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Genotypic performance, adaptability and stability in special types of irrigated rice using mixed models[1]

Desempenho genotípico, adaptabilidade e estabilidade em tipos especiais de arroz irrigado via modelos mistos

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ABSTRACT - There is an increasing demand for special types of rice that have black or red pericarp, low amylose (subspecie *japonica*) or aromatic. However, intense breeding process for obtaining and indicating genetically promising new cultivars and adapted to cultivation environments are demanded. In this sense, for evaluating the special types of irrigated rice genotypes, and determining the adaptability and stability of these using mixed models. First, a preliminary agronomic evaluation of genotypes for special types of irrigated rice was performed, and later, the agronomically promising genotypes were evaluated in multi-site trials, aiming at verifying the interactions with the environment. Statistical analyzes were performed considering mixed models, using the SELEGEN-REML/BLUP software. High genotypic variability among genotypes for special types of irrigated rice was observed, obtaining some agronomically promising and with good adaptability and stability, with high accuracy and selection efficiency using mixed models. The observed wide diversity and rice genetic variability presented new prospects and opportunities for producers for acquiring food of higher added value to consumer market.

Key words: *Oryza sativa*. Black rice. Red rice. Aromatic rice. Japanese rice.

RESUMO - É crescente a demanda por tipos especiais de arroz que apresentem, por exemplo, pericarpo preto ou vermelho, baixa amilose (subespécie *japonica*) ou aromático. No entanto, demandam de intenso processo de melhoramento genético para obtenção e indicação de novas cultivares promissoras geneticamente e adaptadas aos ambientes de cultivo. Neste sentido, com o objetivo de avaliar os genótipos dos tipos especiais de arroz irrigado, determinando a adaptabilidade e estabilidade destes através de modelos mistos. Primeiramente, realizou-se uma avaliação agronômica preliminar de genótipos para tipos especiais de arroz irrigado e, posteriormente, os genótipos promissores agronomicamente foram avaliados em ensaios multi-locais, visando verificar as interações com o ambiente. As análises estatísticas foram realizadas considerando modelos mistos, utilizando o software SELEGEN-REML/BLUP. Verificou-se alta variabilidade genotípica entre os genótipos para tipos especiais de arroz irrigado, obtendo-se alguns promissores agronomicamente e com boa adaptabilidade e estabilidade, com alta acurácia e eficiência de seleção através de modelos mistos. A ampla diversidade e variabilidade genética de arroz observada, remete novas perspectivas e oportunidades aos produtores para aquisição de alimentos de maior valor agregado para o mercado consumidor.

Palavras-chave: *Oryza sativa*. Arroz preto. Arroz vermelho. Arroz aromático. Arroz japonês.

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INTRODUCTION

Rice (*Oryza sativa* L.) is staple food for more than half the world's population (MUTHAYYA *et al*., 2014). Globally, there is a wide variation in the consumption habits of this cereal, mainly due to intrinsic characteristics associated with cultural and socioeconomic factors. The Brazilian market is based on the consumption of polished white rice or parboiled of long-thin class (subspecies *Indica)*, which have a high amylose content, low gelatinization temperature, thus showing, grains with high softness and disintegration after cooking process. However, over the past few years, in general the pattern of food consumption has been changing worldwide, mainly due to globalization and the increasing number of studies concerned to composition and nutritional constituents of functional foods. Rice with black pericarp, is a cereal rich in fiber and polyphenols, especially anthocyanins (XIA *et al*., 2006) and may be good for cardiovascular health (CHIANG *et al*., 2006; CHOI; KIM; FRIEDMAN, 2013; GINTER; SIMKO, 2012; PANDEY; RIZVI, 2009; YANG *et al*., 2011). Salgado *et al*. (2010) found that white rice diet, common in Brazilian diet, has few nutrients compared to black rice, and the phenolic compounds and proteins values in black rice are five to ten times higher than in white rice. Besides black rice, Chen *et al*. (2012) identified high levels of proanthocyanidins in rice bran with red pericarp, with potential for use as a functional food supplement for human consumption.

It is increasingly evident the increasing range of scientific information pointing to the nutritional complexity of genetic rice diversity (HEUBERGER *et al*., 2010), therefore, the future trend is that these functional foods are no longer just market niches, becoming on new prospects and opportunities. Barni *et al*. (2015) aimed at meeting the market acceptance for special types of rice with black and red pericarp in the state of Santa Catarina, performed sensory analysis in 1,068 people and have obtained good consumer acceptance, with high appeal of the attributes of phenolic compound presence.

Special types of rice are still in breeding processes much lower than the cultivars produced nationwide, and show lower yield potential. However, they have greater added value in the consumer market, being economic possible its production.

In order to obtain genotypes potentially more productive, it aims at selecting genotypes that have favorable agronomic characteristics, thus determining a greater genotypic efficiency. In this sense, it is evident the contribution of plant breeding to achieve significant increases in yield potential in rice crop, being mainly obtained through changes in plant architecture. The modern architecture of plants is derived from intensive breeding processes that resulted in plants with high capacity to have tillers, robust, short stems and erect leaves.

