SCIENTIFIC NOTE

Processing agronomically biofortified BRSMG Caravera rice cultivar

Procesamiento del cultivo de arroz BRSMG Caravera biofortificado agronómicamente

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ABSTRACT

The aim of the research was to evaluate the influence of agronomic biofortification of BRSMG Caravera rice on grain processing by analyzing processing yield (PY) and grain yield (GY), in addition to defining the grain classification for each treatment. The analyzed plants received treatments with NPK + foliar and/or soil fertilization from different fertilizer sources. Some treatments had higher PY values compared to the control plants. For the GY parameter, only treatments with soil fertilization using $ZnSO_4 \cdot 7H_2O$ and two foliar fertilizations using a Bayer Antracol-Zn® product showed higher values. There may be an influence of biofortification on rice processing depending on the treatment. The grains of the BRSMG Caravera variety did not achieve a good classification, as only the grains with the treatment of soil fertilization with $ZnSO_4 \cdot 7H_2O$ were classified as type 4, while the grains in other treatments were classified out of type.

Key words: biofortification, grain yield, income from processing.

RESUMEN

El objetivo del estudio fue evaluar la influencia de la biofortificación agronómica en el arroz BRSMG Caravera en el procesamiento de grano mediante el análisis del rendimiento por procesamiento (P) y el rendimiento de grano (G), además de definir la clasificación de los granos en cada tratamiento. Las plantas analizadas recibieron tratamientos con NPK + fertilización foliar y/o edáfica de diferentes fuentes. Algunos tratamientos presentaron valores de PY superiores a los de las plantas control. Para el parámetro G, solo los tratamientos de fertilización del suelo con $ZnSO_4 \cdot 7H_2O$ y dos fertilizaciones foliares con el producto Bayer Antracol-Zn® mostraron mejores valores. Pudo haber una influencia de la biofortificación en el procesamiento dependiendo del tratamiento. Los granos de la variedad BRSMG Caravera no presentaron una buena clasificación, ya que solo los granos en el tratamiento de fertilización edáfica con $ZnSO_4 \cdot 7H_2O$ fueron clasificados como tipo 4, y los granos de los demás tratamientos fueron clasificadas como fuera de tipo.

Palabras clave: biofortificación, rendimiento de grano, ingreso por procesamiento.

Introduction

Rice (*Oryza sativa*) is an essential component of the diet and livelihood of more than 3.5 billion people (Nathani *et al*., 2023; Zhao *et al*., 2020), including in Brazil (Fernades *et al*., 2024), making it one of the grains with the highest production in the world (Lima *et al*., 2002). For rice to reach the table of all consumers in the world, it must be produced and processed in large quantities. Paddy processing has the following main objectives: removal of impurities from the field, separation of the husk and grains through peeling and the straw chamber, separation of rice with husk, burnishing, homogenization, and classification (Bragantinni & Vieira, 2004).

The market value of rice is directly influenced by industrial quality, as rice without defects and with a high number of whole grains achieves the best prices (Canellas *et al*., 1997). Broken grains (grits), rice husks, and bran are the main co-products from rice processing and can be reused; for example, grits can be used to produce pre-cooked starches and flour, bran can be used to produce oil or animal feed, and the husk can be used as an energy source or to produce paper (Lorenzett *et al*., 2012).

All rice marketed for consumption as grains must be classified into types (1, 2, 3, 4, and 5), with this classification defined by the percentage of broken grains, grit, and the occurrence of defects (Brazil, 2009). Thus, paddy rice is classified into "types" according to its quality. The grains that do not meet the classification requirements for the types mentioned are classified as non-standard or disqualified (Brazil, 2009).

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Recently, biofortification of food has emerged as an interesting approach to the problem of hidden hunger. Biofortification seeks to nutritionally enrich food directly in the field during its production process, which can be carried out by two methods: genetic biofortification and agronomic biofortification. The first consists of food enrichment through the genetic improvement of crops (transgenic or conventional), while the second is through crop management (mainly fertilization) (Vergütz *et al.*, 2016).

