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Biological Characteristics and Nutrition of New Colored Rice Lines in Central Vietnam

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ABSTRACT

Background: Colored rice (*Oryza sativa* L.) is considered a nutritious food source than white rice and is becoming increasingly popular worldwide. At present, there have not been many studies of colored rice in Vietnam. The aim of this study to selecting colored rice varieties with short duration, high nutrition, good yield and the ability to be cultivated under intensive farming conditions in Binh Dinh province, Central region of Vietnam.

Methods: The five new colored rice lines, namely BĐ.1, BĐ.2, BĐ.3, BĐ.4 and BĐ.5 and ANS1 variety as control were used in this study. The experiment was conducted in two seasons (2023 and 2024), completely randomized block design (RCBD) was employed with three replications. Morphological characteristics, yield and quality parameters were measured according to the standards in plant research.

Result: From our research, we selected two promising lines, BĐ.1 and BĐ.4, which recordedyield from 64.57 to 73.47 quintals/ha in both seasons, anthocyanin content ranged from 27.83 to 35.79 mg/100 g and iron content ranged from 23.89 to 23.82 mg/kg, respectively. It is recommended to continue developing these lines on a larger scale and to study some suitable technical measures for rice cultivation.

Key words: Anthocyanin, Biological characteristics, Colored rice, Yield.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important cereal, contributes to feeding more than half of the world's population (Tripathy, 2024). Colored rice (*Oryza sativa* L.) is considered a food source containing more nutrients than white rice and is increasingly widely used in the world (Pratiwi and Purwestri, 2017). It has a bran layer that can be red, reddish brown, purple, containing many nutrients such as fiber, iron, vitamins and especially antioxidants that help prevent aging, cancer and allergies (Bett-Garber *et al.*, 2013; Krishna, 2019). Colored rice is grown in several Asian countries, including. India, Bangladesh, China, Korea, Japan, Thailand, Laos, Vietnam and Indonesia (Lee, 2010).

In Vietnam, the rice area reached 7.24 million hectares in 2021, with 5% of this area occupied with colored rice cultivation, mainly in the northern mountainous provinces, the North Central region and the Mekong Delta (Loan *et al.*, 2022). According to the plant resources Center, the Vietnam academy of agricultural sciences is preserving 1,935 colored rice genetic resources collected from across the country. However, local colored rice varieties have good resistance to external conditions, but their yields are often lower and mostly belong to the medium and long growth duration group compared to improved rice varieties (Hanh and Hien, 2017).

Several studies of colored rice have been conducted in Vietnam such as genetic diversity research (Tuyet *et al.*, 2022); evaluation of growth, development and yield of some colored rice lines and varieties in Nam Dinh province (Hoa *et al.*, 2022) and in Hoa Binh province (Loan *et al.*, 2022), which are provinces in the north of Vietnam. However, limited research has been conducted on colored rice in Central Vietnam.

With the aim of selecting colored rice varieties with short growth duration, high nutrition, good yield and the ability to be cultivated under intensive farming conditions, we evaluated some new colored rice lines selected in Binh Dinh province. This contributes to the development of new high-quality rice varieties in the central region of Vietnam in particular and meets the demand for high quality rice consumption in general.

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MATERIALS AND METHODS

Plant materials

A total of five new colored rice lines, BĐ.1, BĐ.2, BĐ.3, BĐ.4 and BĐ.5, were used in this study. These lines were

hybridized and selected by Agricultural Science Institute for Southern Coastal Central of Vietnam (ASISOV). The ANS1 variety was used as control, belonging to the short growth druration group. This variety is being widely produced in Binh Dinh province, Central Vietnam.