In these improvement stages is extremely important that the statistical methods used provide informative genetic parameters and with high accuracy. The REML/ BLUP method, which is the estimation of the variance components by restricted maximum likelihood (REML) (RESENDE; DUARTE, 2007), is a genotypic evaluation technique that has been constantly evolving with high efficiency in information about the correct ordering of genotypes for selection purposes and also on the effectiveness of inference about its genotypic value.

In order to act more effectively on this new reality, the authors aimed at evaluating agronomically and determining the adaptability and stability of special types of irrigated rice breeding program of Embrapa using mixed models.

MATERIAL AND METHODS

The experiment consisted of two stages, where, at first a screening related to agronomic evaluation of genotypes for special types of irrigated rice was performed, and later, the promising agronomically genotypes were evaluated in tests of crop value and use (VCU), in order to verify its interactions with the environment.

The preliminary agronomic evaluation was conducted in the experimental field in the municipality of Capão do Leão, State of Rio Grande do Sul (31°48'45,51" S latitude and 52°28'21,45" W longitude), during a period of five years in the harvest of 2009/2010, 2010/2011, 2011/2012, 2012/2013 and 2013/2014. The experiment was conducted in a randomized block design with four replications and plots consisting of 6 rows of 5 m length with 0.17 m spaced between rows. The usable area of plot was consisted of 4 m at the center of four internal rows, in order to exclude any incident effect on boundary. Thus, a total of 63 genotypes for special types of rice were evaluated (Table 1) which have features of interest and seven witness cultivars, four cultivars with long thin grains (BRS Pampa, BRS 7 'Taim', BR IRGA 409 and IRGA 417), and two with grains of subspecies *japonica* (IAS 12-9 Formosa and BRS Bojuru) and an aromatic cultivar (EMPASC 104).

In this experiment grain yield adjusted to 13% moisture; plant height (cm) at maturation stage, by measuring the length of the soil main stem until the end of panicle; days to flowering, considering the number of days from emergence to 50% of the exposed panicles; and percentage of intact grains after the industrial refining process were evaluated.

Table 1- Genotypes used in preliminary agronomic evaluation for special types of irrigated rice (*Oryza sativa* L.), considering grain class (GC), color of pericarp (CP) and special characteristics (SC)

N	Genotype	GC	CP	SC	N	Genotype	GC	CP	SC	N	Genotype	GC	CP	SC
1	BRS Pampa	LFG	WP	TC	25	SC 461	IG	WP	LA	49	Tomoe Mochi	SG	WP	JC
2	Nippombari	SG	WP	JC	26	LTB 11033	SG	WP	JC	50	Catetinho	SG	WP	JC
3	BRS 358	SG	WP	JC	27	AB 13014	SG	WP	JC	51	Bolinha/Catetinho	SG	WP	JC
4	BRS 7 Taim	LFG	WP	TC	28	LTB 12051	SG	WP	JC	52	LTB 12056	SG	WP	JC
5	SCS119 Rubi	LFG	RP	RP	29	Cateto Coleta	SG	WP	JC	53	Japonês Grande	SG	WP	JC
6	BR IRGA 409	LFG	WP	TC	30	BRS Bojuru	SG	WP	JC	54	Arroz Japonês	SG	WP	JC
7	IRGA 417	LFG	WP	TC	31	LTB 12053	SG	WP	JC	55	Cachinho	SG	WP	JC
8	Jasmine	LFG	WP	AG	32	Originário cinese	SG	WP	JC	56	Moti	IG	WP	LA
9	BRS AG	IG	WP	LA	33	LTB 12048	SG	WP	JC	57	Baldo	IG	WP	LA
10	BRS 902	LFG	RP	RP	34	AB 11008	SG	WP	JC	58	Cateto Seda	SG	WP	JC
11	LTB 12057	SG	WP	JC	35	LTB 12055	SG	WP	JC	59	Sasanishiki	SG	WP	JC
12	EMPASC 104	LFG	WP	AG	36	LTB 10031	SG	WP	JC	60	LTB 11030	SG	WP	JC
13	Balilla	SG	WP	JC	37	Nourin Mochi	SG	WP	JC	61	Ostiglia	SG	WP	JC
14	SC 460	IG	WP	LA	38	AB 12007	SG	WP	JC	62	Yin Lu 30	IG	RP	RP
15	LTB 11032	SG	WP	JC	39	SC 606	LFG	BP	BP	63	Meio Chumbinho	SG	WP	JC
16	LTB 11031	SG	WP	JC	40	Tamorim	SG	WP	JC	64	LTB 10032	IG	WP	LA
17	MNA PB 0405	LFG	RP	RP	41	AB 13015	SG	WP	JC	65	Drago	IG	WP	LA
18	LTB 12054	SG	WP	JC	42	SCS120 Ônix	LFG	BP	BP	66	Arbório	IG	WP	LA
19	AB 12005	SG	WP	JC	43	LTB 11034	SG	WP	JC	67	Carnaroli	IG	WP	LA
20	IAS 12-9 Formosa	SG	WP	JC	44	AB 12006	LFG	RP	RP	68	Cigalon	SG	WP	JC
21	LTB 11029	SG	WP	JC	45	LTB 12052	SG	WP	JC	69	CNAi 9917	LFG	BP	BP
22	LTB 12050	SG	WP	JC	46	Yamada Nishiki	SG	WP	JC	70	Basmati 370	LFG	WP	AG
23	Goyakuman Goku	SG	WP	JC	47	AB 13013	SG	WP	JC					
24	LTB 10029-1B	SG	WP	JC	48	BRS Aroma	LFG	WP	AG					

