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EVALUATION OF DOUBLED HAPLOID RICE LINES DERIVED FROM ANTHER CULTURE OF INPARI-42 GSR AGRITAN MUTANT IN ADVANCED YIELD TRIALS

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SUMMARY

Combining mutation and anther culture technology could accelerate the rice breeding program. This research evaluated the agronomic performance of doubled haploid (DH) lines derived from anther culture of Inpari 42 GSR Agritan mutant in advanced yield trials. The research was conducted in Bogor and Indramayu, Indonesia from December 2023 to April 2024. The material used was 18 DH lines and two check varieties (Inpari 42 GSR Agritan and Inpari 45 Agritan). The experiment used a randomized complete block design with three replications and the rice genotype as a factor. The result indicated a variation in agronomic characters, yield components, and productivity of the DH rice lines. The interaction of genotype by location was notable in the vegetative plant height, the number of vegetative tillers, the percentage of filled and empty grains, the weight of 1000 grains, and productivity. Highly significant and positive correlations to productivity were evident in total grain, percentage of filled grains, the number of filled grains, grain filling period, and days of harvesting. Selection used the index selection method based on productivity, percentage of filled grains, total grains, and days of harvesting, which indicated the 12 DH lines need further evaluation in multi-location trials for their potential yield and stability.

Keywords: anther culture, correlation, green super rice, mutation, selection index, yield

Key findings: The combined mutation and anther culture technology, followed by the index selection method, can accelerate in obtaining advanced rice lines with good agronomic and productivity characteristics.

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INTRODUCTION

Rice is an essential crop consumed by more than 50% of the world's population. Rice, grown in over 100 countries, has 90% of its production in Asia (Fukagawa and Ziska, 2019). Relatedly, world rice production decreased by 1.39%, from 708.7 million tons in 2021 to 698.8 million tons in 2022 (FAO, 2022). The rapid increase in population and changes in the demographic structure, such as modifications in lifestyle and dietary patterns, can be challenges in the demand and production of rice (Bhandari and Mishra, 2018). However, the solution to increasing rice productivity faces various problems. Globally, rice farmers face climate change causing floods, droughts, and increased attacks by plant pests and diseases (Horie, 2019), and locally, they face issues, such as land conversion, resulting in a decrease in rice fields' harvested area and concerns in water availability (Rahayu *et al.,* 2022).

The first step in breeding superior rice varieties is genetic variation availability. Rapidly inducing new genetic variation can proceed through the induction of mutation by both physical and chemical mutagens (Viana *et al*., 2019). Rice breeding using mutagenesis effectively allows genetic changes, such as, shorter days of flowering, reduced plant height, a high number of productive tillers, high panicle fertility, and better rice quality. These caused improved resistance to pest and disease and tolerance to abiotic stresses (Sobrizal, 2017; Poli *et al*., 2021). A major goal in the plant breeding process is reducing time; hence, the need for combined use of mutation induction and other technology to hasten the breeding process. One of the in vitro culture techniques to accelerate rice breeding is anther culture. Pure lines are readily available from regenerating spontaneous doubled haploid (DH) plants within one to two years (Dewi et al., 2017). Recently, by using anther culture technology, four high-yielding climate-resilient varieties, i.e., Bioprima Agritan, Bioemas Agritan, IPB 10G Tanimar, and IPB 11S Bepe, have been released in Indonesia (Purwoko and Dewi, 2022).

