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Yield potential test of promising lines of red and black rice in dryland of low altitude in Central Lombok, Indonesia

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Abstract. Red and black rice are important functional food ingredients because of their high anthocyanin content, which is very beneficial for health. One of the steps to produce new superior varieties of rice is the implementation of field yield testing. The purpose of this activity was to examine yield potential of ideal types of red rice and black rice in upland growing environment of low altitudes. The field test was carried out from April to August 2021 in Central Lombok, at altitude of 100 m above sea level, which was designed using a Randomized Block Design with 15 treatments, namely 5 lines of ideal type red rice resulted from F5 Pedigree selection, 5 lines of black rice resulted from F10 bulk selection of F4 Pedigre, and 4 parents ("F2BC4P19-36" promising line of red rice, "Baas Selem", "Situ Patenggang" and "Inpago Unram 1" varieties), all of which were made in three replications (blocks). Observation variables included plant height, days to flowering and harvest, number of productive and non-productive tillers, panicle length, number of filled and unfilled grains per panicle, weight of 100 grains, grain yield per clump and potential yield in tons/ha. The results showed that the red rice line G6 (F5vIPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/83 (5.14 ton/ha) and the black rice line G10F91/1/6/P3 (5.29 ton/ha) showed higher yields compared to their parents, i.e. the red rice "GH F2BC4P19-36" (5.49 ton/ha), "Baas Selem" (4.83 ton/ha) and "Situ Patenggang" (4.89 ton/ha), which indicates that cross-breeding followed by Pedigree selection can improve yield potential of upland rice.

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1. INTRODUCTION

The development of upland rice cultivation is an alternative way to increase national rice production, because the expansion of lowland rice is increasingly difficult to do. One strategy that can be done is to utilize unused land and use adaptive varieties in the upland environment. In Indonesia, there are approximately 2 million ha of dry land or rainfed land suitable for upland rice. However, the average productivity of upland rice for example in the West Nusa Tenggara Province of Indonesia is still around 3.79 tons/ha (https://ntb.bps.go.id/indicator/53/181/2/luas-panen-produksi-dan-produktivitas-padi-ladang.html), which is far below the productivity of lowland rice, i.e. on average 5.35 tons/ha (https://ntb.bps.go.id/indicator/53/180/1/luas-panen-produksi-dan-produktivitas-padi-sawah.html).

In order to successfully increase production of upland rice in dry land areas, the agronomic properties of upland rice cultivars need to be improved towards high yield potential. This can be done using various plant breeding methods, one of which is by cross-breeding between germplasms, which have the opportunity to produce new superior upland rice varieties. Therefore, it is necessary to carry out research activities to develop new genotypes that are tolerant to drought stress in order to increase the productivity of upland rice under dry land environment (Kanagaraj et al. 2010).

Red rice and black rice are mostly local germplasms, which contain the best pigments, in contrast to white rice. Both red and black rice cultivars have a good taste and aroma with a specific and unique appearance. Rice color is genetically regulated, and may differ due to differences in genes that regulate aleurone color, endosperm, and starch composition in the endosperm. In red and black rice, aleurone and endosperm contain high intensity of anthocyanins so that the color of the rice becomes red or dark purple close to black. Red and black rice have better properties than white rice. Red and black rice cultivars are efficacious in increasing the body's resistance to disease, repairing liver cell damage (hepatitis and chirosis), preventing kidney function disorders, preventing cancer/tumors, slowing aging, as antioxidants, cleaning cholesterol in the blood, and preventing anemia. Black rice is used as a natural colorant for the food industry in the form of cakes, porridge, biscuits, ice cream and fermented drinks. In Bali, red and black rice are used as a means of religious ceremonies. The existence of red and black rice in Indonesia is increasingly rare due to the extensive planting of new high-yielding varieties, which are dominated by white rice (Suardi & Ridwan, 2009; Kristamtini & Purwaningsih, 2010; Ernawati et al., 2016; Aryana et al., 2017).