N - Genotype number; LFG – long-fine grain; SG - short grain; IG - intermediate grain (Italian type); WP - white pericarp; RP – red pericarp; BP - black pericarp; TC - traditional cultivation (witnesses); JC - japanese culinary; LA - low amylose; AG - aromatic grain

Genotypes that showed promising agronomic characteristics were allocated in multi-site trials being installed in three locations of the State of Rio Grande do Sul (Capão do Leão, Santa Vitória do Palmar and Capivari do Sul) during the harvest of 2011/2012, 2012/2013 and 2013/2014. A randomized block design was used with four replications and plots consisted of 9 rows of 5 m length with 0.17 m spaced between rows. The usable area of plot consisted of 4 m in the center of 5 internal rows.

In this experiment, the evaluated characteristics were: grain yield adjusted to 13% moisture; plant height at maturity stage, by measuring the length of the soil main stem until the end of the panicle; days to flowering, considering the number of days from emergence to 50% of the exposed panicles; percentage of intact grains after the industrial refining process; tolerance to plant lodging, leave scald *(Gerlachia oryzae),* brown spot *(Bipolaris oryzae)* and spot of grains (caused by a fungi and bacteria complex); characterization of grain concerned to length, width and thickness of caryopsis, percentage of chalkness grains, grain percentage with white belly, percentage of chalkness grain area, percentage of grain with color defects, amylose content and gelatinization temperature. Considering that the intrinsic physical characteristics of the grains were measured using the S-21statistical rice analyzer.

For both experiments the basis fertilization was 300 kg ha^{-1} of NPK (05-20-20 formula) and 90 kg ha^{-1} of nitrogen as urea, applied 50% of the dose in the V4 stage (early tillering) and the remainder at the R1 stage (panicle differentiation). The permanent flood irrigation system to R9 was used (final stage of genotypes maturation).

Statistical analyzes were performed considering mixed models through REML/BLUP using SELEGEN-

REML/BLUP software (RESENDE, 2007). The statistical model used to estimate the harmonic mean of the relative performance of genetic values (MHPRVG) was obtained from the model y = Xr + Zg + Wi + ε, wherein y is the data vector, r is the block effect vector, considered as fixed, added to the general average; g is the genotypic effect vector, considered as random; i is the genotype x environment (random) interaction effect vector; ε is the error or residue (random) vector; and X, Z and W represent the incident matrices for these effects.

RESULTS AND DISCUSSION

Estimates of genetic parameters (Table 2), considering the combined analysis of agronomic evaluation of 70 genotypes of special types of irrigated rice, showed high genetic variability for evaluated characters and evidenced by the high magnitude of coefficient estimates of genotypic variation and individual heritability. Low environmental variation coefficients with high obtained accuracies demonstrate that the experiment reached high efficiency in reducing environmental effects and showed high inferences of genotypic averages. Tests that have accuracy values above 0.90 can be considered as excellent experimental precision.

The genotypic values with the average interaction among genotypes and environment (u + g) on the analysis of all five agricultural yields (Table 3) indicated high variations in genotypic patterns of special types of rice. The character of days to flowering, showed fluctuations of magnitude between 70 and 134 days, i.e., genotypes was obtained with cycles ranging from extremely early and later. The CNAi 9917 genotype had the lowest plant height with only 75.28 cm, in contrast, Moti was considered the genotype with higher height (145.03 cm).

Regarding the yield predicted genotypic values (Table 3), the BRS Pampa witness cultivar of wide cultivation under irrigation system, stood out for its high yield genotypic value, with genetic potential to exceed 11000 kg ha^{-1}, as established by the superior limit of confidence interval. It should be noted that seven genotypes for special types of rice (Nippombare, BRS 358, SCS119 Rubi, Jasmine, BRS AG, BRS 902 and LTB 12057), showed yield genotypic magnitude higher the best witness for this purpose (EMPASC 104) as well desirable agronomic attributes. The Nippombare genotypes (subspecies *japonica*), BRS 358 (subspecies *japonica*) and SCS119-Rubi (red pericarp) had higher values even the witnesses of traditional crops BR IRGA 409 and IRGA 417. The Nipponbare genotype that shows short type of grain (subspecies *japonica),* is known worldwide for this feature, whose genome was completely sequenced.

