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Agronomic Performance and Yield Potential of Promising Pigmented (Red and Black) Rice Lines in Medium-Altitude Paddy Fields

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Abstract: This study aimed to evaluate the agronomic traits and yield performance of several promising pigmented rice lines, including red and black rice, grown in medium-lowland paddy fields. The research was conducted from March to June 2025 at an altitude of 402 meters above sea level in Tampak Siring Village, Batukliang District, Central Lombok Regency. The experimental method used was a Randomized Complete Block Design (RCBD) consisting of 21 treatments, including 11 red rice lines, 4 black rice lines, and 4 parental lines (IPB3S, Situ Patenggang, Baas Selem, and the red rice promising line F2BC4P19-36), along with 2 check varieties, Impago Unram 1 and IR64. Each treatment was replicated three times, resulting in a total of 63 experimental units. The observed data were analyzed using analysis of variance (ANOVA), and significant differences among treatments were further tested using Duncan's Multiple Range Test (DMRT) at a 5% significance level. The results showed that the agronomic performance of both red and black rice lines exhibited medium maturity, with flowering time ranging from 83 to 93 days after sowing and harvesting time from 120 to 129 days after sowing. The number of productive tillers ranged from 12 to 19 tillers, panicle length ranged from 23 to 27 cm, the number of filled grains per panicle ranged from 130 to 147 grains, and grain weight per clump ranged from 33 to 41 grams. The highest grain yield was recorded in the red rice line G-2M (F7 IPB3S/F2BC4P19-63/FAT/F2BC44P19-63-PD3/15) at 4.99 t/ha, which was higher than its parental lines IPB3S (G1-6IPB3S) at 4.31 t/ha and GH Merah (G-20GHBM) at 3.83 t/ha. Among black rice lines, G-12H (F11BLK.SP/BS 2/1/1/P4) yielded 4.42 t/ha, compared to Baas Selem (G-18BS) at 3.86 t/ha, Situ Patenggang (G-17SP) at 4.63 t/ha, and the check variety IR64 (G-21IR64) at 3.60 t/ha.

Keywords: Agronomic traits; Black rice; Pigmented rice; Red rice; Yield performance

Introduction

Pigmented rice is a type of crop native to Indonesia that has strong potential to be developed as a healthy food source (Limbongan et al., 2023). Pigmented rice has physiological advantages, including high levels of anthocyanins, amino acids, and protein, as well as relatively low glucose content (Agustin et al., 2021). Red rice and black rice are examples of pigmented rice.

The increasing public awareness of the importance of health, particularly through the consumption of red and black rice, has encouraged plant breeders to develop superior pigmented rice varieties. These varieties are expected to have high yield potential, early maturity, and tolerance to environmental stresses (Sari et al., 2021). Many local rice varieties have great potential as sources of germplasm and as gene donors in plant breeding programs (Rahmawati et al., 2023). One approach to obtaining high-yielding and stress-tolerant lines is through hybridization of superior germplasm

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(Mustikarini et al., 2020).

Hybridization conducted by Aryana et al. (2022b) on several red, black, and white rice germplasm resulted in promising lines of red and black rice. Promising red rice lines were obtained from crosses between the red rice line F2BC4P19-36 and IPB 3S and Fatmawati through single and backcross methods, followed by pedigree selection, resulting in semi-ideal rice lines with superior traits (Aryana and Santoso, 2017). The parental lines of black rice originated from the local variety Baas Selem, which is aromatic, soft-textured, and rich in anthocyanins, and the improved upland rice variety Situ Patenggang, which is drought-tolerant and high-yielding. The breeding process began with single crosses, followed by bulk selection across several generations, and then pedigree selection, resulting in promising new-type black rice lines with early maturity and high yield potential (Aryana et al., 2020a). However, the agronomic performance of these promising lines in medium-altitude paddy fields has not yet been evaluated.

The development of lowland rice to increase national rice production has not yet reached its maximum potential, with average productivity still around 5.8 tons per hectare. This relatively low productivity is influenced by both genetic and environmental factors (Andri and Priantoro, 2020).

