Ciência Rural, Santa Maria, v.52:12, e20210418, 2022 http://doi.org/10.1590/0103-8478cr20210418

ISSNe 1678-4596
CROP PRODUCTION

Grain processing, adaptability, and stability of red rice cultivars

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ABSTRACT: *Red rice is consumed in whole grain form due to its beneficial nutritional attributes and has become an option for crop diversification. Several factors during plant development can affect the crop'syield. This study evaluated the adaptability and stability of the post-harvest processing of red rice cultivars and compare them with those of white rice cultivars grown in the municipalities of Campos dos Goytacazes, Seropédica, and Pinheiral, RJ, between 2016 and 2018. Two white rice (BRS Esmeralda and IAC 201) and two red rice cultivars (ENA-AR1601 and Virginia) were distributed in the field under randomized block design with five repetitions. Yield, grain class, ingenuity, and whole grain yield were evaluated. The means of these parameters for cultivars in different locations and years were compared by Tukey's test (P < 0.05). The Eberhart and Russell regression model was used to estimate the adaptability and stability parameters. The grain classification of the cultivars ENA-AR1601 and Virginia was medium and long, respectively. The red rice cultivars ENA-AR 1601 and Virginia showed higher productive performance than the national average. The red rice cultivars and BRS Esmeralda showed highly predictable behavior based on the environmental stimulus. With average values of 62% in the two years evaluated, the red rice cultivars showed excellent processing yield.*
Key words: *whole grain, processing, productivity, Oryza sativa L.*

Beneficiamento de grãos, adaptabilidade e estabilidade de cultivares de arroz vermelho

RESUMO: *O arroz vermelho é um tipo especial de arroz que devido a atributos benéficos a saúde é consumido na forma integral e tornou-se uma opção de diversificação de cultivo. Diversos fatores durante o desenvolvimento da planta podem afetar o rendimento de beneficiamento. Com isso, o objetivo deste trabalho foi avaliar a adaptabilidade, estabilidade e beneficiamento de grãos de cultivares de arroz vermelho e compará-la a de arroz branco produzidas nos municípios de Campos dos Goytacazes, Seropédica e Pinheiral, RJ, durante os anos agrícolas de 2016/2017 e 2017/2018. Os tratamentos foram duas cultivares de arroz branco (BRS Esmeralda e IAC 201) e duas de arroz vermelho (ENA-AR1601 e Virgínia), distribuídos no campo sob o delineamento em blocos ao acaso, com cinco repetições. Foram avaliadas a produtividade, classe do grão, o rendimento de engenho e de grãos inteiros. As médias das cultivares em diferentes locais e anos foram comparadas pelo teste de Tukey (P< 0,05). Foi adotada a metodologia recomendada por Eberhart e Russell para estimativa dos parâmetros de adaptabilidade e estabilidade. A classificação dos grãos das cultivares ENA-AR1601 e Virgínia foi médio e longo, respectivamente. As cultivares de arroz vermelho ENA-AR 1601 e Virgínia apresentaram desempenho produtivo superior a média nacional. As cultivares de arroz vermelho e BRS Esmeralda apresentaram comportamento altamente previsível de acordo ao estímulo ambiental. Com valores médios de 62%, nos dois anos avaliados, as cultivares de arroz vermelho apresentaram excelente rendimento de beneficiamento.*
Palavras-chave: *grão inteiro, processamento, produtividade, Oryza sativa L.*

INTRODUCTION

Red rice (*Oryza sativa* L.) contains proanthocyanidin, the main bioactive compound associated with antioxidant activity (SILVA et. al. 2020). Another flavonoid reported in the pericarp of red rice is anthocyaninwhich, besides its antioxidant properties, inhibits amylase activity, reducing the release of sugars in the blood (RAJENDRAN & CHANDRAN, 2020).

During processing, rice grains may suffer mechanical damage resulting in broken grains, which lower the product's market value (CANELLAS et al. 1997).

The yield of rice cultivars, as with all phenotypic characteristics, is influenced by the genotype, the environmental conditions where the plant developed, and the interaction between both. According to ARTIGIANI et al. (2012),under rainfed conditions, the yield of processing is influenced by the amount of nitrogen fertilizer added, while under irrigated conditions there is no effect of different doses of nitrogen. There can be great variation in

Received 05.26.21 Approved 12.15.21 Returned by the author 03.14.22
CR-2021-0418.R2
Editors: Leandro Souza da Silva Melissa Walter

water content between grains from the same panicle (SOFIATTI et al. 2006) and the water content at harvest can also affect the quantityof whole grains (CANELLAS et al. 1997).