The development of Green Super Rice (GSR) was a breakthrough proposed by Chinese scientists to cultivate new rice varieties with several characteristics. GSR was a genetically designed rice for the following characteristics: adequate resistance to major diseases and insects, high efficiency in nutrient uptake and utilization, resistance to drought and other abiotic stresses, good quality, and increased yield potential (Zhang, 2007; Li and Ali, 2017). Therefore, aside from obtaining high yields, the production of rice with a GSR ideotype targets a resource-saving and environmentally friendly rice variety, with the potential to answer the challenges of climate change (Yu *et al.,* 2020). The first GSR variety released in Indonesia was Inpari 42 GSR. The variety, as introduced from China, had an average productivity of 7.1 t ha^{-1} and a potential yield of 10.58 t ha^{-1}, but is only moderately resistant to the brown plant hopper biotype 1 and bacterial leaf blight pathotype III (Nurhidayah *et al*. 2023; Nurhidayah *et al.*, 2024). From previous research, Azmy (2020) used a combination of mutation and anther culture and obtained 54 DH lines derived from anther culture of Inpari 42 GSR Agritan mutant and Batutegi mutant. Then, Hanif (2023) characterized and conducted a preliminary yield trial on these lines and obtained 19 DH rice lines derived from selected Inpari 42 GSR Agritan mutant using a positive selection index value on productivity characters. Those DH lines need further scrutiny in the follow-up evaluation. This study assessed the agronomic performance of DH lines derived from anther culture of Inpari 42 GSR Agritan mutant in advanced yield trials.

MATERIALS AND METHODS

The research commenced at the Sawah Baru Experimental Station, IPB, Bogor and Sanca, Gantar, Indramayu, from December 2023 to May 2024. Both locations are in West Java, Indonesia. The materials used were 20 rice genotypes, consisting of 18 DH lines obtained from anther culture of Inpari 42 GSR Agritan mutants and two check varieties (Inpari 42 GSR Agritan and Inpari 45 Dirgahayu). Research activities had a randomized complete block design (RCBD) with rice genotype as the factor. Each genotype, as repeated in three replicates, made 60 experimental units per location. Each experimental unit has a plot of 3 m × 3 m.

The seedlings' transplant in the field ensued 21 days after sowing (DAS), with a planting distance of 25 cm × 25 cm and 2–3 seedlings per hill. Plant maintenance included weed control, replanting, control of pests and diseases, irrigation, and fertilization. Replanting occurred one to two weeks after planting (WAP) for damage or missing seedlings due to the pest's attack. Weed control continued manually at three and six WAP. Watering transpired intermittently and stopped before the harvest period. Fertilization treatment had a dose of 200 kg/ha urea, 150 kg/ha SP-36, and 100 kg/ha KCl. Fertilizer application comprised three stages, as follows: at one WAP, with a dose of 40 kg/ha urea, 150 kg/ha SP-36, and 100 kg/ha KCl; at four WAP, with a dose of 80 kg/ha urea; and finally, at seven WAP, with a dose of 80 kg/ha urea. Pest and disease control took place, as needed. Paddy rice generally reaches harvest time when 90% of the panicles in a plot have turned yellow. Harvesting was done by manually cutting the rice stem's lower part and threshing it.

Observations were conducted on five sample plants per experimental unit. The observed variables included the vegetative and generative plant height (VPH and GPH), total number of vegetative (NVT) and productive tillers (NPT), days of flowering (DOF), days of harvesting (DOH), grain filling period (GFP), panicle length (PL), panicle density (PD), total number of grains per panicle (TG), the number of filled (NFG) and empty grains (NEG), percentage of filled (PFG) and empty grains (PEG), 1000-grain weight (TGW), and yield (P).

Data analysis

The data obtained from research activities underwent a combined variance analysis (ANOVA) using Microsoft Excel 2013 software and SAS on Demand for Academic (Statistical Analysis System). If ANOVA was significant, a further least significant different (LSD) test continued at a 95% confidence level or $\alpha = 0.05$. Pearson's correlation analysis and the index selection method helped select genotypes for further testing.

The selected characters based on the significant and positive value of Pearson's correlation analysis incurred weighing of their economic value for use in the selection index formula, according to Kang (2015), as follows:

$$I = \Sigma\, b_i x_i = b_1x_1 + b_2x_2 + \ldots\ldots + b_nx_n$$

Where, I is the selection index; b_n is the weight given to the selected character, i.e., productivity: 3, the percentage of filled grains: 1, the total grains: 1, and -1 on days of harvesting; x_n is the standardized phenotype value, calculated using the standardization formula of Jolliffe and Cadima (2016).

