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SELECTION OF DOUBLE HAPLOID RICE (*ORYZA SATIVA* L.) LINES OBTAINED FROM INPARI 42 AGRITAN GSR MUTANTS UNDER LOW FERTILIZER CONDITIONS

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SUMMARY

Increasing rice (*Oryza sativa* L.) production is essential to meet global food demands amidst population growth, climate change, and limited agricultural resources. However, higher production paired with increased fertilization reduces fertilizer efficiency in rice crops, raises production costs, and negatively impacts the environment. The green super rice (GSR) ideotype's development was successful in achieving high productivity with low input, tolerance to abiotic stress, and resistance to biotic stress. The technology of anther culture and mutation can be helpful in accelerating the development of new varieties. This study aimed to evaluate agronomic characters and the tolerance of double haploid (DH) lines derived from the Inpari 42 Agritan GSR mutant under low fertilization dosage. The experiment arrangement was in a split-plot design, with fertilizer dosage as the main plot (1/3 dosage, 2/3 dosage, and recommended dosage) and genotypes as the subplot (16 DH lines and two check varieties, which are Inpari 42 and Inpari 45). The recommended dosage of fertilizer had the highest productivity; however, it was not significantly different from the 2/3 dosage of fertilizer. Based on MGIDI selection, the DH lines MS36, MS42, MS45, MS46, and MS51 emerged as promising lines with better yield components and productivity and tolerance index values under the 2/3 fertilizer dosage.

Keywords: Green super rice (*O. sativa* L.), anther culture, fertilizer efficiency, MGIDI, tolerance indices, grain yield

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Key findings: Reducing fertilization in rice (*O. sativa* L.) cultivation is a feasible strategy to lower production costs and minimize environmental impact. Based on MGIDI selection, five double haploid lines were selected due to better productivity, yield components, and tolerance index values than the parent under a 2/3 fertilizer dosage.

INTRODUCTION

Rice (*Oryza sativa* L.) has more than 90% of Asians consuming it, with an expectation to increase, especially in Indonesia, the Philippines, Bangladesh, and Vietnam (Rahman and Zhang, 2022). Global per capita rice consumption in 2024 reached 53.3 kg per capita per year, accompanied by a 0.9% increase in rice production (534.9 million tons of milled rice) (FAO, 2024). Efforts to increase production are crucial for addressing the challenge of meeting global food demand amid a growing population, climate change, and limited agricultural resources. Increasing rice productivity often corresponds with high fertilization, as current varieties require significant fertilization to achieve high yields (Singh and Craswell, 2021).

Rice crop production bears influence from high inorganic fertilization, especially in macronutrients such as nitrogen (N), phosphate (P), and potassium (K). High fertilization, especially nitrogen, has been proven to increase productivity in Green Revolution varieties. FAO (2022) noted the increase in demand for N, P, and K fertilizers from 2016 to 2022 has risen by 1% or 6.4 million tons of N (NH_4) fertilizer, 10% or 4.6 million tons of P (P_2O_5) fertilizer, and 13% of potassium K_2O fertilizer by 4.7 million tons. The impact of this high inorganic fertilization is not only on increasing production costs, but also causes several environmental problems. According to Neeraja *et al.* (2021), only about 30% to 50% of the total fertilizer applied reached the rice plant's use; the other amount, especially nitrogen, underwent leaching, affecting the soil, water, and atmosphere. Generally, the breeding direction of rice plants with low fertilizer tolerance sought to improve the efficiency of nutrient uptake, utilization, and accumulation (Tamagno *et al.*, 2024).

Green super rice (GSR) is a new rice ideotype that emphasizes the concept of increasing production along with environmentally sustainable agriculture. Rice breeding with the GSR ideotype seeks to target high grain yield and quality but requires lower fertilizer use, less pesticide, and efficient water use, as well as abiotic tolerance and biotic resistance (Liu *et al.*, 2022). Inpari 42 is the first green super rice (GSR) variety in Indonesia with an average productivity around 7.1 tons of milled dry grain (MDG) per ha and yield potential around 10.6 tons MDG per ha. It has a fairly light 1000-grain weight of around 24.4 grams and a classification of moderately resistant to bacterial leaf blight pathotype III and moderately resistant to brown plant hopper biotype I (BBPSI Padi, 2023). Previous research by Azmy (2020) and Dewi *et al.* (2024) combined mutation and anther culture methods on Inpari 42 Agritan GSR and Batutegi. The research obtained 52 double haploid (DH) lines. Hanif (2023) conducted a preliminary yield trial and obtained 19 DH lines. Purwoko *et al.* (2025) handled advanced yield trials under recommended fertilization, and obtained 12 high productivity DH lines. However, documentation has not yet occurred on whether the GSR background of these lines ensures yield stability under nutrient-limited conditions. This study evaluates agronomic characters and the tolerance of these lines under low-fertilizer-input conditions.

MATERIALS AND METHODS

The novel research on rice (*O. sativa* L.) was conducted at Sawah Baru Experimental Station, IPB, Bogor, West Java, Indonesia (6°33'49.3"S 106°44'05.7"E) from November 2024 to March 2025. The climate conditions during the field trial had a stable average temperature, ranging between 25.99 °C and 26.71 °C. Precipitation levels reached a notable peak in November at 680.4 mm before gradually decreasing to 148.7 mm. The average sunshine duration each day varied from 2.1 to 5.5 hours. Throughout the testing period, these indicators reflected a mostly rainy climate with low solar radiation (BMKG 2025). Soil analysis at a depth of about 20 cm before treatment showed a pH of 5.34 (acid), medium N-total content (0.21%), very high available P (16.84 ppm P_2O_5), low potential K (15.99 mg K_2O/100g), and low cation exchange capacity (CEC) (14.50 cmol/Kg). The soil analysis serves as a key consideration in determining the recommended fertilizer dosage, following the guidelines set by the Indonesian Ministry of Agriculture (Kementan, 2021).

