relative variability of 7,354 kg.ha^{-1} and 7.54 %, respectively; where there were advanced lines with high yield behavior and high stability, such as lines 2, 10, 13, 18, 18, 25, 30, 38, 40 and INIAP FL-Arenillas (control 3), and values ranged from 6,166 to 8,301 kg.ha^{-1}, with relative variability values of 3.37 to 11.84 %. Unlike control 41 (INIAP FL-1480), which showed low yield and low stability, and control 42 (SFL-11), which showed low yield and high stability in the application of the PROMVAR model.

This study agrees with Velasco (2019) who used seven rice lines in F4 in the area of Babahoyo, Ecuador, reporting that the yield per plant in the seven lines were in a range of 51.7-61.9 g.plant^{-1}, compared with the control SFL-11 that obtained a lower value of 50.9 g. plant^{-1}, inferring that the lines were superior to the control; in the present study, the results presented the same tendency when it was observed that the forty lines obtained average yields of 7,395 kg.ha^{-1} in the two seasons, compared with the control commercial varieties that reached 6,809 kg.ha^{-1}.

Conclusions

The best morphological, agronomic and productive performance was obtained in the dry season. The Eberhart and Russell model allowed the selection of lines 1, 2, 10, 11, 13, 13, 18, 25, 26, 30, 32 and 37 with priority score 1. According to the Lin and Binns model, lines 2, 12, 18, 27, 37 and 40 showed high stability and higher production as a function of the yield superiority index. The PROMVAR model identified lines 2, 10, 13, 18, 25, 30, 38, 40 and 43 as having high yield kg.ha^{-1} and high stability (reduced relative variability).

The models that best fit to identify the stability of the rice lines during the two seasons (dry and rainy) in the locality of Babahoyo were Eberhart and Russell and PROMVAR, followed by the Lin and Binns model, due to the coincidence of the lines selected by the three models to determine stability.

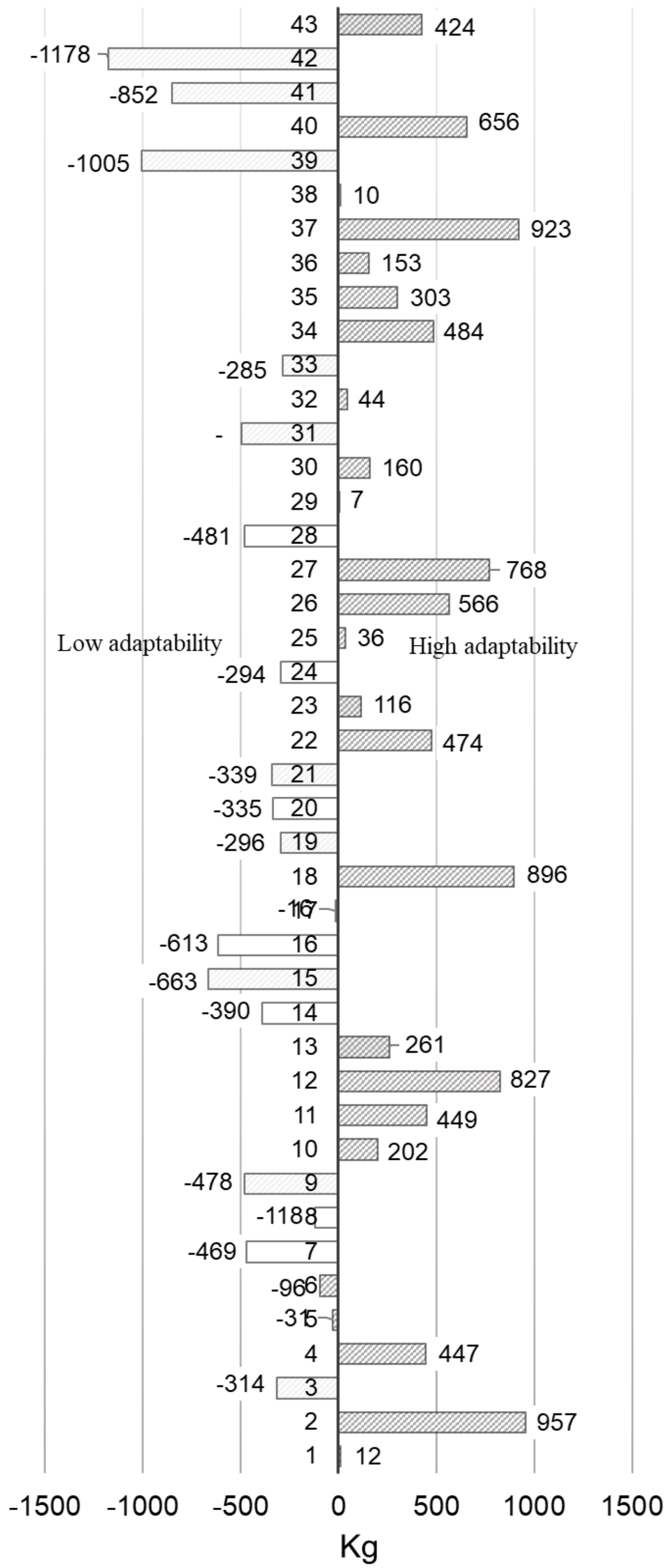

Figure 2. Environmental indices of the Lin and Binns model in two growing seasons (dry and rainy) of forty lines and three commercial rice cultivars in the locality of Babahoyo 2018-2019.

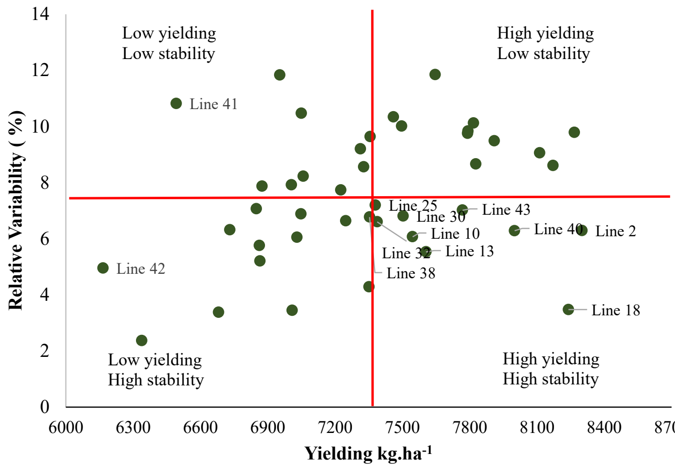

Figure 3. Four-cell plot of the PROMVAR model of the variable Yield (kg.ha^{-1}) in the locality of Babahoyo in two seasons (dry and rainy) 2018-2019.

Lines 2, 10, 13, 18, 25, 30 and 40 converge in the Eberhart and Russell, Lin and Binns and PROMVAR models, also showed high stability and the highest production in the two seasons (dry and rainy) evaluated.

The average yield of lines 2, 10, 13, 18, 25, 30 and 40 determined in the two seasons was 7,797 kg ha^{-1}, higher than the average of the commercial controls, which obtained 6,809 kg ha^{-1}.

The commercial controls INIAP FL-1480, SFL-11 and INIAP-FL Arenillas, showed low productivity and low stability, with respect to the aforementioned lines in the two seasons (dry and rainy) evaluated in the locality of Babahoyo.

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