RESULTS AND DISCUSSION

A combined analysis of variance for estimating variance components related to different sources of variation appears in Table 1. The results showed the significant effect of genotype on all characters. The location did not significantly affect the number of productive tillers, days of flowering, or the total number of grains per panicle. The influence of genotype by environment interaction occurred in the characters of vegetative plant height, number of vegetative tillers, percentage of filled grains, percentage of empty grains, 1000-grain weight, and yield. The notable difference between the genotypes evaluated indicated a measurable deviation in genetic variation. The coefficient of variation (CV) on the observed characters provided a range of values, from 1.28% to 17.46%. A high CV indicated an environmental error, whereas a lower CV value implied an increase in the validity of decision-making (Delgado *et al.,* 2019).

Agronomic characters

Agronomic characters of rice genotypes in the advanced yield trials are available in Table 2.

Table 1. Means square of agronomic characteristics of the rice genotype and check varieties in two locations.

Characters	Means Squares			CV
	Genotypes	Locations[a]	Interaction	
Vegetative plant height	25.31**	677.11*	10.84**	2.99
Number of vegetative tillers	16.74**	427.52*	7.396**	8.74
Generative plant height	201.67**	6690.28**	4.853ns	10.97
Number of productive tillers	7.14*	16.99ns	6.00ns	3.15
Days of flowering	8.62**	28.03ns	1.28ns	1.28
Days of harvesting	4.18**	603.01**	1.69ns	1.28
Grain filling period	10.47**	891.07**	2.42ns	5.41
Panicle length	10.67**	91.47**	1.33ns	4.21
Number of filled grains per panicle	3578.58**	106.392.03**	700.79ns	17.46
Number of empty grains per panicle	486.64**	113.858.36**	380.09ns	15.38T
Number of total grains	3015.47**	126.59ns	575.48ns	10.64
Percentage of filled grain	311.06**	27.56**	190.82**	11.72
Percentage of empty grain	306.35**	27.985.63**	193.016**	15.39T
Panicle density	6.16**	8.15**	0.58ns	10.99
1000-grain weight	17.60**	0.15ns	2.502*	4.78
Productivity	2.05**	316.80**	1.673*	17.41

Note: ** = significant at $P \leq 0.01$; * = significant at $P \leq 0.05$; ns= not significant; T = root and arc sin transformation results; [a]: location = environment.

Table 2. Mean plant height, number of tillers, days of flowering, and harvesting in two locations.

Lines/ Varieties	VPH (cm)	GPH (cm)	NVT (stems/hill)	NPT (stems/hill)	DOF (DAS)	DOH (DAS)	GFP (Days)
SB5-8-1-1	79.90	93.79	18.4	16.2	86.2	120.0	33.8
SB5-8-1-2	80.78	94.07	21.4	18.1	85.7	118.2	32.5
SB5-8-1-3	77.78	94.93	20.9	18.0	86.5	120.3	33.8
SB5-46-1-2	73.57	91.59	19.1	18.9	86.0	119.5	33.5
SB5-46-1-3	74.29	92.73	20.8	16.5	85.8	121.5	35.7
SB5-46-1-4	77.28	94.10	20.6	16.5	86.5	121.0	34.5
SB5-46-2-1	75.90	92.41	22.4	17.8	85.8	120.8	35.0
SB5-46-2-2	75.54	94.68	21.5	18.4	85.7	121.2	35.5
SB5-46-2-3	76.59	93.16	23.0	19.1	87.5	120.3	32.8
SB5-46-2-4	77.51	97.35	21.3	18.8	88.2	121.5	33.3
SB6-3-1-1	78.08	100.42	21.8	17.6	86.7	121.3	34.7
SB6-3-1-2	77.06	95.19	19.2	16.6	86.7	121.2	34.5
SB6-3-1-3	79.53	102.20	20.9	17.3	87.5	120.5	33.0
SB6-3-1-4	78.95	97.97	18.9	15.6	85.5	120.5	35.0
SB6-9-1-1	77.04	97.80	19.5	18.0	86.2	120.0	33.8
SB6-13-1-1	76.44	91.94	17.1	16.9	87.0	120.3	33.3
SB6-24-1-1	74.08	92.33	23.3	19.3	89.7	121.5	31.8
SB6-24-1-2	73.53	90.36	22.3	19.0	88.0	121.0	33.0
Inpari 42	77.29	98.41	20.2	16.7	87.7	120.3	32.7
Inpari 45	78.29	116.91	22.8	17.4	89.3	119.5	30.2
LSD 0.05	2.65	3.49	2.09	2.23	1.28	1.78	2.09
Locations							
Bogor	79.34	103.58	22.66	18.01	87.4	118.3	30.9
Indramayu	74.60	88.65	18.88	17.26	86.4	122.8	36.3
LSD 0.05	0.83	1.10	0.66	0.70	0.40	0.56	0.66