The classification of processed grains is necessary for determining the adequacy of methodologies. According to BOÊNO et al. (2011), when evaluating the grain processing yield of red rice genotypes, the average value was 72.8%, which is higher than that reported in Japan (60% or less).

Thus, this research evaluated the adaptability and stability and grain yield of red rice cultivars and compare it to that of white rice cultivars produced in the state of Rio de Janeiro, Brazil.

MATERIALS AND METHODS

The experiments were conducted during the growing season of 2016/2017 (Year 1) and 2017/2018 (Year 2), in three locations in the state of Rio de Janeiro:L1 - Campos dos Goytacazes Campus of the Federal Rural University of Rio de Janeiro (UFRRJ), in the municipality of Campos dos Goytacazes, located at 21°45’15” S and 41°19’28” W; L2 - Experimental area of the Department of Phytotechny of the Agronomy Institute - UFRRJ, in the municipality of Seropédica, located at 22°44’29” S and 43°42’49” W; L3 - Federal Institute of Education, Science and Technology of Rio de Janeiro (IFRJ) - Câmpus Nilo Peçanha, in the municipality of Pinheiral, located at 22°30’46” S and 44°00’02” W.

The trials were conducted in rainfed systems, with supplementarysprinkler irrigation, and under organic production management. Seeds were sown in beds with a density of 200 g seeds m^{-2}, adjusted according to germination and seed mass of each treatment. Subsequently, when the seedlings presented an average of six definitive leaves, they were transplanted as planting clumps of 8 to 12 seedlings, spaced at 0.20 m from each other. The plots consisted of eight rows of plants, each 4.0 m long and with spacing of 0.5 m between rows. The useful area of the plot consisted of the four central rows, excluding 1.0 m from their ends, corresponding to 4.0 m^2. Invasive plants were controlled by manual removal.

The experimental design included a randomized block design with four treatments and five repetitions. The treatments were the registered white rice cultivars, BRS Esmeralda and IAC 201; and the traditional red rice cultivars, ENA-AR1601 and Virginia. Productivity (Prod) was obtained by averaging the total grain yield at 13% moisture in the useful area of the plots of each treatment, expressed in kg ha^{-1}.

The evaluations regarding the industrial and technological quality of the grains, including the grade, yield, and whole grain yield, were performed in the Official Classification Laboratory of the Inspection Service and Plant Health of the Federal Superintendence of Agriculture, Livestock and Supply (SISV/SFA) of the Ministry of Agriculture, Livestock and Supply (MAPA), in the municipality of Rio de Janeiro (RJ). For these evaluations, 100g of sample from each plot was obtained, the grains were dried naturally to 13% humidity, and processed using a proof mill (Suzuki, São Paulo, Brazil). The grains were dehulled and evaluated for yield and whole grain levels using a trieur classifier, following Normative Instruction No. 6 of February 16, 2009 and No. 2 of February 7, 2012 (BRASIL, 2009; 2012).

All data obtained were subjected to individual analysis of variance and means were compared using Tukey’s test ($P < 0.05$). After the homogeneity of variances was verified, joint analysis was performed to study the temporal and regional interactions. Parameters indicating adaptability and stability of the cultivars’ responses, were analyzed using the regression model described by Eberhart and Russell’s (1966). The statistical analyses were performed using the Computational Application in Genetics and Statistics - GENES (CRUZ, 2013)

RESULTS AND DISCUSSION

A significant genetic variability was reported between all cultivars, as determined by the F-test (Table 1), due to expected differences in the origin and characteristics of red and white rice cultivars. Similarly, a significant effect was found for environmental inputs, indicating the heterogeneity in the environmental conditions of the test sites. Further more, a GxA interaction was detected (Table 1).

The red rice cultivars ENA-AR 1601 and Virginia showed the highest productivity averages in all locations and years, but it was only possible to identify significant difference with the white rice cultivar BRS Esmeralda in L1 of Year 1 and L2 of Year 2 (Table 2). These results showed that the productivity of the red rice cultivars was high, in contrast with the general expectation that cultivars of special types of rice are less productive than those of white rice (MAGALHÃES JÚNIOR et al. 2012). MENEZES et al. (2011) and MOREIRA et al. (2011) evaluated the productivity of ENA-AR 1601 and Virgínia in rainfed and conventional management

Table 1 - Joint analysis of variance for the four cultivars (ENA-AR 1601, Virginia, BRS Esmeralda, and IAC 201) and six environments (Campos dos Goytacazes, Seropédica, and Pinheiral, in both seasons 2016/2017 and 2017/2018).