Due to the scarcity of studies that relate biofortification with technological aspects, as well as to the importance of processing for the subsequent commercialization of biofortified rice, the aim of the research was to evaluate the influence of agronomic biofortification on the processing of BRSMG Caravera rice. BRS stands for Brazilian Agricultural Research Corporation – Embrapa and MG corresponds to EPAMIG – Agricultural Research Company of Minas Gerais and UFLA – Federal University of Lavras (Brazil). This cultivar was obtained in a breeding program carried out in partnership between Embrapa, EPAMIG, and UFLA. The research analyzed rice processing yield and grain yield, in addition to classifying the rice samples according to the standards of the Ministry of Agriculture, Livestock and Food Supply (MAPA) of Brazil (Brazil, 2009).

Materials and methods

Description of samples

This study analyzed rice grains of the BRSMG Caravera variety, cultivated by EPAMIG (Empresa de Pesquisa Agropecuária de Minas Gerais), in the municipality of Lambari, state of Minas Gerais (Brazil). Lambari is located at an altitude of 887 m a.s.l. with geographic coordinates of 21°58' S and 45°20' W. Throughout the year, the air temperature typically varies from 10°C to 28°C. The climate is humid subtropical. The rice samples included a control treatment, which was not biofortified, and agronomically biofortified plants in 15 different treatments. The 16 treatments were:

A) **Control (NPK):** Application of fertilizer to the soil: nitrogen (N), phosphorus (P) and potassium (K). The fertilizer doses per ha were 32 kg of N, 112 kg of P_2O_5, and 64 kg of K_2O, at sowing, in addition to 112 kg ha^{-1} of urea, resulting in 50.4 kg ha^{-1} of N. The application was at sowing using a seeder in the planting furrow;

B) **NPK + $ZnSO_4 \cdot 7H_2O$ soil application** (soil application of 50 kg ha^{-1} $ZnSO_4 \cdot 7H_2O$);

C) **NPK + two foliar applications of $ZnSO_4$** (0.5% $ZnSO_4 \cdot 7H_2O$ in 800 L ha^{-1});

D) **NPK + ATP ReLeaf® spray** (ReLeaf® 6-18-5 Cereal, ATP, Canada), which contained Fe and Zn, was applied twice as a foliar application; additionally, the product contained N, P, K, B, Cu, Mn, and seaweed extract;

E) **NPK + two foliar applications of potassium iodate (KIO_3):** The amount of iodine applied in each spray was 0.05% KIO_3 in 800 L ha^{-1} equivalent to 400 g ha^{-1} KIO_3;

F) **NPK + two foliar treatments of 0.05% potassium iodate (KIO_3) together with 2% potassium nitrate (KNO_3):** The application was the same as described for treatment E, however using water containing 2% KNO_3 in the preparation of 0.05% KIO_3;

G) **NPK + two foliar treatments of ADOB® 2.0 Zn IDHA– 10%** (ADOB, Poland): The amount of Zn applied with each foliar spray was the same as the one applied in treatment C;

H) **NPK + two foliar treatments of ADOB Basfoliar®** (ADOB, Poland): In this treatment, Basfoliar® 2.0 was applied in a similar way as treatment C. The composition of the product included water-soluble S and Zn;

I) **NPK + two foliar treatments of EPSO Combitop®** (K+S Minerals and Agriculture GmbH, K+S Company, Germany) **together with urea** (the foliar treatment solution contained 0.4% urea): The EPSO Combitop® contained water-soluble Mg, S, Mn, and Zn. The volume at the time of application was 500 L ha^{-1} of spray;

J) **NPK + VALAGRO (Company Valagro, Italy) solution:** This solution contained 1.4% Zn;

K) **NPK + Bayer Antracol-Zn®:** Three kg of Antracol-Zn per ha in 800 L was sprayed twice - once at the ear stage and the second one at the early milk stage. Antracol-Zn is a Zn-containing fungicide, and spraying 3 kg Antracol-Zn provides about 510 g Zn per ha. If the size of the experimental plot is 10 m^2, the amount of Antracol-Zn to be sprayed on plants will be 3 g ml^{-1};

L) **NPK + Foliar Cocktail micro spray.** This product is referred in HarvestZinc Project - IPNI Research (http// research.ipni.net) and contained I, Zn, Fe, and Se;

M) **NPK + Foliar Cocktail micro spray-II.** This product is referred in HarvestZinc Project - IPNI Research (http// research.ipni.net) and contained I, Zn, Fe, and Se in different proportions when compared to the treatment L;

N) **1.5 kg Mg (gypsum) - 10 m^2:** Soil application of a mixed sulfate of Ca and Mg;

O) **3.0 kg Mg (gypsum) - 10 m^2:** Soil application of a mixed sulfate of Ca and Mg;

P) **Quimifol Znitro®** (Fênix Agro-Pecus Industrial Ltda., Brazil. Product registration: SP-002645-0.000048): Nutrient compound for foliar application. This foliar applied product contained water soluble 10% N and 15.0% Zn.