Table 2 - Deviance, variance components, accuracy and coefficient of genotypic and residual variation of the characters: days to flowering (DTF), height of plants (HP), percentage of intact grain after processing (PIGAP) and grain yield, obtained through individual REML, considering combined analysis of 70 genotypes of special types of irrigated rice (*Oryza sativa* L.) evaluated in five harvest

Variance Components	DTF (days)	HP (cm)	PIGAP (%)	Yield (kg ha^{-1})
Deviance	1637.13	2727.53	1620.11	7058.94
V_g	213.98	299.56	13.26	2897222.62
V_{ga}	7.50	75.13	15.83	708080.05
V_e	3.02	38.83	4.53	260233.24
V_f	224.49	413.52	33.62	3865535.91
h^2_g	0.95±0.12	0.72±0.10	0.39±0.08	0.75±0.10
c^2_{ga}	0.03	0.18	0.47	0.18
h^2_{mg}	0.98	0.87	0.60	0.88
A^c_g	0.99	0.93	0.77	0.94
r_{ga}	0.97	0.80	0.46	0.80
CV_g (%)	15.35	15.49	5.62	30.45
CV_e (%)	1.82	5.58	3.28	9.13
Average	95	111.72	64.86	5589.41

V_g - genotypic variance; V_{ga} - variance of genotype x years; V_e - residual variance; V_f - individual phenotypic variance; h^2_g - heritability of individual parcels in the wide sense, ie, the total genotypic effects; c^2_{ga} - coefficient of determination of the effects of genotypes x years; h^2_{mg} - heritability in the wide sense the level of middle genotypes; A^c_g - accuracy of selection at the level of middle genotypes; r_{ga} - genotypic correlation between genotype x year; CV_g - genotypic variation coefficient; CV_e - residual variation coefficient

Table 3 - Predicted genotypic values (u + g) of agronomic attributes of days to flowering (DTF), height of plants (HP), percentage of intact grains after processing (PIGAP), accuracy, phenotypic mean and inferior (LIIC) and superior limits (LSIC) of the confidence interval of grain yield evaluated in special types of irrigated rice (*Oryza sativa* L.) in five harvest

N	Genotype	DTF (days)	HP (cm)	PIGA (%)	Yield (kg ha^{-1})				
					u + g	Accuracy	LIIC	LSIC	Phenotypic Average
1	BRS Pampa	86	105.78	65.28	9900.85	0.93	8663.40	11138.30	9816.15
2	Nippombare	99	107.03	66.60	9173.74	0.93	7936.29	10411.19	8992.04
3	BRS 358	90	85.51	66.84	8474.26	0.95	7414.39	9534.12	9170.80
4	BRS 7 Taim	90	96.65	65.60	8376.21	0.93	7138.76	9613.66	8088.10
5	SCS119 Rubi	95	96.28	67.22	8325.75	0.95	7265.88	9385.61	9009.08
6	BR IRGA 409	98	97.74	64.53	8215.85	0.95	7152.37	9279.33	8903.28
7	IRGA 417	84	93.30	61.32	8150.11	0.95	7090.24	9209.97	8817.82
8	Jasmine	94	104.02	63.09	7904.78	0.95	6844.91	8964.65	8550.67
9	BRS AG	88	118.37	70.70	7816.78	0.95	6768.04	8865.52	7534.47
10	BRS 902	99	96.88	64.35	7273.38	0.88	5673.59	8873.16	7601.31
11	LTB 12057	89	105.01	67.96	7253.53	0.93	6016.08	8490.98	6815.63
12	EMPASC 104	101	96.75	65.05	7219.36	0.93	5975.44	8463.28	8157.46
13	Balilla	84	95.26	65.92	6890.47	0.88	5285.77	8495.17	6232.23
14	SC 460	114	103.45	63.29	6795.17	0.95	5735.30	7855.03	7342.36
15	LTB 11032	116	132.82	66.27	6764.68	0.93	5538.23	7991.13	6703.55
16	LTB 11031	112	131.15	66.95	6676.57	0.93	5450.11	7903.02	6603.68
17	MNA PB 0405	104	103.03	67.23	6662.24	0.95	5602.37	7722.11	7197.61
18	LTB 12054	120	104.33	65.89	6582.58	0.88	4980.25	8184.91	6533.16
19	AB 12005	95	118.63	65.17	6412.94	0.88	4810.61	8015.27	6318.25
20	IAS 12-9 Formosa	95	105.80	67.38	6357.83	0.97	5500.41	7215.25	6398.84
21	LTB 11029	92	106.19	-	6277.79	0.88	4678.01	7877.58	6340.06
22	LTB 12050	114	122.88	67.27	6132.92	0.93	4895.47	7370.37	5545.51
23	Goyakuman Goku	75	96.42	65.60	6032.96	0.88	4433.65	7632.26	6044.92
24	LTB 10029-1B	79	95.80	59.32	6008.63	0.88	4403.93	7613.32	5115.08
25	SC 461	117	100.44	63.23	6005.94	0.95	4946.07	7065.81	6482.94
26	LTB 11033	116	133.68	67.71	5951.50	0.95	4902.76	7000.24	5503.29
27	AB 13014	113	139.13	65.68	5862.48	0.88	4257.79	7467.18	4929.94
28	LTB 12051	114	124.66	66.80	5825.58	0.93	4588.13	7063.03	5197.17
29	Cateto Coleta	93	114.22	67.15	5799.07	0.93	4555.16	7042.99	6547.68
30	BRS Bojurú	103	99.70	67.26	5769.71	0.88	4170.40	7369.01	5711.43
31	LTB 12053	117	123.56	67.05	5666.24	0.93	4428.79	6903.69	5016.56
32	Originário cinese	83	115.37	62.02	5621.17	0.88	4016.48	7225.87	4624.24
33	LTB 12048	113	130.52	66.51	5620.60	0.88	4015.91	7225.30	4623.52
34	AB 11008	92	112.88	64.84	5599.35	0.95	4550.61	6648.09	5119.81
35	LTB 12055	114	119.84	67.52	5396.77	0.93	4159.32	6634.22	4711.15
36	LTB 10031	93	118.08	66.49	5209.98	0.95	4161.24	6258.72	4695.81
37	Nourin Mochi	77	117.86	63.73	5182.86	0.93	3938.95	6426.78	5849.26
38	AB 12007	88	89.16	61.22	5177.21	0.93	3939.76	6414.66	4462.29
39	SC 606	92	85.66	61.09	5140.80	0.93	3896.89	6384.72	5801.58
40	Tamorim	76	102.03	64.53	5121.04	0.88	3518.71	6723.38	4681.63
41	AB 13015	119	126.28	65.12	5110.00	0.88	3505.30	6714.70	3976.67