Experimental design

The experiment was conducted during Winter-Spring 2023-2024 (WS) and Summer-Autumn 2024 (SA) in An Nhon town, Binh Dinh province (Central region of Vietnam). The site is located at 13°54′13.1″N latitude, 109°06′23.8″E longitude. A completely randomized block design (RCBD) was employed with three replications for each variety. Each experimental plot measured 10m^2 with a planting density of 42 plants/m^2. Fertilization applied per hectare included 8 tons of decomposed manure, 110 kg of N, 80 kg of P_2O_5, 90 kg of K_2O and 300 kg of lime powder. Basal fertilizer application comprised all lime, decomposed manure, P_2O_5, 40% N and 30% K_2O before planting. Top dressing was conducted twice: initially before tillering stage, (50% N and 40% K_2O); and subsequently 17-22 days before flowering. (10% N and 30% K_2O).

Biological characteristics

Evaluation of growth, development, morphological characters and yield were conducted according to Ministry of Science and Technology (2023) of Vietnam instruction. The parameters evaluated for each plant included time to maturity, plant height, panicle length, number of total tillers, number of fertilized tillers. The leaf area index (LAI) was calculated as m^2 of green leaves/m^2 soil, using the formular and was evaluated at each growth stage.

$$\text{m}^2 \text{ leaves/plant} \times \text{Number of plants/m}^2$$

Yield indicators included the number of effective panicles/m^2, number of filled spikelet/panicle, 1000-grains weight and yield. The yield was calculated using the formula:

$$\frac{\left(\text{Weight of fresh rice of the experimental plot} \times \text{Ratio of dry rice and fresh rice}\right) + \text{Weight of dry rice from 10 sample plants at 14\% moisture content grain}}{\text{Experimental plot area and conversion factor to quintals/ha}}$$

Nutritional indicators including amylose content following to Ministry of Science and Technology (2017), protein content (Ministry of Science and Technology, 2015), iron content (Ministry of Science and Technology, 2010) and anthocyanin content by pH differential method (Giusti *et al.*, 1999) were observed in rice grain and quality characteristics in Winter-Spring 2023-2024 season.

Data analysis

Data were calculated as the mean and analyzed by ANOVA, with the least significant difference at α = 0.05. Statistical analysis was performed using Statistix 10.0 software.

RESULTS AND DISCUSSION

Biological characteristics of the materials

Some biological characteristics of our materials are shown in Table 1. The BĐ.3 had the longest growing duration in both seasons (106-112 days). The growing period of the lines/variety in the Winter-Spring season was 6-7 days longer than the Summer-autumn season. According to the Vietnamese classification, the studied colored rice lines were all in the short duration group. This is appropriate because during the growth process, if the temperature is high, the rice plant will quickly reach the required total temperature, causing it to flower and ripen earlier, thereby shortening the growing period. Conversely, at low temperatures, the growing period is extended. Yoshida and Hara (1977) and Oh-e *et al.* (2007) observed that the rate of grain growth was faster and the grain-filling period was shorter at higher temperatures.

There was no significant difference in plant height of the lines in the two seasons compared to the control variety ANS1, with heights ranging from 100.3 to 114.3 cm in both crops. According to IRRI (2014), plant height is divided into three categories: short (<110 cm), intermediate (110-130 cm) and

Table 1: Some biological characteristics of experimental materials.

Materials	Time to maturity (days)		Plant height (cm)		Panicle length (cm)		No. of total tiller/plant		No. of effective tillers/plant	
	WS	SA	WS	SA	WS	SA	WS	SA	WS	SA
BĐ.1	105	98	110.0^{a}	114.3^{a}	25.2^{a}	25.4^{a}	7.3^{b}	8.3^{abc}	6.2^{b}	6.9^{bc}
BĐ.2	105	98	103.2^{a}	107.2^{a}	21.5^{b}	22.0^{b}	7.4^{b}	8.0^{bc}	6.3^{b}	6.7^{bc}
BĐ.3	112	106	100.3^{a}	109.3^{a}	24.2^{ab}	24.6^{ab}	7.6^{ab}	8.7^{ab}	6.5^{ab}	7.2^{ab}
BĐ.4	105	98	107.8^{a}	110.2^{a}	24.0^{ab}	24.3^{ab}	8.3^{a}	9.2^{a}	7.0^{a}	7.7^{a}
BĐ.5	105	98	110.5^{a}	113.4^{a}	24.2^{ab}	24.7^{ab}	7.5^{ab}	8.5^{abc}	6.4^{ab}	7.1^{abc}
ANS1	104	97	105.3^{a}	108.5^{a}	22.8^{ab}	22.9^{ab}	6.4^{c}	7.7^{c}	5.5^{c}	6.4^{c}
$LSD_{0.05}$			12.37	11.58	2.97	3.07	0.86	0.98	0.67	0.79