Note: VPH = vegetative plant height; GPH = generative plant height; NVT = number of vegetative tillers; NPT = number of productive tillers; DOF = days of flowering; DOH = days of harvesting; GFP = grain filling period; and DAS = days after sowing.

The vegetative plant height of the DH lines ranged from 73.53 to 80.78 cm, while the generative plant height ranged from 90.33 to 102.20 cm. IRRI (2014) categorizes the height of lowland rice plants into three: short plants with a height of less than 110 cm, medium plants between 110–130 cm, and tall plants with more than 130 cm. Thus, all lines tested in this study achieved a short plant classification based on this category. The height of the check variety Inpari 42 GSR Agritan, also used as a parent in this study, was also in the short plant category. In contrast, the check variety Inpari 45 was under the medium plant height class, with an average height of 116.91 cm. Plant height is an important characteristic affecting biomass, lodging, and productivity. Plant height has a positive correlation with the lodging character and biomass production but a negative link with productivity (Wu *et al*., 2022).

The average number of vegetative tillers of DH lines ranged from 17.1 to 23.3 tillers, while the number of productive tillers of DH lines ranged from 15.6 tillers (SB6-3-1-4) to 19.3 tillers (SB6-24-1-2). Based on IRRI (2014) classification, the number of rice tillers in the generative phase is very low (less than five tillers per plant), low (five to nine tillers per plant), medium (10 to 19 tillers per plant), high (20 to 25 tillers per plant), and very high (more than 25 tillers per plant). Based on these categories, all DH lines in this study are rice plants belonging to the category with medium number of tillers, with the check varieties used also classified as plants with a medium number of tillers. According to Nuruzzaman *et al*. (2000), the percentage of productive tillers bore influence from the amount of nitrogen absorbed and dry matter produced per stem from the maximum tiller number stage to heading. This indicated the extent of competition for the substances among the stems within a hill, which could play an important role in determining the quantity of non-productive tillers.

The days of flowering of the DH lines ranged from 85.5 to 89.7 DAS, while the days of harvesting ranged from 118.2 to 121.5 DAS. The line with the earliest days of flowering was SB6-3-1-4. Genotypes with a longer day of flowering generally indicated that the days to maturity of those genotypes will be longer than those that flower faster (Dewi *et al.,* 2009). Flowering time has also appeared to influence final yield, as early flowering genotypes produced lower yields than those that flower late. Thus, the improvement in rice yield potential could come from increased biomass production (Zhao *et al.*, 2020). However, this study did not investigate the biomass of rice plants. BB Padi (2015) categorized the days of harvesting into six groups, namely, ultra (<90 DAS), very early (90–104 DAS), early (105–124 DAS), medium (125–150 DAS), and long (>165 DAS). Thus, all the DH lines belonged to the early maturing category. Early maturing plants can be options for planting in rainfed rice fields due to limited and unpredictable irrigation water sources. Early maturing plants are also favorable to farmers because they can increase the cropping index (Fatimah *et al.,* 2014).