Source of variation	Prod	G.int	Income
Cultivar	5242759*	187.77213**	113.00403**
Environment	40422377*	1001.13801**	487.39946**
GxE	1074319**	139.37068**	12.13444*
Waste	261998	27.823	5.71528
CV(%)	14.41	8.22	3.25

Prod: yield, in kg ha^{-1} ; G.int, percentage of whole grains; Rend, percentage of ingrain yield. *significant ($P < 0.05$); **significant ($P < 0.01$).

systems and recorded average yields of 3658 and 4240 kg $ha^{-1}$for the former, and 5072 and 2487 kg ha^{-1} for the latter cultivar (respective to management system). PASSERI LIMA (2014) reported a yield of 4145 kg ha^{-1} for the cultivar ENA-AR 1601, grown under the same management conditions mentioned above.

The IAC 201 cultivar, in general, had the lowest yields, ranging from 1114 to 5174 kg ha^{-1} (Table 2). In two locations, L1 and L3 of Year 2, yield was above the mean, and in L3 it was the second highest, but did not differ significantly from that of ENA-AR 1601 and BRS Esmeralda. The edaphoclimatic and management conditions may interfere in the agronomic performance of cultivars. MASNI &WASLI (2019) evaluated the effect of different levelsof nitrogen, phosphorus, and potassium on a red rice cultivar. They observed that productivity did not increase by increasing fertilizer amounts beyond the minimum required levels (Nitrogen 60 kg ha^{-1}, Phosphorus 35 kg ha^{-1}, Potassium 40 kg ha^{-1}).

The parameters β_0, β_1, and σ^2 were estimated using the methodology described by EBERHART & RUSSELL (1966), where β_0 = genotype mean, β_1 = linear regression coefficient (which measures the response of the genotype to environmental variation), and σ^2 = variance of the regression deviation. The ideal cultivar in this analysis is the one with β_0 as large as possible, β_1= 1 and σ^2 as small as possible (σ^2 = 0). Genotypes with a high linear regression coefficient value and regression variance deviation close to zero are responsive to the improvement of environmental conditions and production stability (OLIVEIRA et al., 2020). The desirable genotype for genetic improvement is the one that is stable and has above-average productivity (ALVES et al., 2020).

The value of the adaptability parameter, β_1, ranged from 0.93 to 1.04 (Table 3), and for all cultivars in this study, these values were not significantly different (β_1 = 1), suggesting that they are cultivars of wide adaptability, with a productivity and yield that is proportional to environmental conditions.

Table 2 - Productivity (Prod) of the cultivars ENA AR - 1601, Virginia, BRS Esmeralda, and IAC 201, in sites L1 (Campos dos Goytacazes), L2 (Seropédica), and L3 (Pinheiral), in the seasons 2016/2017 (Year 1) and 2017/2018 (Year 2).

Genotype	Prod (kgha $^{-1}$)					
	Year 1			Year 2		
	L1	L2	L3	L1	L2	L3
ENA AR - 1601	2128 Cab	3767 Ba	6057 Aa	2139 Ca	4251 Bab	4644 Bab
Virginia	2506 CDa	3370 Ca	5923 Aa	2237 Da	4365 Ba	5317 Aa
BRS Esmeralda	1554 Dbc	3302 Ca	5436 Aa	2125 Da	3419 Cb	4395 Bb
IAC 201	1114 Dc	2215 Cb	4057 Bb	2326 Ca	3407 Bb	5174 Aab
Average	1825.5	3163.5	5368.2	2206.7	3860.5	4882.5
CV(%)	24.22	16.74	12.19	15.95	10.41	12.67

Means followed by the same lower-case letter in the column and capital in the row do not differ by Tukey's test ($P < 0.05$).

Table 3 - Adaptability and stability parameters of the four rice cultivars (ENA-AR1601, Virginia, BRS Esmeralda, and IAC 201) analyzed by the method of EBERHART & RUSSELL (1966). Mean yield in kgha^{-1} (β_0), estimates of regression coefficients (β_1), variance of regression variance (σ^2) and coefficient of determination (R^2).