Continued Table 3

42	SCS120 Ônix	93	85.82	56.23	5013.49	0.95	3953.62	6073.35	5402.21
43	LTB 11034	92	99.41	-	4996.39	0.88	3396.61	6596.18	4716.73
44	AB 12006	92	125.69	69.54	4984.88	0.93	3747.43	6222.33	4244.30
45	LTB 12052	91	107.52	64.92	4867.17	0.88	3264.84	6469.51	4360.01
46	Yamada Nishiki	101	110.61	67.17	4830.58	0.88	3231.27	6429.88	4521.70
47	AB 13013	111	135.08	65.93	4802.71	0.88	3198.01	6407.40	3587.37
48	BRS Aroma	90	105.07	63.01	4776.52	0.88	3177.21	6375.82	4453.21
49	Tomoe Mochi	78	100.12	66.69	4743.81	0.88	3144.51	6343.11	4411.78
50	Catetinho	96	137.26	63.47	4729.89	0.88	3130.59	6329.19	4394.15
51	Bolinha/Catetinho	94	132.86	62.54	4688.12	0.88	3088.82	6287.42	4341.23
52	LTB 12056	120	109.20	65.23	4572.91	0.88	2970.58	6175.24	3987.23
53	Japonês Grande	88	128.34	63.88	4550.57	0.88	2951.26	6149.87	4166.97
54	Arroz Japonês	87	96.93	65.15	4464.28	0.88	2864.97	6063.58	4057.66
55	Cachinho	89	109.61	67.18	4443.78	0.95	3383.92	5503.65	4781.83
56	Moti	95	145.03	66.55	4429.16	0.93	3185.24	5673.07	4994.99
57	Baldo	74	106.09	64.06	4394.00	0.88	2789.31	5998.70	3069.61
58	Cateto Seda	86	127.95	65.60	4153.89	0.88	2554.58	5753.19	3664.44
59	Sasanishiki	99	139.47	66.28	3988.28	0.93	2744.36	5232.20	4495.29
60	LTB 11030	86	115.31	64.47	3986.24	0.88	2386.45	5586.03	3437.03
61	Ostiglia	76	121.02	60.32	3852.95	0.88	2248.25	5457.64	2384.18
62	Yin Lu 30	108	135.71	63.60	3796.77	0.88	2192.08	5401.47	2313.02
63	Meio Chumbinho	104	123.09	67.04	3789.22	0.93	2545.30	5033.13	4269.67
64	LTB 10032	85	106.01	62.51	3613.26	0.93	2386.81	4839.71	3131.67
65	Drago	73	103.00	61.37	3469.70	0.88	1867.37	5072.03	2589.64
66	Arbório	78	108.83	56.16	3306.99	0.97	2449.57	4164.41	3185.18
67	Carnaroli	79	113.44	-	3290.27	0.88	1690.48	4890.05	2555.34
68	Cigalon	68	100.00	61.08	3056.09	0.88	1453.75	4658.42	2065.66
69	CNAi 9917	70	75.28	64.58	3050.35	0.93	1806.43	4294.26	3432.22
70	Basmati 370	134	144.78	64.09	2877.09	0.88	1277.79	4476.39	2046.95
Average	95	111.7	64.9	5589.4	-	-	-	5354.7	