The planting density in the experiment was approximately 360 panicles m^2 at harvest, with the area of each plot of 8 m^2 totaling 480 m^2 experimental area.

Experimental design

Treatments were arranged in a completely randomized block design, including 15 treatments and control, with four replicates. Each experimental plot consisted of 4 rows of 5 m in length spaced 40 cm apart, totaling 64 plants.

Rice processing

The processing of the rice was carried out using a Suzuki testing device (Model MT96, Rice Processing Machine, Brazil). Rice samples were husked using the equipment husking rollers and passed through rollers three times. Then, husked rice grains were manually separated from rice grains with husk (*i.e.*, the rice grains that remained unhusked even after passing through the husking rollers three times). Next, husked rice grains were burnished for 1 min to separate the bran and germ from rice grains. Finally, grains were classified according to their size using rotary trieur classifiers (Model MT96, Rice Processing Machine, Brazil). The burnished grains were placed in the trieur with alveoli number 2 and rotated for 1 min to separate whole rice grains. The remaining grains were placed in the trieur with alveoli number 1 and 0 to separate the ¾ size rice and ½ size grains, respectively. The remaining rice grains were those of size ¼ and broken grains. After these procedures, all the separate portions were weighed, namely: husk, rice grains with husk, bran with germ, whole grains, ¾ size grains, ½ size grains, and ¼ size grains plus broken grains.

Processing yield and grain yield

Processing yield (PY) is a quality standard that measures the number of polished grains (whole, ¾, ½, ¼ with broken grain) in relation to the weight of paddy rice, expressed as a percentage. Grain yield (GY) is a quality reference that measures the fraction of whole grains among the fractions of broken and whole grains, expressed as a percentage.

Classification of rice grains

Rice samples submitted to agronomical biofortification treatments were classified according to Normative Instruction 6 of February 16, 2009 by MAPA (Brazil, 2009). The purpose of classifying paddy rice into "types" (1, 2, 3, 4, and 5) was to define its quality. The grains that do not meet the classification requirements for these types were classified as non-standard or disqualified (Brazil, 2009).

Statistical analysis

Analysis of variance was performed using the F test. Comparison of means obtained from different treatments was tested by the Scott-Knott test ($P \leq 0.05$). These analyses were performed using Sisvar 5.6 software (Ferreira, 2014).

Results and discussion

Results of the PY quality parameter (Tab. 1) indicate that some treatments increased the number of processed grains in relation to the weight of paddy rice, *i.e.*, there was an improvement in PY for some treatments compared to the control.

TABLE 1. Mean values for processing yield (%) and grain yield (%) for the different agronomic biofortification treatments in BRSMG Caravera rice.

Treatment	Processing yield (PY) %	Grain yield (GY) %
A	64.24 a	38.61 a
B	67.29 b	56.67 c
C	64.03 a	34.89 a
D	63.44 a	33.10 a
E	66.57 b	35.20 a
F	67.16 b	36.50 a
G	65.23 a	33.05 a
H	65.11 a	38.70 a
I	66.28 b	40.68 a
J	63.01 a	34.53 a
K	66.09 b	47.08 b
L	66.50 b	36.23 a
M	63.78 a	38.94 a
N	67.09 b	39.25 a
O	66.64 b	40.86 a
P	63.28 a	30.24 a

The treatment abbreviations are explained in the Materials and methods. Comparison of means from different treatments was tested by Scott-Knott test ($P \leq 0.05$). Means followed by the same letter in the column do not differ from each other according to the Scott-Knott test at 5% probability.