Cultivars	β_0	β_1	σ^2	R^2 (%)
ENA-AR 1601	3831	1.03ns	112393ns	94.2
Virginia	3953	1.04ns	14864ns	97.6
BRS Esmeralda	3371	0.98ns	33076ns	96.6
IAC 201	3048	0.93ns	414510*	82.4
Overall average	3551			

Ns, not significant; * significant at 5% by t test (H_0: $\beta_1 = 1.0$) and by F test; F (H_0: $\sigma^2 i = 0$)

The cultivars ENA-AR 1601 and Virginia presented β_0 greater than the overall average, which was 3551 kg ha^{-1}(Table 3). The red rice cultivars and BRS Esmeralda showed non-significant σ^2 values and high determination coefficients (R^2), ranging from 94.2 to 97.6% (Table 3), which suggested that they are cultivars with high stability for the environments where they were tested, and exhibit highly predictable behavior based onthe environmental stimulus (CRUZ et al. 2012). Following COLOMBARI FILHO et al. (2013), in a study conducted in seven states with 264 strains and cultivars, BRS Esmeralda ranked third in adaptability and stability. For example, these cultivars, in environments of lower productivity (L1 and L4), with better rainfall distribution or implementation of a more efficient irrigation system, would respond positively, increasing grain yields.

Cultivar IAC 201 was responsive to changes in the environment, but hadlow stability and a yield below the general average. When evaluating different strains and varieties of rice from the highlands of São Paulo State, REGITANO NETO et al. (2013) observed that the cultivar IAC 201 presented non-significant β_1 and σ^2, but with β_0 below the general average.

According to IN 6 a dimensions, the grains are classified as follows: long-fine: ≥ 6mm and C/L ratio ≥ 2.75; long: ≥ 6mm; medium: ≥ 5mm and < 6mm; short: < 5mm (BRASIL, 2009). The grains of the red rice cultivars, ENA-AR 1601 and Virginia, were classified according to Normative Instruction n°6 (BRASIL, 2009) as medium and long, respectively. The white rice cultivars had their grains classified as long-fine (Table 4), as published by the Agronomic Institute of Campinas and in CASTRO et al. (2014). BÔENO et al. (2011) studied the technological quality of four genotypes of red rice and found that three of them had long grains and one has medium grains. THAWORNA et al. (2021) when evaluating grains of white, red, and purple rice reported higher antioxidant activity of red rice compared to that of white rice. However, the red rice grains were smaller in size.

The grade of the rice grain is one of the determining factors for marketing the product. The most valued white rice grain in Brazil, for example, is classified as long-fine. Special types of rice are defined by MAGALHÃES JÚNIOR et al. (2012), as any type that has sensory or processing qualities different from those predominantly consumed by the population. In addition, various shapes, sizes, amylose contents, grain colors, or aromas allow marketing as a different product for consumption by specific niche markets, and do not need to follow the marketing standards determined for white rice.

Significant effects were observed between the grains of the cultivars evaluated at the different sites in relation to whole grain and yield, at sites L2 and L3. No difference between the treatments could be identified (Tables 5 and 6).

In the grains produced in sites L2 and L3 of Year 1, the highest yield of whole grains was reported

Table 4 - Classification of the grains of the cultivars ENA-AR 1601, Virgínia, BRS Esmeralda, and IAC 201.

Cultivar	Class
ENA-AR 1601	Medium
Virginia	Long
BRS Esmeralda	Long-thin
IAC 201	Long-thin

Table 5 - Whole grain yield (G.int) of the genotypes ENA AR - 1601, Virginia, BRS Esmeralda, and IAC 201, at sites L1 (Campos dos Goytacazes), L2 (Seropédica), and L3 (Pinheiral), in the agricultural years 2016/2017 (Year 1) and 2017/2018 (Year 2).

Genotype	G.int (%)						
	Year 1			Year 2			
	L1	L2	L3	L1	L2	L3	Average
ENA AR - 1601	59.9 Cc	70.6 Aab	68.8 ABc	47.3 Db	63.4 BCa	62.3 BCa	62
Virginia	70.8 Aa	66 Ab	72.1 Abc	58 Ba	53.9 Bb	52.2 Bb	62.1
BRS Esmeralda	63.4 Bbc	71.6 Aab	76 Aab	59.5 Ba	58 Bab	61.3 Ba	64.9
IAC 201	66.1 Bab	74.7 Aa	78.6 Aa	57.9 Ca	63.7 Ba	62.7 BCa	67.2
Average	65	70.7	73.9	55.7	59.7	59.6	
CV(%)	6.82	2.49	2.40	8.98	8.40	3.57	

Means followed by the same lower-case letter in the column and capital in the row do not differ by Tukey's test (P < 0.05).

for all cultivars (Table 5). With the exception of L1 for the cultivar BRS Esmeralda, Year 1 was statistically superior to Year 2. The greatest variation was found in the cultivar ENA-AR 1601, with averages ranging between 47.3% in L1 of Year 2 to 70.6% in L2 of Year 1 (Table 3). In L3 of Year 1 the highest yield was detected for all cultivars and L1 of Year 2 was the least productive environment (Table 6).