Agronomic characteristics of a plant represent the expression of its traits under specific growing conditions, resulting from the interaction between genetic and environmental factors (Mangoendidjojo, 2000). Several agronomic traits that can be used for evaluation include plant height, number of tillers, plant age, yield components, and yield potential (Dulbari et al., 2018). The performance of a plant genotype may vary across different environments. According to Agustiani et al. (2018), cultivation practices and altitude significantly affect the growth and yield of rice plants. Rice grown in lowland to medium-altitude areas generally shows better growth compared to highland areas. In highland conditions, plant growth tends to be lower across various observed variables, which is closely related to lower growth rates and assimilation rates compared to those in lowland and medium-altitude environments.

Medium-altitude paddy fields are agricultural lands located at moderate elevations, generally ranging from 300 to 700 meters above sea level. Rice cultivation is not only concentrated in lowland areas but can also be carried out in medium-altitude regions, which typically receive an average of 8–9 hours of sunlight per day, with air temperatures ranging from 22°C to 24°C and relative humidity between 83% and 89%. These conditions are favourable for optimal rice growth (Tu et al., 2022). Previous research by Katahadimaja and Syuriani (2018) showed that hybrid rice lines have good adaptability to medium-altitude irrigated paddy fields. However, it should be noted that each rice line has different yield potential depending on altitude conditions.

Based on the above description, it is necessary to conduct research on the agronomic traits and yield performance of various promising pigmented rice lines, including red and black rice, in medium-altitude paddy fields.

Method

This study was conducted from March to June 2025 using a field experimental method in medium-altitude paddy fields at 402 meters above sea level, located in Tampak Siring Village, Batukliang District, Central Lombok Regency. The experimental design used was a Randomized Complete Block Design (RCBD) consisting of 21 treatments, including 11 red rice lines (G-1M to G-11GHAKBC), 4 black rice lines (G-12H to G-15H), 2 parental lines of red rice, namely G-16IPB3S (national superior variety IPB3S) and G-20GHBM (promising red rice line F2BC4P19-36), 2 parental lines of black rice, namely G-17SP (national superior variety Situ Patenggang) and G-18BS (local variety Baas Selem), and 2 check varieties, G-19INPAGO (national superior variety Inpago Unram 1) and G-21IR64 (national superior variety IR64). Each treatment was replicated three times, resulting in a total of 63 experimental units. The names of the tested genotypes are presented in Table 1.

Planting was carried out using 21-day-old seedlings with one plant per hill and a spacing of 22 cm × 22 cm. Each experimental plot measured 2.2 m × 2.2 m. Fertilization was applied using 300 kg/ha of Phonska fertilizer and 200 kg/ha of urea. Sample plants were determined using a screening method, with 10 plants selected as samples in each plot. The observed parameters included flowering time, harvesting time, plant height, number of productive tillers, number of non-productive tillers, panicle length, number of filled grains per panicle, number of empty grains per panicle, weight of 100 grains, grain weight per hill, and grain yield (t/ha).

The collected data were analysed using analysis of variance (ANOVA) at a 5% significance level. Parameters showing significant differences were further analysed using Duncan's Multiple Range Test (DMRT) with the SAS program.

Table 1. Codes and names of treatment genotypes

Code	Genotype	Rice Color
G-1M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/7	Red
G-2M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/15	Red
G-3M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/20	Red
G-4M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/13	Red
G-5M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/71	Red
G-6M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/7 B	Red
G-7M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/7 A	Red
G-8M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/20 C	Red
G-9M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/13 D	Red
G-10M	F7 IPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/71 E	Red
G-11GHBM	Promising Red Rice Line AKBC86	Red
G-12H	F11.Blk.SP/BS/2/1/1/P4	Black
G-13H	F11.Blk.SP/BS/1/2/1/P4	Black
G-14H	F11.Blk.SP/BS/1/1/6/P4	Hitam
G-15H	F11.Blk.SP/BS/1/1/1/P4	Hitam
G-16IPB35	IPB3S	Putih
G-17SP	Situ Patenggang	Putih
G-18BS	Baas Selem	Hitam
G-19INPAGO	Inpago Unram I	Merah
G-20GHBM	Promising Red Rice Line F2BC4P19-36	Merah
G-21IR64	IR64	Putih