(Note: WS- Winter-spring season; SA- Summer-autumn season; Values in the same column with the same letters indicate no significant difference at α = 0.05).

tall (>130 cm). Tall plants are undesirable because they are sensitive to lodging, which reduces grain yield (Shahidullah *et al.*, 2009). Furthermore, Bhadru *et al.* (2011) stated that plant height is highly correlated with the level of lodging and ease of harvest, making it one of the important characters in influencing farmer acceptance of new cultivars.

Raisheed *et al.* (2002) suggested that panicle length is less influenced by the environment. Therefore, panicle length variation might be due to the genetic of the varieties. The panicle length of the experimental lines in both seasons was recorded as shortest in line BĐ.2 (21.5 and 22.0 cm, respectively) and longest in line BĐ.1 (25.2 and 25.4, respectively).

The total number of tillers in all lines was higher than that of the control variety ANS1 by 1-2 tillers per plant. The number of effective tillers varied from 6.2 to 7.7 tillers per plant in both seasons, with the highest was BĐ.4 and the lowest being BĐ.1. This difference was statistically significant.

Leaf area index (LAI) is one of the important parameters closely related to photosynthesis, respiration and other interaction processes of plants. In agricultural production, LAI serves as an effective index for diagnosing crop growth, estimating biomass and predicting yield (Fang *et al.*, 2019). The results in the Table 2 showed that the LAI begins to differ from the end of tillering to maturity, reaching its highest value at the beginning of flowering and gradually decreasing at the maturity stage. In both crops, BĐ.3 had the highest LAI (4.9 and 5.0, respectively) and the lowest was ANS1 (4.0 and 4.1, respectively) at flowering stage. This evaluation result was similar to the research conducted by Manh, (2015) and Ky, (2017), who studied the growth of LAI in experimental formulas in a similar experimental area (in Central Vietnam) and found that LAI reached its highest value at the beginning of flowering and gradually decreased at the maturity period in short-term rice varieties.

The distribution of anthocyanin pigments in rice plant parts is a special trait of rice varieties, especially in colored rice varieties. Ryu *et al.* (1998) stated that purple rice and red rice were more nutritious for human health than white rice due to the presence of anthocyanins. The evaluation of this character is shown in Table 3. The results indicated that anthocyanin pigments were only present at the edge of the leaf blade in BĐ.4 and BĐ.5 (score 2). These two lines also had anthocyanin pigments in the leaf sheath at a light level (score 3). At the stem nodes and internodes, BĐ.4 and BĐ.5 exhibited anthocyanin in the form of purple to dark purple (score 9), while the remaining lines/varieties did not have this pigment and displayed a light green to green color (score 1).

The color of the husk is a variety-specific trait and is less affected by external conditions. Evaluation of the research lines showed that the majority of the husks were yellow, except for BĐ.4 and BĐ.5, which were brown. The color of rice grains is created by the presence of pigments in the bran layer. The grain coat is also a trait of interest for colored rice because most of the high nutritional value is found in the grain coat (Tumanian *et al.*, 2020). Our observations showed that BĐ.4 and BĐ.5 had dark purple rice grains while BĐ.1, BĐ.2 and BĐ.3 had red rice grains.