The BRS 358 genotype was introduced in Brazil by Embrapa in 1999 through the International Irrigated Rice Observational Nursery (IIRON), recorded in the Bank of Rice Germplasm of Embrapa as its lineage named CNAi 9903. This genotype is originally from Egypt, obtained from simple crossing, involving GIZA 175 and MILYANG 49 cultivars and its main feature is low amylose content in grains (<22%) typical of Japanese culinary. After these preliminary assessments and subsequent tests of crop value and use (VCU), was recorded in the RNC (Registro Nacional de Cultivares) and released in 2015. In contrast, SCS119-Rubi cultivar is derived from collection by technical of EPAGRI (Empresa Brasileira de Pesquisa Agropecuária e Extensão Rural de Santa Catarina), in the south of Santa Catarina, being identified as SC 608 (WICKERT *et al*., 2014).

Other genotypes that stood out in terms of yield and agronomic standards were: Jasmine genotype that presents as highlight the aroma presence in grains; BRS AG, nicknamed "Giant" is a result of a crossing conducted at Embrapa Temperate Climate involving genes of introduced genotype SLG1 (super large grain) (TAKITA, 1983), whose grain dimensions are larger than those of conventional rice and weight of thousand grains of approximately 52 g (twice of the traditional cultivars), therefore, due to its excellent agronomic performance become the first cultivar of irrigated rice released as raw material for ethanol production and also for animal feed; BRS 902, released in 2015 by Embrapa by showing red pericarp; and LTB 12057 that have characteristic grains to the Japanese culinary.

Several genotypes also stood out in relation to IAS 12-9 Formosa and BRS Bojuru witnesses for special types, being promising for future releases or selection for use in hybridizations to obtain superior genotypes for interest features.

The estimate of individual accuracy, which measures the correlation between predicted genetic values and phenotypic values of each genotype, varied between high and very high (0.88 to 0.97). Thus, this analysis has been highly informative concerned to data and with good statistical reliability.

Table 4 shows the variance components and the interactions of genotypes that have shown promising agronomic characteristics to nine environments (3 sites x 3 years), through four evaluated agronomic characteristics. And for days to flowering (DTF), plant height and yield variables, the statistical model provided high genotypic variance, associated to high genotypic heritability of character and accuracies higher than 0.97 (very high). Therefore, we can infer that, for these variables, there was high genetic variability of rice genotypes for special types, associated to high efficiency on phenotypic evaluations performed at field.

The identification of genotypes with high yield, production stability and wide adaptability to various environments is one of the main targets of rice breeding programs. Thus, Table 5, through the harmonic mean of relative performance of genetic values (MHPRVG), efficiently provided the simultaneous interaction conception of genetic values for yield, adaptability and stability conditioned to evaluation environments. Regitano Neto *et al*. (2013) and Carbonell *et al*. (2007) also found that MHPRVG method was advantageous for presenting results on the same measurement scale of assessed character and simultaneously for production, stability and adaptability and it can be performed efficiently in the context of mixed models.

Among the evaluated genotypes of irrigated rice, it was found that Jasmine (aromatic), SCS 119 Ruby (red pericarp), BRS 358 (subspecies *japonica*) and BRS AG (high amylose) were genetically superior in terms of yield to IAS 12-9 Formosa cultivar (witness for special types of rice), combining both high yield, adaptability and genotypic stability.

Table 4 - Variance components, accuracy and coefficient of variation of characters - day to flowering (DTF), height of plants (HP), percentage of intact grain after processing (PIGAP) and grain yield, considering combined analysis of 15 genotypes of special types of irrigated rice (*Oryza sativa* L.) evaluated in nine environments (three sites and three harvest)

Variance components	DTF (days)	HP (cm)	PIGAP (%)	Yield (kg ha^{-1})
Deviance	555.86	890.17	933.94	2982.10
V_g	116.77	280.41	23.95	2948359.97
V_{bloc}	0.29	2.78	4.06	13388.77
V_{ga}	5.42	22.04	26.18	707146.25
V_e	2.04	19.48	28.41	93721.41
V_f	124.52	0.86	82.59	3762616.41
h^2_g	0.94	0.86	0.29	0.78
h^2_{mg}	0.99	0.98	0.75	0.95
A^c_g	0.99	0.99	0.86	0.97
c^2_{bloc}	0.00	0.01	0.05	0.00
c^2_{ga}	0.04	0.07	0.32	0.19
r_{ga}	0.96	0.93	0.48	0.81
CV_{gi} (%)	10.88	15.80	7.59	32.12
CV_e (%)	1.44	4.16	8.27	5.73
Average	99	105.97	64.44	5346.47