Result and Discussion

The analysis of agronomic traits of pigmented rice genotypes (red and black rice) was conducted on plant height, number of productive and non-productive tillers per hill, panicle length, number of filled grains per panicle, number of empty grains per panicle, 100-grain weight, grain weight per hill, and yield (t/ha). All observed characters showed significant differences at the 5% significance level (Table 2). Overall, these parameters indicate cause-and-effect relationships that may influence yield performance.

Plant height showed significant differences among genotypes. The average plant height ranged from 101.40 to 122.03 cm. The genotype with the lowest plant height and significantly different from all treatments was G-21IR64 (check variety IR64), as shown in Table 3. The tallest genotype was G-12H (black rice line). The analysis indicated that the plant height of genotype G-12H was significantly different from all red rice lines (G-1M to G-10M and G-11GHAKBC), the two red rice parental lines IPB3S and F2BC4P19-36 (G-16IPB3S and G-20GHBM), other black rice lines (G-13H to G-15H), the two black rice parental lines Situ Patenggang and Baas Selem (G-17SP and G-18BS), as well as the check varieties Inpago Unram 1 (G-19INPAGO) and IR64 (G-21IR64). According to IRRI (2013), plant height is classified as short (<110 cm), medium (110–130 cm), and tall (>130 cm). The results showed that the average plant height ranged from short to medium. One of the factors influencing plant height in rice is the genetic background of the parental lines (Rembang et al., 2018).

Table 2. Analysis of Variance for Agronomic Traits of Functional Red and Black Rice

Parameter	Notation
Plant height	S
Number of productive tillers per hill	S
Number of non-productive tillers per hill	S
Panicle length	S
Number of filled grains per panicle	S
Number of empty grains per panicle	S
100-grain weight	S
Grain weight per hill	S
Flowering time	S
Harvesting time	S
Yield (t/ha)	S

The average number of productive tillers per hill among the observed genotypes ranged from 12.37 to 19.03 tillers. The highest average number of productive tillers per hill was observed in lines G-2M, G-19INPAGO, G-12H, and G-18BS, which were significantly different from other genotypes. The number of tillers influences the number of panicles, where a higher number of productive tillers leads to higher yield (Afdila et al., 2021). This finding is consistent with the results of this study, where G-2M produced the highest number of productive tillers per hill and the highest yield per plot compared to other genotypes. The genotypes with the lowest average number of productive tillers per hill were G-9M and G-21IR64 (12.37 tillers). These lines were not significantly different from G-3M, G-4M, G-5M, G-8M, G-11GHAKBC, G-13H, G-14H, G-15H, G-16IPB3S, and G-20GHBM.

The average number of non-productive tillers per hill ranged from 1.17 to 5.70 tillers. The highest number of non-productive tillers was observed in G-20GHBM (5.70 tillers), which was not significantly different from G-21IR64 and G-9M, with 5.54 and 5.01 tillers, respectively. Non-productive tillers refer to tillers that do not produce panicles, which may be caused by inhibited growth during the late vegetative stage (Aryana et al., 2018). The variation in the number of tillers among genotypes is influenced by genetic factors and the adaptability of each genotype in producing tillers (Wijayanto et al., 2021).