Table 2: Leaf area index (LAI) of rice materials.

Materials	LAI							
	Beginning of tillering stage		Ending of tillering stage		Beginning of flowering		Harvesting stage	
	WS	SA	WS	SA	WS	SA	WS	SA
BĐ.1	0.1	0.1	2.9^{a}	3.1^{a}	4.5^{ab}	4.7^{a}	3.5^{a}	3.6^{ab}
BĐ.2	0.1	0.1	2.7^{ab}	2.9^{abc}	4.8^{a}	4.9^{a}	3.6^{a}	3.7^{a}
BĐ.3	0.1	0.1	3.0^{a}	3.2^{a}	4.9^{a}	5.0^{a}	3.8^{a}	3.9^{a}
BĐ.4	0.1	0.1	2.7^{ab}	3.0^{ab}	4.7^{a}	4.9^{a}	3.4^{ab}	3.5^{ab}
BĐ.5	0.1	0.1	2.5^{b}	2.7^{bc}	4.4^{ab}	4.6^{ab}	3.0^{bc}	3.2^{bc}
ANS1	0.1	0.1	2.4^{b}	2.6^{c}	4.0^{b}	4.1^{b}	2.8^{c}	3.0^{c}
$LSD_{0.05}$	-	-	0.32	0.36	0.58	0.56	0.44	0.45

(Note: Values in the same column with the same letters indicate no significant difference at α = 0.05).

Table 3: Distribution of anthocyanin pigments in rice materials.

Materials	Anthocyanin				Husk color	Grain color
	Leaf (score)	Leaf sheath (score)	Stem nodes (score)	Stem internodes (score)		
BĐ.1	0	0	1	1	Yellow	Red
BĐ.2	0	0	1	1	Yellow	Red
BĐ.3	0	0	1	1	Yellow	Red
BĐ.4	2	3	9	9	Brown	Dark purple
BĐ.5	2	3	9	9	Brown	Dark purple
ANS1	0	0	1	1	Yellow	White

Table 4: Yield components and yield of rice materials.

Materials	Number of effective panicles/m²		Number of filled spikelet/plant		1.000 grains weight (gam)		Yield (quintal/ha)	
	WS	SA	WS	SA	WS	SA	WS	SA
BĐ.1	259.6^{bc}	291.4^{ab}	152.4^{abc}	130.4^{ab}	24.37^{b}	23.42^{bc}	73.47^{ab}	66.12^{ab}
BĐ.2	263.1^{abc}	280.2^{b}	158.3^{a}	142.5^{a}	23.92^{bc}	23.24^{c}	74.32^{a}	68.24^{a}
BĐ.3	273.2^{ab}	302.0^{ab}	153.3^{abc}	128.7^{abc}	23.06^{cd}	22.51^{d}	72.65^{ab}	65.85^{ab}
BĐ.4	296.0^{a}	322.8^{a}	140.0^{bc}	122.6^{bc}	22.52^{d}	22.26^{d}	70.14^{ab}	64.57^{ab}
BĐ.5	269.3^{ab}	298.2^{ab}	137.3^{c}	115.3^{c}	24.27^{b}	23.92^{ab}	67.45^{b}	60.34^{b}
ANS1	229.9^{c}	270.0^{b}	155.7^{ab}	126.4^{bc}	25.75^{a}	24.25^{a}	68.31^{ab}	60.17^{b}
$LSD_{0.05}$	34.61	32.67	16.78	14.63	1.04	0.66	6.82	7.30

(Note: Values in the same column with the same letters indicate no significant difference at α = 0.05).

Table 5: Nutritional indicators of rice materials.