In this research, the grain-filling period of DH lines ranged from 31.8 to 35.6 days. The SB6-24-1-1 line had the longest days of flowering and harvesting than other genotypes, although, it had the shortest grain-filling period. According to Okamura *et al*. (2018), the seeds' sink capacity increase, with effects from the number of grains per panicle and the grain size, influenced the grain-filling period.

Yield and its components

The mean of yield components of DH lines and the check varieties occur in Table 3. A variation surfaced in the characters of the total number of grains per panicle, filled grain, empty grain, and panicle density of DH lines. The DH lines had panicle lengths ranging from 21.63 to 27.00 cm, the total number of grains ranging from 148.4 to 235.0 grains per panicle, and the panicle density ranging from 5.7 to 9.4 spikelets/cm. Moreover, the DH lines had the number of filled grains ranging from 78.1 to 181.8, with the percentage of filled grains ranging from 47.4% to 80.2%, and percentage of empty grains, from 19.7% to 52.6%.

Generally, rice genotypes tested in Bogor were lower than Indramayu in panicle density and in the number and percentage of

Table 3. Mean yield components of DH mutants in two locations.

Lines/ Varieties	PL (cm)	TG	NFG	NEG	PFG (%)	PEG (%)	PD (spikelet/cm)	TGW (g)
		(grain/panicle)						
SB5-8-1-1	23.68	219.7	170.9	48.8	77.0	22.9	9.3	22.08
SB5-8-1-2	24.43	201.8	161.9	39.8	80.3	19.7	8.3	22.83
SB5-8-1-3	24.32	228.3	183.3	45.0	80.1	19.8	9.4	22.73
SB5-46-1-2	23.72	215.0	162.9	52.1	76.2	23.8	9.1	22.55
SB5-46-1-3	25.52	235.0	181.8	53.2	77.1	23.0	9.2	23.20
SB5-46-1-4	24.34	224.0	174.7	49.3	77.8	22.1	9.2	22.85
SB5-46-2-1	23.11	201.2	151.6	49.6	75.3	24.6	8.7	22.37
SB5-46-2-2	24.05	200.8	156.5	44.4	78.1	21.8	8.3	21.95
SB5-46-2-3	23.46	222.1	178.0	44.1	80.2	19.7	9.5	22.77
SB5-46-2-4	25.26	210.7	150.8	59.9	72.0	28.1	8.2	22.23
SB6-3-1-1	24.80	214.7	167.6	47.1	77.9	22.1	8.7	22.68
SB6-3-1-2	24.69	225.6	157.1	68.6	68.8	30.1	9.1	22.53
SB6-3-1-3	24.29	225.7	164.0	61.7	72.1	27.9	9.4	22.75
SB6-3-1-4	25.15	219.6	155.3	64.3	70.1	29.8	8.7	21.73
SB6-9-1-1	23.42	202.0	139.9	62.1	70.1	29.6	8.6	21.55
SB6-13-1-1	27.00	148.4	78.1	70.3	47.4	52.6	5.7	28.65
SB6-24-1-1	22.67	196.6	140.8	55.8	72.3	27.7	8.7	23.00
SB6-24-1-2	21.63	173.2	124.1	49.1	73.2	26.8	8.0	22.20
Inpari 42	24.99	209.8	152.4	57.4	73.0	26.9	8.4	24.43
Inpari 45	27.34	164.3	123.6	40.7	73.5	26.6	6.0	26.93
LSD 5%	1.18	25.32	30.88	-	9.92	9.90	1.08	1.27
Locations								
Bogor	25.27	207.9	123.99	83.96	58.4	41.56	8.27	23.09
Indramayu	23.52	205.9	183.54	22.36	88.75	11.02	8.79	23.02
LSD 0.05	1.99	-	9.76	6.68	3.14	3.13	0.34	-