Table 3. Mean Values of Plant Height, Number of Productive Tillers per Hill, Number of Non-Productive Tillers per Hill, and Panicle Length of Pigmented Red and Black Rice

GENOTYPE	TT (cm)	JAP (tillers hill^{-1})	JANP (tillers hill^{-1})	PM (cm)
G-1M	108,13 j	15,33 bc	2,73 gh	25,99 bcde
G-2M	116,37 cd	19,03 a	2,09 hij	27,60 a
G-3M	117,93 c	13,97 bcd	4,67 bcd	25,47 cdef
G-4M	112,80 def	13,83 bcde	3,93 def	25,43 cdef
G-5M	107,17 j	14,23 bcde	4,47 cde	24,57 fgh
G-6M	111,33 fghi	15,67 b	1,17 j	26,73 abc
G-7M	106,15 j	15,27 bc	1,90 hij	26,77 ab
G-8M	106,10 j	14,23 bcde	2,63 hg	25,63 bcdef
G-9M	112,17 efg	12,37 e	5,01 abc	23,84 h
G-10M	107,60 ij	14,67 bcd	3,53 efg	25,54 bcdef
G-11GHAKBC	108,47 ghij	13,03 de	2,93 gh	24,67 fgh
G-12H	126,37 a	17,77 a	2,03 hij	25,59 bcde
G-13H	122,73 b	14,30 bcde	2,90 gh	24,21 gh
G-14H	119,72 bc	13,40 cde	2,07 hij	23,83 h
G-15H	119,60 bc	14,00 bcde	2,50 gh	25,26 efg
G-16IPB3S	107,87 ij	13,00 de	1,56 ij	25,59 bcdef
G-17SP	112,26 efg	15,57 b	3,20 fg	24,02 h
G-18BS	115,80 cde	17,67 a	4,60 bcd	26,43 abcde
G-19INPAGO	112,03 efgh	18,70 a	4,70 bcd	26,60 abcd
G-20GHBM	105,96 j	13,36 cde	5,70 a	24,01 h
G-21IR64	101,40 k	12,37 e	5,54 ab	23,66 h

Note: (TT = plant height; JAP = number of productive tillers per hill; JANP = number of non-productive tillers per hill; PM = panicle length) G-16IPB3S and G-20GHBM = parental lines of red rice; G-17SP and G-18BS = parental lines of black rice; G-19INPAGO and G-21IR64 = check varieties. Values followed by the same letter within the same column are not significantly different according to DMRT at 5%.

Panicle length is classified into three categories: long (>30 cm), medium (21–30 cm), and short (<20 cm) (Diptaningsari, 2013). The average panicle length observed in this study ranged from 23.66 to 27.60 cm (Table 3), indicating that all genotypes fell into the medium category. The longest panicle length was recorded in G-2M (27.60 cm), which was not significantly different from G-6M, G-7M, G-18BS, and G-19INPAGO, but significantly different from other genotypes. The shortest panicle length was observed in G-21IR64, G-14H, G-9M, G-20GHBM, and G-17SP, which were not significantly different from G-5M, G-11GHAKBC, and G-13H. Differences in panicle length among genotypes are influenced by genetic factors and the adaptability of each genotype to environmental conditions (Rahmayuni et al., 2024). Panicle length affects the total number of grains per panicle, where longer panicles tend to produce more grains (Handoko et al., 2017). This is consistent with the results of this study, where G-2M, which had the longest panicle length (27.60 cm), also produced the highest number of filled grains (147.83 grains) compared to other genotypes.

The highest number of filled grains was observed in G-2M (147.83 grains), as well as in the red rice parental line G-16IPB3S (147.98 grains), and several other genotypes, except G-17SP, G-19INPAGO, G-20GHBM, and G-21IR64. The observation of the average number of empty grains per panicle showed that the highest value was recorded in G-9M (49.06 grains), while the lowest values were observed in G-2M and G-12H, with 20.60 and 21.24 grains, respectively. Genotype G-9M showed significant differences compared to G-1M, G-2M, G-3M, G-5M, G-6M, G-7M, G-8M, G-12H, G-13H, and G-19INPAGO.