Materials	Amylose content (%)	Protein content (%)	Anthocyanin content (mg/100 g)	Iron content (mg/kg)
BĐ.1	14.61	7.88	27.83	23.89
BĐ.2	22.33	7.44	19.65	20.56
BĐ.3	14.04	7.18	21.49	21.19
BĐ.4	16.11	7.79	35.79	23.82
BĐ.5	14.20	7.18	39.08	22.81
ANS1	18.03	7.00	1.61	19.31

Yield and quality of materials

The results in Table 4 showed that the number of effective panicles per m² of the research lines was higher than that of the control. However, the 1000-grain weight of the control variety ANS1 was higher in both seasons and this difference was statistically significant (25.75 g and 24.25 g, respectively). The experimental rice lines showed yield variations ranging from 64.57 to 74.32 quintals/ha across both seasons, generally tending to have higher yields than the ANS1 variety. However, no statistically significant differences were observed compared to the control, except for BĐ.2 line. Similar results were reported by Han *et al.* (2023) when evaluating the yield performance of these newly developed colored rice lines at another experimental site in Binh Dinh province (An Tin commune, Hoai An district). These lines were not only the growth traits but also the yield component traits of the studied lines showed the stability. Table 2 showed that the BĐ.1, BĐ.2, BĐ.3 and BĐ.4 lines had higher LAI than BĐ.5 and ANS1 and those lines also had higher yields than BĐ.5 and ANS1. This was reasonable because the yield of a plant is closely related to LAI (Manikanta *et al.*, 2019). The study by Manickam *et al.* (2024) suggested that the number of effective tillers per square meter contributes materially towards the final grain yield. However, our results showed that the yield depends on other factors such as effective panicles per square meter, number of filled grains per panicle and 1000-grain weight.

The nutritional indicators of rice grains are shown in Table 5. All lines had lower amylose content than the control variety ANS1, except for BĐ.2, the lowest was BĐ.3 (14.04%). According to IRRI's evaluation standards (IRRI, 1996), rice with amylose content at a low level of 10-20% usually produces soft and sticky rice. The protein content between the studied materials was similar, ranging from 7% to 7.79%. The anthocyanin content was high in BĐ.5 (39.08 mg/100 g), BĐ.4 (35.79 mg/100 g) and BĐ.1 (27.83 mg/100 g), while ANS1 had anthocyanin content of only 1.61 mg/100g. This result aligns with the finding of Gunaratne *et al.* (2013) which showed that anthocyanin pigments are mainly found in colored rice such as black and purple rice. Iron content in rice grains is also of interest in the quality rice group. The iron content of the lines ranged from 20.56 to 23.89 mg/kg and was higher than the control variety ANS1 (19.31 mg/kg). In a previous season (Winter-Spring 2022-2023), Han *et al.* (2023) also reported that the anthocyanin content of lines BĐ.1, BĐ.4 and BĐ.5 was higher than that of the other lines, 25.69, 34.57 and 37.92 mg/100 g, respectively. Similarly, the iron content of these three lines was also higher, recorded at 25.14, 24.05 and 23.27 mg/kg, respectively. Although rice feeds more than half of the world's population, it is a poor source of zinc (Zn) and iron (Fe) (Tripathy, 2024). Several breeding programs focusing on micronutrients have been conducted in the past two decades, aiming at the genetic enrichment of foodstuffs with vital nutrients required for human health (Singh *et al.*, 2017; Bouis, 2002).

CONCLUSION

The results from our evaluation of newly developed colored rice lines across two seasons indicated that three lines,

namely BĐ.1, BĐ.4 and BĐ.5, showed good nutritional traits (iron and anthocyanin content). However, when additional agronomic factors such as yield components were considered, two promising lines were selected, BĐ.1 (66.12-73.47 quintals/ha) and BĐ.4 (64.57-70.14 quintals/ha). Their anthocyanin content ranged from 27.83 to 35.79 mg/100g and iron content ranged from 23.89 to 23.82 mg/kg, respectively. It is recommended that these lines be further developed on a larger scale, along with studies on appropriate technical measures for rice cultivation.

Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

All authors declared that there is no conflict of interest.

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