Up to now, the high-yielding varieties released by the Ministry of Agriculture have reached more than 233 varieties, which consist of 144 high-yielding varieties of lowland rice (INPARI), 35 varieties of hybrid rice (HIPA), 30 high-yielding varieties of upland rice (INPAGO) and 24 varieties of swamp rice (INPARA), most of which are produced by the Indonesian Agency for Agricultural Research and Development (Suprihatno et al., 2010). In addition, some varieties have been released by several universities such as IPB University with its IPB 3S and IPB 4S varieties (2012), which are in the category of lowland rice, UNSOED with Inpago Unsoed 1 (2011) and UNRAM with Inpago Unram 1 (2011) through the National Rice Consortium activities initiated by the Sukamandi Rice Research Center. The high-yielding varieties of rice that have been released so far are mostly white rice, while Inpago Unram I is a high-yielding variety of upland red rice. So far, no upland rice varieties of ideal types of red and black rice have been released.

Sources of new genes potential for formation of high yielding varieties of paddy and “new types” with early maturity are urgently needed considering that there are still many germplasms for these traits have not been identified. From the results of research conducted by Aryana et al. (2013) through back crossing up to 4 (four) times between the promising line of drought tolerant red rice and the local cultivar of red rice “Kala Isi Tolo” which has a high anthocyanin content and early maturity, the promising line of upland red rice “F2BC4P19-36” was produced. This promising line of red rice has high anthocyanin content, large number of tillers, 107 maturity days (early) but still has a relatively low yield of 5.8 tons/ha. This line was then crossed with “IPB 3S” variety (which has a potential yield of 11.2 tons/ha, 112 maturity days, white rice textured, a small number of tillers) and “Fatmawati” variety (which has a potential yield of 9 tons/ha, 115 maturity days, with white rice textured, and few tillers) through single crosses and repeated cross-selection, which was then continued with pedigree selection until F3, and resulted in new superior red rice lines of ideal types (Aryana et al., 2017). Suliartini et al. (2021), through further selection of the above-mentioned lines, resulted in red rice lines of ideal type by the F5 pedigree selection, which have high yielding capacity and early maturity. Likewise, from the results of a single cross between local lowland black rice "Baas Selem" (which has fluffier properties, has a fragrant aroma, with very high anthocyanin content, but low yields ranging from 2-4 tons/ha) and the upland rice variety “Situ Patenggang” (which has dry tolerant, high yield of > 6 tons/ha with white rice color), which was then subjected to Bulk selection to F10 and followed by Pedigree selection up to F4. These breeding activities resulted in the promising upland rice lines of black rice with “new type” properties, high yielding capacity and early maturity (Aryana et al., 2018b).

The above upland rice lines have not been tested for yield strength in upland areas of low altitude. Through this yield test, it was expected to obtain more uniform lines in the population, increase the number of promising lines, and produce promising lines that have relatively high yield potential which will later be tested under a Multi-location Test. The purpose of this activity was to test the yield potential of ideal-type red rice and black rice lines in upland growing environment of low altitude.

2. MATERIALS AND METHOD

The experiment was carried out in the rice fields of Mujur village, East Praya sub-district, Central Lombok regency, West Nusa Tenggara (Indonesia), at an altitude of 103 m above sea level (ASL) from April to August 2021.

2.1. Design of the experiment

The experiment was arranged in a Randomized Block Design with 15 rice genotypes as the treatments, which were replicated three times. The treatments were 6 red rice lines (G1 to G6), 5 black rice lines (G7-G11), 3 parent genotypes, namely red rice GH F2BC4P19-36 (G12), Baas Selem (G13), and Situ Patenggang (G14) varieties, and 1 comparison variety, i.e. Inpago Unram 1 (G15). All these genotypes were grown in three blocks, which function as the replications. Therefore, each block consisted of 15 plots for randomly growing each genotype on each plot.

All the tested genotypes, their parents and the comparison variety are as listed in Table 1 with each genotype or variety name. The parent “Baas Selem” is a local cultivar of black rice, and the comparison variety “Inpago Unram 1” is a national variety of upland red rice.

2.2. Implementation of the experiment

Each genotype as the treatment was planted on a plot of 2 x 4 m size, with plant spacing of 25 x 25 cm. After finishing soil tillage using a tractor, the land was divided into three blocks, and in each block, 15 plots were made with a size of 2 x 4 m, surrounded with a furrow of 40 cm width. Before seeding, all plots were spread with the insecticide Furadan 3 G granules at a dose of 5 gram/m^2. At seeding, the pre-germinated seeds of those genotypes were dibbled by planting 3-4 seeds per planting hole, and at 10 days after seeding, the young plants were tinned to leave one rice seedling to grow per planting hole.