Note: PL = panicle length; TG = number of total grains; NFG = number of filled grains; NEG = number of empty grains; PFG = percentage of filled grains; PEG = percentage of empty grains; PD = panicle density; TGW = 1000- grain weight.

filled grains (Table 3). This is due to the high volume and frequency of rainfall throughout the planting season until harvest. In Bogor, the average rainfall and duration of sunlight per day during the ripening stage (April 2024) were 758.10 mm and 5.54 hours, respectively (BMKG, 2024). The number of filled grains and the number of empty grains bore influences from genetic and environmental factors, such as, the amount of rainfall and solar radiation. The advantage of planting rice in the rainy season was the available water for growth and development. However, during the rainy season, relatively less solar radiation inhibited the process of photosynthesis (Diyoprakuso *et al*., 2022). The effect of solar radiation was most significant on the percentage of filled grain during the ripening stage. More solar radiation during ripening enhanced the rice yield by increasing the filled-grain percentage and 1000-grain weight (Kim *et al.,* 2021). Additionally, the reduction in nitrogen and dry matter accumulation accounted for the changes in the number of grains per panicle, grain-filling rate, and grain size (Ji *et al*., 2023).

The mean of a thousand-grain weight (TGW) in the DH lines ranged from 21.55 to 28.65 g (Table 3). Categorizing TGW can comprise as light (<25 g), medium (25–30 g), and heavy (>30 g) (IRRI, 2014). Only one DH line with a medium 1000-grain weight category emerged, i.e., SB6-13-1-1. The 17 other lines have a light 1000-grain weight category similar to their parent (Inpari 42 GSR Agritan). The TGW is a key component of grain yield in rice and a trait closely related to grain length, grain width, and shape, which are crucial traits for grain quality. Many minor and major genes genetically control these traits, as quantitatively inherited through generations (Anilkumar *et al*., 2022). Previously, Wang and Zhang (2017) reported that *SPL* genes regulate plant architecture and grain size in rice. Thus, fine-tuning the corresponding *SPL* expression provides a strategy for modulating grain size, shape, and yield for rice improvement.

The results in Table 4 showed the variation of yield of DH lines in two environmental conditions, i.e., Bogor and Indramayu. The mean yield of the DH lines in Indramayu was 6.84 t/ha, which indicated a significantly higher yield than that in Bogor (3.59 t/ha). The line with the highest yield in Indramayu was the SB5-8-1-3 line (7.83 t/ha), while in Bogor, it was the SB5-46-2-3 line (5.07 t/ha). Line SB5-8-1-3 achieved the highest average yield for the two locations (6.17 t/ha). The high yield of the SB5-8-1-3 line had its support from the number of grains per panicle (TG > 200 grains/panicle), the number of filled grains (NFG > 180 grains/panicle), and the percentage of filled grains (PFG > 80%) (Table 3).

The grain yield of rice receives direct effect from the grain number per panicle, grain weight, and grain filling, which are typical quantitative traits, while indirectly from plant height and tillering capacity (Sakamoto and Matsuoka, 2008; Zhu *et al*., 2019). However, the panicle architecture, especially the panicle length, determined the grain number per panicle. In this research, although it has shown the SB6-13-1-1 line with the longest panicle length similar to the check variety Inpari 45 (Table 3), the line had the lowest average yield (Table 4). This refers to the least number of grains per panicle, lightest panicle density, minimum percentage of filled grains, and the maximum percentage of empty grains among all DH lines and check varieties (Table 3). The lowest panicle density of the SB6-13-1-1 line could be because of its 1000-grain weight (TGW) being more than 28 g. TGW signified a positive correlation with grain size in cereals and affected the panicle density or the number of spikelets per cm (Ali *et al.*, 2020).

Table 4. DH lines and check varieties productivity.