Table 4. Mean Values of Flowering Time, Harvesting Time, Number of Filled Grains per Panicle, and Number of Empty Grains per Panicle of Pigmented Red and Black Rice

GENOTYPE	FT (DAP)	HT (DAP)	JGB (grains panicle⁻¹)	JGH (grains panicle⁻¹)
G-1M	83,00 fgh	120,67 b	134,63 abc	33,73 bcdef
G-2M	83,00 fgh	120,67 b	147,83 a	20,60 f
G-3M	86,67 cde	121,33 b	138,73 ab	32,02 bcdef
G-4M	82,00 gh	121,00 b	133,79 abc	36,32 abcde
G-5M	86,67 cde	122,33 b	141,45 ab	28,76 cdef
G-6M	87,67 cd	122,00 b	134,75 abc	26,39 def
G-7M	87,67 cd	122,00 b	141,28 ab	26,26 def
G-8M	85,00 defg	122,00 b	139,31 ab	31,83 bcdef
G-9M	80,33 h	120,67 b	130,23 abc	49,06 a
G-10M	85,33 def	122,00 b	137,25 abc	34,87 abcdef
G-11GHAKBC	86,00 defg	121,67 b	130,66 abc	38,09 abcde
G-12H	91,67 ab	127,33 a	140,80 ab	21,24 f
G-13H	93,33 a	129,00 a	135,70 abc	33,45 bcdef
G-14H	92,67 a	128,67 a	134,44 abc	39,41 abcd
G-15H	92,67 a	129,00 a	136,64 abc	41,96 abc
G-16IPB3S	86,67 cde	121,67 b	147,98 a	42,64 abc
G-17SP	84,33 efg	122,00 b	126,78 bcd	35,07 abcdef
G-18BS	92,00 a	128,67 a	132,52 abc	34,59 abcdef
G-19INPAGO	84,67 defg	121,00 b	111,95 d	23,80 ef
G-20GHBM	86,67 cde	122,33 b	126,29 bcd	43,88 ab
G-21IR64	89,00 bc	121,00 b	118,64 cd	43,10 abc

Note: UB = flowering time; UP = harvesting time; JGB = number of filled grains; JGH = number of empty grains. G-16IPB3S and G-20GHBM are parental lines of red rice; G-17SP and G-18BS are parental lines of black rice; G-19INPAGO and G-21IR64 are check varieties. Values followed by the same letter within the same column are not significantly different according to DMRT at the 5% level.

The observed flowering time ranged from 80.33 to 93.67 days after planting (DAP) (Table 4). Line G-9M showed the earliest flowering time and was not significantly different from G-1M, G-2M, and G-4M. The harvesting time of the observed genotypes ranged from 120.67 to 129 DAP. Based on the results, red rice lines (80.33–87.67 DAP) flowered earlier than black rice lines (91.67–93.33 DAP); similarly, red rice lines (120.67–121 DAP) matured earlier than black rice lines (121.3–129 DAP). According to Siregar (1981), rice maturity is classified as very early (<110 DAP), early (110–115 DAP), medium (115–125 DAP), and late (>125 DAP). The results indicate that all observed genotypes were classified as medium to late maturity.

Table 5. Mean Values of 100-Grain Weight, Grain Weight per Hill, and Yield (t/ha) of Pigmented Red and Black Rice

GENOTIPE	B100 (g)	GW/hill (g)	Yield (t/ha)
G-1M	2,81 ab	35,21 c	4,22 bcdefg
G-2M	2,92 a	41,68 a	4,99 a
G-3M	2,58 bcde	34,61 c	3,98 defghi
G-4M	2,44 cdef	34,71 c	4,13 cdefgh
G-5M	2,50 bcdef	34,76 c	4,20 bcdefg
G-6M	2,65 abcd	35,56 bc	4,43 bcde
G-7M	2,72 abc	36,81 bc	4,45 bcd
G-8M	2,46 cdef	37,32 bc	4,01 cdefghi
G-9M	2,17 f	33,69 c	3,80 hi
G-10M	2,71 abc	36,55 bc	4,08 cdefgh
G-11GHAKBC	2,34 def	36,40 bc	4,32 bcdef
G-12H	2,33 def	36,19 bc	4,28 bcdefg
G-13H	2,25 ef	35,54 bc	3,97 efghi
G-14H	2,24 ef	35,81 bc	3,96 efgh
G-15H	2,26 ef	34,58 c	3,99 defghi
G-16IPB3S	2,50 bcdef	36,49 bc	4,31 bcdef
G-17SP	2,24 ef	36,80 bc	4,63 ab
G-18BS	2,39 cdef	33,93 c	3,86 fghi
G-19INPAGO	2,64 abcd	39,09 ab	4,47 bc
G-20GHBM	2,24 ef	29,90 d	3,83 ghi
G-21IR64	2,15 f	27,56 d	3,60 i