Table 1. The genotypes of upland red and black rice used as the treatments in the field yield test

Treaments	Genotypes	Treaments	Genotypes
G1	F5 IPB3S/F2BC4P19-63// Fat/F2BC4P19-63-PD3/7	G9	F91/1/6//P3
G2	F5IPB3S/F2BC4P19-63// Fat/F2BC4P19-63-PD3/15	G10	F91/1/1/6/P3
G3	F5 IPB3S/F2BC4P19-63// Fat/F2BC4P19-63-PD3/20	G11	IPB3S
G4	F5 IPB3S/F2BC4P19-63// Fat/F2BC4P19-63-PD3/13	G12	Red rice GH F2BC4P19-36
G5	F5 IPB3S/F2BC4P19-63// Fat/F2BC4P19-63-PD3/71	G13	Baas Selem
G6	F91/1/6/I/P3	G14	Situ Patenggang
G7	F92/1/1/4/I/P3	G15	Inpago Unram 1
G8	F92/1/2/1//I/P3		

Fertilization was done with NPK (15-15-15) fertilizer at 300 kg/ha and Urea fertilizer at 200 kg/ha. The fertilizers were applied three times. The first was the basal fertilization using the NPK fertilizer at a dose of 300 kg/ha, which was done by dibbling it at seeding the pre-germinated seeds. The second and third fertilizations were application of the supplementary fertilizers in the form of Urea each at an application dose of 100 kg/ha respectively, which were applied at the age of 30 and 50 days after seeding, by dibbling the fertilizer. Weeding was done twice, namely one day before application of the second and third fertilization. Irrigation was based on rainwater. However, if there was no rain for longer than two weeks, water pumping machine was use to irrigate the plots by flowing the water through the furrows surrounding the plots, and this was done 7 times during this field experiment. To avoid bird attacks, rice plants were covered with nets since seed-filling stages. To avoid the attack of stink bugs, spraying was done with an insecticide containing *Lamda Sihalotrin* 25 g/L (Matador 25 EC) at a concentration of 2 cc/liter of water. Harvesting was carried out after 80% of the plants had reached harvest criteria.

2.3. Observation variables and data analysis

Observations were made on days to flowering, plant height, number of productive and non-productive tillers per clump, panicle length, number of filled and unfilled grains per panicle, weight of 100 grains, and weight of grain per clump. For potential yield (t/ha), the weight of grains of 14% moisture content harvested from a sampling area of 1 m^2 was converted to ton/ha. Analysis of variance was carried out using CoStat for Windows ver. 6.303 followed by the DMRT (Duncan Multiple Range Test) test at 5% level of significance.

3. RESULT AND DISCUSSION

Based on the results of the analysis of variance (ANOVA) of the observation variables, from the 11 tested red and black rice lines of functional rice (6 ideal types of red rice (G1-G6) and 5 black rice lines (G7-G11)), their three parent varieties (red rice GH F2BC4P19-36, Baas Selem, and Situ Pategang), and 1 comparison variety (Inpago Unram 1), it appears that they are significantly different in plant ages at flowering and harvest, plant height, number of productive tillers per clump, number of non-productive tillers per clump, number of filled and unfilled grains per panicle, 100-grain weight, grain yield per clump and potential grain yield per hectare. In contrast, panicle length showed no significant differences among the tested genotypes (Table 2). For significantly different variables, the results of the DMRT test are presented in Table 3 and Table 4.

The days to flowering ranged from 78.00 – 88.33 days after sowing (DAS) (Table 3). The earliest flowering genotype was the Inpago Unram 1 variety, which was 78.0 DAS and the latest one was the G8 black rice line, which was 88.33 DAS. The earliness of flowering of rice plants was classified into five categories: very early (< 71 days), early 71-90 days), moderate (91-110 days), late (111-130 days), and very late (> 130 days) maturity (Shobha-Rani et al., 2004). Based on this classification of flowering age, all the tested genotypes were classified as early flowering genotypes (71-90 days) (Putra, 2010). Chandrasari et al. (2012) stated that rice plants achieving a faster flowering date have a faster generative phase, so the faster the rice plants get flowering, the faster the harvest age will be. Aryana et al. (2013) added the importance of knowing the flowering date in order to determine the time of sowing and planting in order to get the synchronization of flowering to get the same time of harvest between varieties.