Lines/Varieties	Productivity (t/ha)		
	Bogor	Indramayu	Genotype Average
SB5-8-1-1	3.67abcd	7.43a	5.55abc
SB5-8-1-2	4.27abc	7.80a	6.03ab
SB5-8-1-3	4.50ab	7.83a	6.17a
SB5-46-1-2	3.67abcd	7.00ab	5.33abcd
SB5-46-1-3	3.87abcd	6.50abc	5.18abcd
SB5-46-1-4	4.23abcd	6.97ab	5.60abc
SB5-46-2-1	3.73abcd	7.30ab	5.52abcd
SB5-46-2-2	4.03abcd	6.63abc	5.33abcd
SB5-46-2-3	5.07a	6.53abc	5.80abc
SB5-46-2-4	3.27bcd	6.50abc	4.88cd
SB6-3-1-1	4.13abcd	6.40abc	5.27abcd
SB6-3-1-2	3.47bcd	7.37a	5.42abcd
SB6-3-1-3	2.83cd	7.10ab	4.97cd
SB6-3-1-4	3.60abcd	7.23ab	5.42abcd
SB6-9-1-1	3.03bcd	6.67abc	4.85cd
SB6-13-1-1	0.47e	6.47abc	3.47e
SB6-24-1-1	3.77abcd	5.20c	4.48de
SB6-24-1-2	3.70abcd	5.87bc	4.78cd
Inpari 42	3.70abcd	6.67abc	5.18abcd
Inpari 45	2.77d	7.30ab	5.03bcd
Location Average	3.59B	6.84A	

Note: Numbers followed by the same lowercase letter in the same column are not significantly different based on the results of the LSD test at the 5% level, while numbers followed by capital letter indicate statistical difference for location average.

Table 5. Pearson's correlation between variables.

Traits	PROD	TGW	TG	PEG	PFG	NFG	NEG	GFP	DOH	DOF	GPH	NPT
PROD	1											
TGW	-0.10ns	1										
TG	0.23**	-0.40**	1									
PEG	-0.89**	0.18*	-0.22*	1								
PFG	0.89**	-0,18*	0.22*	-0.99**	1							
NFG	0.82**	-0.28**	0.60**	-0.89**	0.8**	1						
NEG	-0.8**	0.03ns	0.06ns	0.94**	-0.9**	-0.76**	1					
GFP	0.68 **	-0.12ns	0.07*	-0.61**	0.60**	0.55**	-0.62**	1				
DOH	0.63 **	-0.04ns	0.0004ns	-0.57**	0.57**	0.48**	-0.59**	0.87**	1			
DOF	-0.37 **	0.18*	-0.14 ns	0.31**	-0.30**	-0.33**	0.293**	-0.6**	-.15ns	1		
GPH	-0.63 **	0.17ns	-0.05ns	0.61**	-0.60**	-0.54**	0.64**	-0.7**	-.66**	0.39**	1	
NPT	-0.13ns	-0.11ns	-0.12ns	0.19*	-0.19*	-0.21*	0.18*	-0.2*	-0.13ns	0.24**	0.12ns	1

Notes: ** = significantly correlated at α 1%, * = significantly correlated at α 5%, ns = not significant. PROD = productivity; TGW = 1000 grain weight; TG = total grains; PEG= percentage of empty grains; PFG = percentage of filled grains; NFG = number of filled grains; NEG = number of empty grains; DOF = days of flowering; DOH = days of harvesting; GFP = grain filling period; GPH = generative plant height; and NPT = number of productive tillers.

Correlation and selection index

Correlation is a statistical method used to measure whether there is a linear relationship between variables (Schober *et al.,* 2018). The correlation analysis is a widely used method in plant breeding programs as an essential step in selecting the desired characters. Correlation analysis in rice plants is widely applicable to increase yield by looking at its relationship with other characters so that the selection of lines can be done more effectively (Saleh *et al.,* 2020). Table 5 shows that the yield-related traits or yield component characteristics, namely, total grain, percentage of filled grains, the number of filled grains, the grain-filling period, and days of harvesting showed a significant positive correlation with yield. Conversely, the yield with the number of empty grains and the percentage of empty grains had a negative correlation. The results agreed with the research of Zhao *et al.* (2020), who reported the total number of grains, the number of filled grains, and the percentage of filled grains have a remarkable and positive correlation with rice productivity.