According to SWAMY & BHATTACHARYA (1979), the yields of whole and coarse grains are closely related to the cropping system, genetic characteristics of the cultivar, climatic conditions and cultural practices during development, maturation and harvest as well as types of post-harvest processing and handling. Among these, the key factor affecting the yield is the timing of harvest. For MARCHEZAN et al. (1993), harvests performed with a moisture content above the recommended levels (18 to 22%), lead to a high percentage of malformed, chalky and immature grains during processing. However, the drying of the grain, the management of the crop, and the equipment used in processing should also be considered.

According to VIEIRA & RABELO, (2006), in rain fed rice there is greater variation in the intensity of lower whole grain yields due to the effects of climatic variations in which the rice produced is adversely affected. Fluctuations can be significant from one year to the next depending on the intensity of environmental stresses, such as water deficiency.

In three locations, L1 and L3 of Year 1 and L1 of Year 2, the cultivar ENA-AR 1601 obtained the lowest yields, with 70.1; 76.7 and 64.1% respectively (Table 6). Virginia obtained similar results to those

Table 6 - Yield of ingenuity (Rend) of the genotypes ENA AR - 1601, Virginia, BRS Esmeralda, and IAC 201, in sites L1 (Campos dos Goytacazes), L2 (Seropédica), and L3 (Pinheiral), in the seasons 2016/2017 (Year 1) and 2017/2018 (Year 2).

Genotype	Yield (%)						
	Year 1			Year 2			
	L1	L2	L3	L1	L2	L3	Average
ENA AR - 1601	70.1 Bb	75.9 Ab	76.7 Ab	64.1 Cb	69 Ba	69.1 Ba	70.8
Virginia	76.6 Ba	77.6 ABab	80.4 Aa	69.6 Ca	71.6 Ca	69.9 Ca	74.3
BRS Esmeralda	76.8 Ba	78.4 ABab	81.4 Aa	68.7 Ca	68.9 Ca	70.3 Ca	74.1
IAC 201	77.1 Ba	79.8 ABa	82.8 Aa	69.7 Ca	71.4 Ca	71 Ca	75.3
Average	75.2	77.9	80.3	68	70.2	70.1	
CV(%)	2.80	0.86	1.43	3.82	3.44	1.55	

Means followed by the same lower-case letter in the column and capital in the row do not differ by Tukey's test (P < 0.05).

of white rice cultivars, with its yield ranging from 69.6 to 80.4%. BOÊNO et al (2011) reported 72.8% average yield and 64.2% whole grain yield in red rice genotypes. In this study red rice cultivars showed very high whole grain yields (Table 6).

Regarding white rice cultivars, CASTRO et al. (2014) classified BRS Esmeralda as having a “high yield of whole grains when harvested at the appropriate stage” and BORDIN et al (2003) and FARINELLI et al. (2004) observed yields above 70% and of whole grains above 60% with the cultivar IAC 202. MINGOTTE et al (2012) reported a yield of 72% and a whole grain yield of 53.1% for the cultivar IAC 201, correlating with the results of the 13 cultivars evaluated in this study.

The Brazilian legislation requires a base yield of 68% for white rice, consisting of 40% of whole grains and 28% of broken grains and chirera, with values below these being outside the national standards for marketing the product (BRASIL, 1988). It is worth noting that to produce red rice with quality pigments, more modern processing methods are required, because most of the phytochemical components of rice grains are found in the bran fraction or in the epidermis (SADIMANTARA et al. 2019).

CONCLUSION

For rainfed systems, the red rice cultivars ENA-AR 1601 and Virginia showed yields above the national average. The grain ratings of the cultivars ENA-AR1601 and Virginia were medium and long, respectively. The grains produced in the first year of the trial had the highest yield of whole and coarse grains for all four cultivars in all locations. In both years, excellent processing yields of 62% were recorded.

ACKNOWLEDGEMENTS

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. The Official Classification Laboratory of the Inspection Service and Plant Health of the Federal Superintendence of Agriculture, Livestock and Supply (SISV/SFA) of the Ministry of Agriculture, Livestock and Supply (MAPA) for performing the analyses.

DECLARATION OF CONFLICT OF INTEREST

We declare that there is no conflict of interest.

AUTHOR CONTRIBUTION

All authors contributed equally to the conception and writing of the article. All authors critically reviewed the article and approved the final version.

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