Table 2. Summary of ANOVA results for all observation variables

No.	Variables	Probability	Significance
1	Days to flowering	0.0001	S
2	Plant height	0.0043	S
3	Number of productive tillers	0.0187	S
4	Number of non-productive tillers	0.0241	S
5	Panicle length	0.4555	NS
6	Filled grain number per panicle	0.0417	S
7	Unfilled grain number per panicle	0.0233	S
8	Weight of 100 filled grains	0.0053	S
9	Grain yield per clump	0.0402	S
10	Potential yield (ton/ha)	0.0001	S

Remarks: S = significant; NS = non-significant

Plant height is a measure that is often observed as an indicator of growth and as a parameter used to determine plant production (Wibowo, 2010). IRRI (2013) classified plant height into short (<110 cm), medium (110-130 cm) and tall (>130 cm) categories. Based on this category, all of the tested rice lines were classified as short, except for the G2 red rice line which was classified as medium (113.80 cm). The comparison variety "Inpago Unram 1" was also classified as medium (116.82 cm). Rice plants that are under high criteria tend to fall easily due to environmental factors such as strong winds, and usually if they fall down, the grain yield will decrease. Zen (2013) adds that short plants will avoid collapsing due to wind, so that such plants are easy to care for. Yoshida (1981) stated that the short plant height is a change in morphological traits selected by breeders. In addition, Aryana et al., 2012 stated that the ideal type of rice plant has a plant height ranging from 90 - 105 cm because it is easy to care for the rice plants and ir generally resistant to fall. The rice plants that were classified as ideal type based on plant height were G1, G3, G5, G7, and G9 lines.

The number of productive tillers per clump ranged from 9.78 to 17.74. The lowest number of productive tillers was recorded in the G7 and G8 lines of black rice, i.e. 9.89 and 9.78 tillers respectively, and the highest was in Inpago Unram 1, with an average of 17.74 tillers per clump (Table 3). According to Endrizal and Bobihoe (2007), productive tillers per clump are the determinants of panicle numbers, thus the number has a direct effect on the level of grain yield. Hatta (2011) added that the number of productive tillers is related to yield, so a small number of productive tillers would result in low grain yields. Aryana et al. (2018b) also added that tillers formed in the late stages of the vegetative phase tend not to be able to produce panicles, and those types of tillers are categorized as non-productive tillers.

Table 3. Average days to flowering (DF), plant height (PH), panicle length (PL), productive tiller number per clump (PTN), and non-produtive tiller number per clump (NTN)

Treatments	Days to flowering	Plant height (cm)	Penicle length (cm)	Produtive tiller number per clump	Non-produtive tiller number per clump
G1	82.00 ab	100.03 cd	20.45 a	11.89 bcd	2.56 a
G2	79.33 ab	113.80 ab	22.75 a	12.11 abcd	1.07 ab
G3	82.67 ab	102.46 cd	22.06 a	15.04 abcd	1.00 ab
G4	83.00 ab	107.77 abc	21.37 a	11.52 cd	0.85 ab
G5	78.67 b	102.58 cd	22.03 a	16.04 abc	0.59 b
G6	83.67 ab	109.01 abc	22.99 a	16.22 abc	0.59 b
G7	84.67 ab	102.58 cd	20.59 a	9.89 d	0.93 ab
G8	88.33 a	106.11 bc	20.35 a	9.78 d	1.33 ab
G9	84.33 ab	94.09 d	20.08 a	14.74 abcd	0.30 b
G10	85.00 ab	109.60 abc	20.81 a	12.11 abcd	0.48 b
G11	82.00 ab	106.20 bc	20.78 a	16.78 abc	0.78 b
G12/GH	80.33 ab	110.38 abc	21.63 a	15.85 abc	0.93 ab
G13/BS	85.33 ab	100.88 cd	21.23 a	14.19 abcd	0.11 b
G14/SP	83.00 ab	104.84 bc	22.73 a	17.48 ab	0.15 b
G15/IU	78.00 b	116.82 a	21.61 a	17.74 a	1.30 ab

Remarks: Mean values in the same column followed by the same letters are not significantly different

Table 4. Average filled grain number per panicle (FGN), unfilled grain number per panicle (UGN), weight of 100 filled grains, grain yield per clump (GYC), and yield potential (YP) for each treatment