V_g - genotypic variance; V_{bloc} - block variance V_{ga} - variance of genotype x environment; V_e - residual variance; V_f - individual phenotypic variance; h^2_g - heritability of individual parcels in the wide sense, ie, the total genotypic effects; h^2_{mg} - heritability in the wide sense the level of middle genotypes; A^c_g - accuracy of selection at the level of middle genotypes; c^2_{bloc} - coefficient of determination of the effects of blocks; c^2_{ga} - coefficient of determination of the effects of genotypes x environment; r_{ga} - genotypic correlation between genotype x environment; CV_g - genotypic variation coefficient; CV_e - residual variation coefficient

Table 5 - Genotypic values (u+g+gem) of days to flowering (DTF), plant height (HP), percentage of intact grains (PIGAP), production adaptability and stability parameters of the genotypic values (MHPRVG) and production adaptability and stability parameters multiplied by the overall average of all trials (MHPRVG*MG) of special types of irrigated rice (*Oryza sativa* L.)

N	Genotype	DTF (days)	HP (cm)	PIGAP (%)	Yield (Kg ha^{-1})		
					u+g+gem	MHPRVG	MHPRVG*MG
1	Jasmine	99	104	62.7	7894.94	1.45	7733.40
2	SCS119 Rubi	100	95	70.2	7853.71	1.44	7715.90
3	BRS 358	94	85	66.8	7474.09	1.37	7299.78
4	BRS AG	91	115	72.1	7077.83	1.33	7088.67
5	IAS 12-9 Formosa	96	105	64.4	6457.07	1.18	6317.96
6	BRS 902	101	90	66.8	6259.68	1.14	6087.93
7	AB 12005	98	109	62.0	5362.27	0.99	5311.20
8	SCS120 Ônix	98	83	60.0	4730.75	0.88	4718.11
9	AB 11008	96	107	63.0	4585.80	0.83	4461.33
10	AB 13014	117	136	64.0	4415.69	0.79	4239.26
11	AB 12007	92	81	57.3	4096.03	0.71	3821.80
12	AB 13013	113	127	63.6	4039.88	0.70	3763.91
13	AB 13015	121	127	62.2	3632.63	0.61	3282.79
14	AB 12006	89	113	72.4	3399.12	0.56	3009.51
15	Arbório	80	107	58.2	2917.56	0.45	2400.93

The current breeding programs of irrigated rice, aims at combining genotypes with high yield that have high genotypic plasticity in order to minimize the vulnerability to main biotic and abiotic factors, thus mitigating interference in the expression of its genetic potential.

Table 6 shows the genotypes responses concerned to lodging and principal diseases inherent to crop. Genotypes that presented high yields and good agronomic attributes in Table 5 also showed good tolerance to lodging and principal crop diseases. The best performances were obtained by already commercial genotypes (BRS 358, BRS AG, IAS 12-9 Formosa, BRS 902, Jasmine, SCS 119 Rubi, SCS 120 Ônix) due to rice breeding programs for special types combine high yield with good agronomic attributes and good tolerance to stresses in its genotypes. The unique grain pattern for special type that has not been much worked in Brazil to genetic performance improvement are the Italians types (Arbório, Carnaroli), which showed low genotypic performance for both grain production and agronomic attributes.

The attributes related to grain provide important parameters for the final product knowledge after cooking process. The most polished rice components consists of starch (until 95% of dry weight), protein (5% to 7%) and lipids (0.5% to 1%). The amount of these compounds affects sensory (FITZGERALD *et al*., 2008) and food appearance properties.

Physical properties include grain yield after processing, uniformity, whiteness and grain translucency. The defects associated to rice combined grain quality characteristics dictate its market value and have a key role in the adoption of new cultivars. Thus, in Table 6 it can be seen that there is a great variation in grain dimensions, which results in the different grain forms, as well the main physical properties. Regarding the caryopsis dimensions, it was found that eight of the fifteen genotypes have more rounder shape, i.e. it showed the relationship between length and width, less than 2.0 (<1.50 = rounded; 1.50 - 2.00 = half-rounded), characteristic of *Japonica* subspecies. Moreover, these genotypes by genetic constitution had high chalkness area index.