There was a significant effect of treatments and blocks at 1% probability according to the F test. Applying the Scott-Knott test at 5% probability showed that treatments B, E, F, I, K, L, N, and O differed from the control. These treatments had a mean PY value of 66.7%, higher than the control treatment (64.24%), indicating results were satisfactory.

In the soil fertilization treatments, the application of $ZnSO_4·7H_2O$ (treatment B) showed better PY results compared to foliar application (treatment C). The foliar application of potassium iodate (KIO_3) (treatments E and F) showed significantly positive and statistically similar results. Treatment F combined the foliar application of KIO_3 with 2% KNO_3. Treatment I, containing Zn and urea, was also a foliar application and showed good results, as did treatment K, with two foliar applications of the fungicide Bayer Antracol-Zn. Treatment L, containing Zn, Fe, I, and Se as a foliar application also showed positive results compared to the control. Finally, treatments N and O, with different concentrations of Mg (gypsum) applied to the soil, also showed positive and statistically similar effects (Tab. 1). Boêno *et al.* (2011) evaluated processing yield in red rice samples and found values ranging from 71.1% to 74.7%. Farinelli *et al.* (2004) evaluated processing yield of upland rice samples under no-till and nitrogen and potassium fertilization and found values ranging from 71.4% to 72.3%.

In general, samples had many broken grains, which can be the result of numerous factors occurring during polishing, namely: cracks before harvesting, immature and chalky grains, rapid drying, and uneven moisture distribution in the grains (Luz *et al.*, 2005).

The best PY result found in rice samples submitted to agronomic biofortification showed an improvement of approximately 3% in the number of polished grains (whole, ¾, ½, ¼ with broken grain) in relation to the weight of paddy rice, compared to the control.

For the GY quality, only two samples differed from the control. There was an increase in whole grain percentage in relation to processed grains (broken and whole), as illustrated in Table 1.

There was a significant effect of treatments and blocks at 1% probability according to the F test. Applying the Scott-Knott test at 5% probability showed that control samples differed from samples of the B treatment, which consisted of the application of $ZnSO_4·7H_2O$ to the soil, and the K treatment, which consisted of the foliar application of Bayer Antracol-Zn; these samples were significantly different from each other and from the control. The B and K treatments showed higher GY with values of 56.67% and 47.08% (Tab. 1). The analysis of GY plays an important role for producers, because the greater the GY, the smaller the losses and, consequently, the greater the profit, since whole grains have higher market values. These same samples also showed good results when analyzing the PY. Boêno *et al.* (2011) evaluated the GY of red rice samples and found values ranging from 62.8% to 65.4%. Farinelli *et al.* (2004) evaluated the GY of upland rice samples under no-till and nitrogen and potassium fertilization and reported values ranging from 43.4% to 46.7%. When comparing the results of the present study with the literature data, in general, the values for GY in the present experiment were low, averaging 36.48%, except for treatments B and K.

In general, rice consumers prefer a uniform product, with reduced levels of damaged and broken grains. Therefore, producers and cereal manufacturers aim to achieve optimal performance during rice processing to obtain good yields of whole grains. The value of this product on the market varies according to the breakage index obtained during grain processing. This factor is also essential in determining the acceptance of new cultivars (Castro *et al.*, 1999).

The treatments used in agronomic biofortification did not affect the BRSMG Caravera rice variety in terms of the percentage of whole grains obtained from polished grains.

Classification of rice grains

According to the mentioned methodology for rice classification, the following results of sample classification were obtained: rice grains of treatment B, which consisted of the application of Zn to the soil as $ZnSO_4 ·7H_2O$, were classified as type 4 and the other samples as out of type.

All rice grains intended for consumption must be classified into types, expressed numerically (type 1, 2, 3, 4, and 5). This classification is defined according to the total number of broken grains and grit and to the percentage of occurrence of defects, such as foreign matter, impurities, moldy, discolored, chopped, stained, chalky, green, streaked, and yellow grains.

The rice samples in this study showed high breakage during processing but did not present other defects considered for classification. Except for treatments B and K, all the other treatments showed a percentage of broken and grit greater than 45%, which classified them as out of type. Treatment B grains presented 33.47% of total broken and grits, with a maximum percentage of grit of 2.88, qualifying them as type 4. Treatment K grains presented 40.84% of total broken grains and grits, which would classify them as type 5, however they presented a maximum percentage of grit of 5.39, which also classifying them as out of type. The total percentage of broken grains for all samples can be seen in Table 2. Without the high breakage rate, these samples would have obtained a higher classification, as no other defects were observed.