Perlakuan	Filled grain number per panicle	Unfilled grain number per panicle	Weight of 100 grains (g)	Grain yield (g/clump)	Yield potential (ton/ha)
G1	98.19 bc	32.02 abc	2.84 bcd	21.96 d	4.21 bc
G2	106.00 abc	27.70 abcd	3.04 abc	30.42 abcd	3.60 c
G3	102.00 bc	29.07 abcd	2.84 bcd	30.00 bcd	4.72 bc
G4	115.11 ab	28.09 abcd	3.28 a	31.49 abcd	4.78 bc
G5	99.81 bc	36.48 abc	2.85 bcd	33.09 abcd	3.77 c
G6	115.11 ab	30.78 abc	2.90 bcd	41.14 ab	5.14 b
G7	111.57 ab	26.15 abcd	2.68 d	27.07 cd	4.93 bc
G8	116.37 ab	24.87 cd	2.61 d	25.23 cd	4.88 bc
G9	81.13 c	37.44 ab	2.85 bcd	31.42 abcd	4.17 bc
G10	110.78 ab	25.50 bcd	2.67 d	34.64 abcd	5.29 b
G11	100.65 bc	37.96 a	2.81 bcd	35.53 abc	4.61 bc
G12/GH	120.02 ab	27.50 abcd	2.79 bcd	31.82 abcd	5.49 b
G13/BS	91.35 bc	36.98 abc	2.70 cd	29.89 bcd	4.83 bc
G14/SP	109.44 abc	32.17 abc	2.74 cd	36.01 abc	4.89 bc
G15/IU	134.19 a	17.94 d	3.11 ab	43.06 a	7.58 a

Remarks: Mean values in the same column followed by the same letters are not significantly different

Almost all genotypes tested in this study showed very low number of non-productive tillers, while the results of the ANOVA showed that number of non-productive tillers between genotypes was not significantly different. Thamrin et al. (2010) stated that non-productive tillers are competitors of productive tillers in utilizing solar energy and nutrients. In addition, more non-productive tillers will lead to a more humid micro-environment that provides opportunities for the development of pests and diseases. The number of productive tillers in rice plants was classified into three categories, namely many (>20), moderate (11-20), and few (<11) tillers (Shobha-Rani et al., 2004). Based on these classifications, the G7 and G8 lines are classified as having few productive tillers while the other lines are classified as moderate in terms of productive tiller number per clump.

Panicle length is a selection criterion for rice plants because it affects grain yield. The panicle length of the tested genotypes ranged from 20.08 to 22.99 cm, but it was not significantly different between those genotypes. The panicle length is classified into 3 (three) categories namely short panicles (< 20 cm), medium panicles (20-30 cm) and long panicles (> 30 cm) (Aryana and Santoso, 2017). Based on these classifications, all the tested genotypes are in the category of medium panicle length (20-30 cm). Plants that have long panicles will provide more grain so that the yield obtained would be higher (Makarim et al., 2009).

The number of filled grains per panicle ranged from 81.13 – 134.19 grains (Table 4). Three genotypes with the highest number of filled grain were Inpago Unram 1 (134.19 grains), the GH parent G12 (120.02 grains), and G8 (116.37 grains). According to Jun et al. (2006) the number of grains per panicle for the ideal type of rice ranges from 180-240 grains per panicle with more than 85% of filled grains. Yang et al. (2007) added that in order to increase rice yields, the parents need to have a large number of grains per panicle, with a long panicle size. Xu et al. (2005) developed an ideal type of rice with more than 200 grains per panicle. Bobihoe and Nafisah (2008) added that the number of filled grains per panicle is correlated with crop yields but it is also affected by the number of unfilled grains per panicle. Furthermore, rice yields are also determined by other yield components such as the number of filled grains per panicle and the weight of 1000 grains. Wibowo (2010) added that each genotype has different grain production capabilities depending on its genetic characteristics.

For the number of unfilled grains, the highest average value was found in the G11 black rice line (37.96 grains) and the lowest in the comparison variety “Inpago Unram 1” (17.94 grains). The level of unfilled grain number, apart from being a genetic influence, can also be influenced by environmental factors (Aryana et al., 2012). Peng et al. (2008) also stated that the low seed filling capacity was caused by a small apical dominance in the panicle, the arrangement of grain in the panicle, and the limited sheath for transporting assimilate. Yoshida (1981) also indicated that the level of unfilled grain number is influenced by climate (low or high temperatures around the stages of reduction and anthesis division can induce sterility), fertilization and pests and diseases.