Note: B100 = 100-grain weight; BRMPN = grain weight per hill. G-16IPB3S and G-20GHBM are parental lines of red rice; G-17SP and G-18BS are parental lines of black rice; G-19INPAGO and G-21IR64 are check varieties. Values followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test (DMRT) at the 5% level.

The 100-grain weight ranged from 2.15 to 2.92 g (Table 5). The genotype with the highest 100-grain weight was G-2M, while the lowest was G-21IR64. Line G-2M showed significant differences compared to its parental lines (G-16IPB3S and G-20GHBM), as well as G-3M, G-4M, G-5M, G-8M, G-9M, G-11GHAKBC, G-12H, G-13H, G-14H, G-15H, G-17SP, G-18BS, and G-21IR64. Genotypes G-21IR64 and G-9M showed the lowest 100-grain weight, with values of 2.15 g and 2.17 g, respectively. The 100-grain weight and grain weight per hill are more strongly influenced by genetic factors than environmental factors (Rembang et al., 2018).

The highest grain weight per hill was recorded in G-2M (41.68 g), which was not significantly different from the check variety Inpago Unram 1 (G-19INPAGO) with 39.09 g, but significantly different from all red rice lines (G-1M and G-3M to G-11GHAKBC), as well as from the parental lines of red rice, IPB3S (G-16IPB3S) and GHBM (G-20GHBM). Line G-2M also showed significant differences compared to all black rice lines (G-12H to G-15H), the parental lines of black rice (G-17SP and G-18BS), and the check variety IR64 (G-21IR64).

Yield (t/ha) represents the total production obtained per unit area in one cropping cycle. Yield per hectare was calculated by converting plot yield data. Grain yield per hectare is influenced by yield components, including the number of productive tillers, panicle length, number of filled grains, 100-grain weight, and grain weight per hill (Aryana et al., 2022). This is consistent with the results of this study, where line G-2M produced the highest yield among all genotypes. The high yield of G-2M was supported by its superior yield components, including panicle length (27.60 cm), number of productive tillers per hill (19.03 tillers), number of filled grains per panicle (147.83 grains), 100-grain weight (2.92 g), and grain weight per hill (41.68 g). Yield components showed a positive relationship with grain weight (Reda et al., 2024).

Conclusion

The agronomic performance of red and black rice lines showed medium to late maturity, with flowering and harvesting time ranging from 83–93 and 120–129 days after planting, respectively. The number of productive tillers ranged from 12 to 19 tillers, panicle length ranged from 23 to 27 cm, the number of filled grains per panicle ranged from 130 to 147 grains, and grain weight per hill ranged from 33 to 41 g. The highest grain yield was recorded in the red rice line G-2M (F7 IPB3S/F2BC4P19-63/FAT/F2BC44P19-63-PD3/15) at 4.99 t/ha, which was higher than its parental lines IPB3S (G1-6IPB3S) at 4.31 t/ha and GH Merah (G-20GHBM) at 3.83 t/ha. Among black rice lines, G-12H (F11BLK.SP/BS 2/1/1/P4) produced 4.42 t/ha, compared to Baas Selem (G-18BS) at 3.86 t/ha, Situ Patenggang (G-17SP) at 4.63 t/ha, and the check variety IR64 (G-21IR64) at 3.60 t/ha.

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