TABLE 2. Total of broken grains and grain classification of biofortified BRSMG Caravera rice samples.

SWG		1/2 grains (g)	1/4 grains + grit (g)	SBG (g)	SPPG (g)	BGG (%)	WG (g)	GT (%)	Cl
T	W (g)								
A	532.66	66.89	428.74	495.64	1028.29	48.20	-	-	*
B	719.07	55.54	306.13	361.67	1080.73	33.47	31.21	2.89	**
C	563.16	66.53	454.60	521.13	1025.43	50.82	-	-	*
D	490.52	71.51	461.33	532.84	1023.36	52.07	-	-	*
E	535.89	79.66	451.30	530.96	1066.86	49.77	-	-	*
F	555.93	60.44	461.21	521.66	1077.58	48.41	-	-	*
G	501.02	80.78	472.72	553.51	1054.53	52.49	-	-	*
H	546.11	64.08	434.70	498.78	1044.89	47.74	-	-	*
I	573.56	77.43	419.32	496.75	1070.31	46.41	-	-	*
J	492.04	63.06	460.76	523.83	1015.86	51.56	-	-	*
K	629.15	61.00	373.31	434.31	1063.46	40.84	57.38	5.40	*
L	535.06	74.25	461.30	535.55	1070.61	50.02	-	-	*
M	533.43	54.73	434.23	488.96	1022.39	47.83	-	-	*
N	575.99	63.65	442.76	506.41	1082.41	46.79	-	-	*
O	571.66	71.64	426.18	497.82	1069.48	46.55	-	-	*
P	458.34	78.72	478.45	557.17	1015.51	54.87	-	-	*

SWG = sum of whole grains = whole grains (g) + 3/4 grains (g), SBG = sum of broken and grits (g) = 1/2 grains (g) + 1/4 grains + grit (g), SPPG = sum of processed and polished grains (g), BGG = broken grains and grits in relation to the total processed and polished (%), WG = weight of grits (g), GT = grits in relation to total processed and polished (%), Cl = classification, T = treatment, W = weight (g), * = out of type, ** = type 4.

Depending on their importance and effect on the rice grain product, defects are classified as general or severe. In products considered of good quality, the percentage of defects must be reduced as much as possible, especially severe defects, which result from contamination by foreign matter, moldy and discolored grains. Streaked, yellow, stained, chopped, and chalky grains refer to general defects. Rice samples that do not meet the requirements for commercial type classification are considered as substandard or out of type. The sale of substandard products is prohibited for both human and animal consumption, as they are in poor condition (Brazil, 2009). Products classified as out of type can be sold, provided this is clearly indicated on the packaging, or they can also be reprocessed, broken down and recomposed to fit into types (Brazil, 2009; Castro *et al.*, 1999).

Conclusions

Agronomic biofortification treatments can improve, in some cases, the technological quality parameters of rice such as processing yield and grain yield. Specific treatments show better results compared to the control treatment.

However, the rice samples did not present a good classification. According to the Ministry of Agriculture, Livestock and Food Supply of Brazil (MAPA), these rice grain samples must be classified as out of type, except for the sample of treatment B, which was classified as type 4. This classification is due to the large amount of broken grains, despite the absence of other defects, such as foreign matter, impurities, moldy, discolored, chopped, stained, chalky, green, streaked, and yellow grains. When considering all the parameters analyzed, the sample of treatment B, which consists of applying $ZnSO_4 \cdot 7H_2O$ to the soil, showed the best results.

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Conflict of interest statement
The authors declare that there is no conflict of interests regarding the publication of this article.

Author's contributions

SMS: conceptualization, methodology, validation, formal analysis, research, resources, writing – original draft, writing – review & editing, visualization, supervision, project administration, and funding acquisition. LAA: conceptualization, research, resources, writing – review & editing, and visualization. JP: conceptualization, research, resource acquisition, supervision, visualization, writing – original draft, and writing – review & editing. All authors reviewed and approved the final version of the manuscript.

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