In addition to grain physical characteristics, amylose content and gelatinization temperature are critical to determine sensory and cooking characteristics of rice. The amylose content is considered one of the main parameters for the technological quality and rice consumption and due to this reason, this characteristic should be assessed during cultivars development (WALTER; MARCHEZAN; AVILA, 2008). Table 6 shows that evaluated genotypes showed amylose content

Table 6 - Response of special types of irrigated rice (*Oryza sativa* L.) compared to attributes: plant lodging (PL), scald (Esc), brown spot (BS), grain spot (GS), caryopsis length (CL), caryopsis width (CW), caryopsis thickness (CT), relationship between length and width of caryopsis (LWR), percentage of chalkness grains (G), percentage of grains with white belly (WB), percentage of grain chalkness area (CA), percentage of grains with color defects (CD), amylose content (AT) and gelatinization temperature (GT)

Genotype	PL[(1)] (1-9)	Esc[(1)] (1-9)	BS[(1)] (1-9)	GS[(1)] (1-9)	CL (mm)	CW (mm)	CT (mm)	LWR [(2)]	G (%)	WB (%)	CA (%)	CD (%)	AT[(3)]	GT[(4)]
Jasmine	1	2	2	1	7.65	2.20	1.91	3.48	0.22	0.15	14.53	0.31	I	I
SCS119 Rubi	1	2	2	3	7.07	2.07	1.71	3.42	np	np	np	np	I	I
BRS 358	1	2	3	1	5.28	2.65	1.92	1.99	0.28	0.12	13.91	0.54	L	I
BRS AG	1	1	2	3	7.95	3.83	2.76	2.08	1.52	53.63	49.41	8.17	L	L
IAS 12-9 Formosa	1	2	2	2	4.56	2.98	2.10	1.53	0.39	0.10	13.40	2.05	L	L
BRS 902	1	2	5	4	6.34	2.88	2.01	2.20	np	np	np	np	I	I
AB 12005	1	2	1	2	4.43	2.93	1.96	1.51	0.34	3.67	15.11	0.81	L	L
SCS120 Ônix	1	1	3	3	7.22	1.77	1.44	4.08	np	np	np	np	I	I
AB 11008	2	2	2	2	4.45	2.87	2.11	1.55	0.11	0.20	12.87	1.72	L	L
AB 13014	5	2	1	4	5.12	3.14	2.05	1.63	0.23	0.27	14.15	2.60	L	L
AB 12007	1	2	3	2	5.63	2.86	1.99	1.97	0.19	3.60	21.55	8.03	L	L
AB 13013	3	1	1	4	5.63	3.17	2.11	1.78	0.92	0.81	18.38	3.05	L	L
AB 13015	3	2	2	4	5.09	2.94	1.97	1.73	0.28	0.38	13.91	2.75	L	L
AB 12006	2	2	1	2	5.84	2.80	1.94	2.09	np	np	np	np	I	I
Arbório	2	2	2	4	7.09	3.48	2.16	2.04	1.27	20.64	34.74	2.01	L	L

[(1)]Notes between 1-9 (lowest notes correspond to better agronomic performance or tolerance); [(2)] grain form on the relationship between length and width of the caryopsis: <1.50 = rounded; 1.50 to 2.00 = half-rounded; 2.01 to 2.75 = half-elongated; 2.76 to 3.50 = elongated; > 3.50 = very elongated; [(3)] L = low (> 22%), I = intermediate (23 to 27%); [(4)] L = low (63 to 68 °C), I = intermediate (69 to 73 °C) [np:] genotypes that have not been polished for presenting color in pericarp, used in full form

(AC) between low to intermediate, while the genotypes of *japonica* subspecies showed low amylose, i.e., soft and “sticky” grains after cooking. In contrast, genotypes of *Indica* subspecies both aromatic and color pericarp types, showed intermediate amylose levels, with loose and soft grains after cooking process, being highly compatible with market requirements.

In addition to amylose content, gelatinization temperature (GT) is a very important quality parameter for rice, due to its evaluation of cooking resistance index. In Table 6 it was found that nine genotypes showed GT between 63 °C and 68 °C (low) and six genotypes between 69 ºC and 73 °C (intermediate).

Even demonstrating yield and agronomic characteristics inferior compared to BRS Pampa cultivar, which is one of the main traditional cultivars of irrigated crop in southern of Brazil, the special types presented in great prominence, due to its added value, either for human consumption as well for other uses such as animal feed, ethanol production, among others. This inferior yield of special types of rice compared to traditional crops corroborates several previous studies worldwide. Ji *et al*. (2012) found that rice genotypes with black pericarp showed yield, weight of 1,000 grains and thickness of caryopsis significantly lower when compared with white pericarp genotypes in two crops. Furthermore, differences in physiological characteristics of plants were observed.

Thus, the special types have wide source for new prospecting studies in all stages of the production chain, using the great diversity and genetic variability of rice in order to expand opportunities for farmers in the cultivation of foods with added value and with higher quality to consumer market.

CONCLUSIONS

1. A high genetic variability among genotypes for special types of rice for the main agronomic characteristics using mixed models was found;
2. The commercial genotypes BRS 358, BRS AG, IAS 12-9 Formosa, BRS 902, Jasmine, SCS 119 Rubi, SCS 120 Ônix were agronomically superior through simultaneous selection for yield, stability, adaptability and agronomic attributes for special types of irrigated rice;
3. The use of mixed models and MHPRVG method proved to be suitable, efficient and highly informative about the inference of genotypic values for the use in rice breeding programs aiming at assessing special types of rice.

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