Yield alone should not serve to select promising lines because of its complexity and relationship with other yield-related traits. Oladosu *et al.* (2018) emphasized that selection based on yield-related traits on rice grain yield characters is effective and will give an optimum response for increasing productivity. By considering several traits, simultaneously using the selection index method, selection to obtain the best genotype can be easier because it is desirable to choose individuals with the best combination of these traits (Hidayatullah *et al*., 2018; Rahimi and Debnath, 2023).

In this study, the selected characters used in index selection were productivity, the percentage of filled grains, total grain number, and days of harvesting based on the result of Pearson's correlation (Table 5). Yield traits should have a weight three times greater than the other attributes because the productivity character has the highest economic value (Akbar *et al.* 2021; Hadianto *et al*., 2023). Thus, the four selected characters received a weight of productivity = 3, percentage of filled grains = 1, total grains = 1, and days of harvesting = -1. Index selection is a method in the selection process using a standardized coefficient weighting. Then, assigning a weight value to each selected trait is according to its importance. The selection of 18 DH lines using the selection index method indicated that 12 DH lines have a positive selection index value and above the parent Inpari 42 GSR Agritan. They are SB5-8-1-3, SB5-8-1-2, SB5-46-2-3, SB5-8-1-1, SB5-46-1-4, SB5-46-1-2, SB5-46-1-3, SB6-3-1-4, SB6-3-1-2, SB6-3-1-1, SB5-46-2-1, and SB6-3-1-3. These lines can be open for further testing (Table 6).

Table 6. Index selection of doubled haploid lines

Lines/Varieties	Standardized index value of				Weighted index value
	PROD	PFG	TG	DOH	
SB5-8-1-3	0.49	0.71	0.34	-0.07	2.57
SB5-8-1-2	0.42	-0.17	0.35	-0.86	2.28
SB5-46-2-3	0.30	0.51	0.34	-0.07	1.81
SB5-8-1-1	0.17	0.43	0.18	-0.19	1.31
SB5-46-1-4	0.20	0.57	0.22	0.17	1.20
SB5-46-1-2	0.06	0.27	0.13	-0.37	0.96
SB5-46-1-3	-0.02	0.94	0.18	0.35	0.72
SB6-3-1-4	0.10	0.42	-0.18	-0.01	0.56
SB6-3-1-2	0.10	0.62	-0.25	0.23	0.45
SB6-3-1-1	0.03	0.26	0.22	0.29	0.27
SB5-46-2-1	0.15	-0.19	0.09	0.11	0.25
SB6-3-1-3	-0.13	0.63	-0.08	-0.01	0.18
Inpari 42	-0.02	0.10	-0.03	-0.07	0.09
SB5-46-2-2	0.06	-0.20	0.23	0.23	-0.02
SB6-9-1-1	-0.19	-0.17	-0.18	-0.19	-0.71
SB5-46-2-4	-0.17	0.13	-0.09	0.35	-0.82
Inpari 45	-0.09	-1.42	-0.01	-0.37	-1.33
SB6-24-1-1	-0.37	-0.34	-0.07	0.35	-1.88
SB6-24-1-2	-0.22	-1.12	-0.02	0.17	-1.97
SB6-13-1-1	-0.89	-1.95	-1.38	-0.07	-5.93

Note: PROD= productivity. PFG= percentage of filled grain, TG= Number of total grains, DOH= Days of harvesting.

CONCLUSIONS

The selection of 18 DH lines using the selection index method based on yield, the percentage of filled grains, total number of grains, and days of harvest characters resulted in obtaining 12 DH lines with positive selection index values above their parent Inpari 42 GSR Agritan.

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