The weight of 100 filled grains was in the range of 2.67–3.28 g. The highest weight was in the ideal type of black rice line G4 (3.11 g) and the lowest was in the black rice line G7, G8, and G10, with an average of 2.68 g; 2.61 g and 2.67 g, respectively. According to Jun et al. (2006) for the ideal type rice, the weight of 1000 grains is between 28-30 g. The weight of 1000 grains is also a yield component, because the heavier the weight of 1000 grains, the higher the grain yield will be (Chandrasari et al., 2012). However, Maintang et al. (2010) stated that the weight of 1000 grains is not always followed by high yields. This can be seen in G4 which has the highest weight of 100 grains (3.28 g) but a low grain yield (4.78 t/ha) when compared to G15 having a lower weight of 100 grains (3.11 g), but it actually produced the highest yield, with an average of 7, 58 t/ha (Table 4).

Grain yield per clump of rice plants is generally strongly influenced by the weight of filled grain, the number of panicles, and the weight of 1000 grains (Sumarjan et al., 2014). Ramdani et al. (2015)

also stated that the amount of filled grains determines the weight of grain per clump of a rice plant. This can be seen in the G15 genotype which has a relatively large number of filled grains when compared to the parents, i.e. Baas Selem (G13) and Situ Patenggang (G14) which have a small amount of filled grains (Table 4), so that grain yield per clump obtained by the G15 genotype was the highest, and this was also consistent with its highest potential yield per hectare.

The potential yield per hectare is a quantity that describes the amount of yield obtained in one hectare of land in one cropping cycle. According to Aryana et al. (2012) high yields in rice plants can be influenced by yield components such as the number of productive tillers per clump, panicle length, number of filled grains per panicle, and grain weight per clump. The genotype G15 (Inpago Unram 1), which is the comparison variety, is a genotype that has the highest yield potential (7.58 ton/ha), compared with the tested lines and the red and black rice parents. This yield potential showed significantly linear regression with other observation variables either in simple and multiple regression analyses with two or three X-variables (Table 5). It can be seen from Table 5 that yield potential was 84.4% contributed by such variables as panicle length (PL), productive tiller number per clump (PTN), and unfilled grain number per panicle (UGN). As an individual variable, the unfilled grain number per panicle showed a highly significant correlation with the potential yield, with a negative correlation coefficient (r) of -0.677, which means that unfilled grain number per panicle has a significant potential to reduce yield potential of rice.

Table 5. Regression equation between 1-3 X-variables and potential yield of the tested rice lines (in ton/ha)

X-vars	The X variables	Regression equation	R-square	p-value
3 X-var	PL, PTN, UGN	$YP= 14.48 - 0.414 X1^{*} + 0.257 X2^{**} - 0.146 X3^{**}$	84.40%	0.000
3 X-var	PL, PTN, FGN	$YP = 6.15 - 0.486 X1^{*} + 0.178 X2^{**} + 0.062 X3^{**}$	79.80%	0.000
2 X-var	PTN, UGN	$YP = 6.28 + 0.180 X1^{**} - 0.132 X2^{**}$	71.60%	0.001
2 X-var	PTN, FGN	$YP = -2.13 + 0.098 X1^{ns} + 0.052 X2^{**}$	62.90%	0.003
1 X-var	FGN	$YP = -0.87 + 0.053 X^{**}$	54.80%	0.002
1 X-var	UGN	$YP = 8.19 - 0.111 X^{**}$	45.80%	0.006
1 X-var	GYC	$YP = 1.79 + 0.095 X^{*}$	32.70%	0.026

Remarks: ns = non-significant; *, ** = significant at p-value <0.05 and p-value <0.01, respectively; PL= panicle length; PTN = productive tiller number; UGN = unfilled grain number per panicle; FGN = filled grain number per panicle; GYC = grain yield per clump; YP = yield potential (ton/ha)

4. CONCLUSION

The results showed that the red rice line G6 (F5vIPB3S/F2BC4P19-63//Fat/F2BC4P19-63-PD3/83 (5.14 ton/ha) and the black rice line G10F91/1/6/P3 (5.29 ton/ha) showed higher yields compared to their parents, i.e. the red rice “GH F2BC4P19-36” (5.49 ton/ha), “Baas Selem” (4.83 ton/ha) and “Situ Patenggang” (4.89 ton/ha), which indicates that cross-breeding followed by Pedigree selection can improve yield potential of upland rice.

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AUTHORS' CONTRIBUTIONS

All authors contributed to the implementation of the field experiment, data analysis, and writing the draft and finally rewrite the English version of the manuscript.

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