The experiment had a split-plot design, with fertilization dosages as the main plot and genotypes as subplots. Fertilization consisted of three levels, namely, P1 or 1/3 dosage of recommendation (83 kg/ha urea + 17 kg/ha SP-36 + 25 kg/ha KCl); P2 or 2/3 dosage (167 kg/ha urea + 34 kg/ha SP-36 + 50 kg/ha KCl); and P3 or the recommended dosage (250 kg/ha urea + 50 kg/ha SP-36 + 75 kg/ha KCl). Genotypes used in this experiment totaled 16, consisting of 14 double haploid lines derived from the Inpari 42 Agritan GSR mutant (MS36, MS37, MS38, MS40, MS41, MS42, MS43, MS44, MS45, MS46, MS47, MS49, MS51, and MS54) and two check varieties (Inpari 42 and Inpari 45). Inpari 45 was a choice for a high-yielding check with distinct morphology and a larger sink capacity than the GSR variety Inpari 42. Lines MS36–MS46 resulted from 300 Gy irradiated Inpari 42, then culturing the anther, while MS47–MS54 used a 450 Gy gamma dose, with the anther cultured. Each treatment entailed three repeats, hence making a total of 144 experimental units in an area of 2 m × 2 m for each experimental unit. Seeds underwent sowing before transplanting into the field. Seedlings aged 21 days after sowing were planted at a spacing of 25 cm × 25 cm at a depth of about 3–5 cm. Plant maintenance was replanting, weed control, control of plant pests and diseases, irrigation, and fertilization. Replanting continued at 1–2 weeks after transplanting (WAT) to maintain the population. Weed control proceeded manually at 3 and 6 WAT. Watering took place intermittently before stopping at the harvest period. Fertilization followed the dosage in each treatment. Fertilizer application succeeded in three stages, namely, at 1 WAT with a dosage of 1/3 of urea, 1 dosage of SP-36, and 1 dosage of KCl, and at 4 and 7 WAT with a dosage of 1/3 urea. Pest and disease control ensued by applying pesticides according to the field conditions. Harvesting began when 90% of the panicles had turned yellow by cutting the bottom of the rice stem and then manually threshing the rice.

The observed agronomic characters included plant height in the generative phase (cm) measured from the soil to the tallest panicle tip, the number of productive tillers, and harvesting time recorded from the sowing day until 90% yellow grains/maturity. Other traits recorded were the total number of grains (grains), the percentage of filled grains, and the percentage of unfilled grains, calculated based on the ratio of filled and unfilled grains to the total number of grains. Finally, the study recorded the weight of 1000 grains (grams) and yield (t/ha). The observations occurred on four representative plant samples per experimental unit.

The calculation of yield-based tolerance indices proceeded using several types of tolerance indices as follows:

Geometric mean productivity (GMP): $\sqrt{Y_P \times Y_S}$ (Fernandez, 1992);

Yield stability index (YSI): Y_s/Y_p (Bouslama and Schapaugh, 1984);

Stress susceptibility index (SSI) (Fischer and Maurer, 1978),

$$SSI = \left(1 - \frac{Y_s}{Y_p}\right)/SI \; ; \; SI = \left(1 - \frac{\bar{Y}_s}{\bar{Y}_p}\right)$$

Yield index (YI): $Y_s/\bar{Y}_s$ (Gavuzzi *et al.,* 1997);

Mean productivity (MP): $(Y_p + Y_s)/2$ (Rosielle and Hamblin, 1981);

Tolerance index (TOL): $Y_p - Y_s$ (Rosielle and Hamblin, 1981); and

Stress tolerance index (STI): $Y_p \times Y_s/Y_p^2$ (Fernandez, 1992)

Where, Yp refers to the productivity character of each genotype under optimum fertilization conditions, Ys refers to the productivity of each genotype under suboptimum conditions (Treatment P2), $\bar{Y}_s$ refers to the average productivity of genotypes under treatment P2, and $\bar{Y}_p$ refers to the average productivity of genotypes under optimum conditions.

Data analysis

Analysis of variance (ANOVA) at the 5% to 10% level, followed by the least significant difference (LSD) test at the 5% level, sought to determine the effects of fertilization, genotype, and their interaction. The tolerance index calculation used Microsoft Excel software. Spearman correlation served to analyze tolerance indices and productivity. The Multi-Trait Genotype–Ideotype Distance Index (MGIDI) enabled the selection of ideal genotypes (Olivoto *et al*., 2022). All data analysis related to MGIDI used the Metan R package.

The MGIDI analysis had four stages: a) rescaling the values of each character used in the selection to values between 0 and 100, b) determining the factor analysis to see the correlation structure and reduce the dimensions of the data used, c) determining the target ideotype based on the desired characters, and d) calculating the distance between the test genotype and the target ideotype (Olivoto and Nardino, 2021). In this study, the selection intensity used was 35%, based on productivity, total grain yield, grain-filling percentage, 1000-grain weight, the number of productive tillers, and tolerance index. The productivity trait received a high weight of 3 due to its high economic value.

RESULTS AND DISCUSSION

Fertilization affects only the number of productive tillers, although it tends to have a significant effect on yield in rice (*O. sativa* L.) (Table 1). Genotypes significantly influenced all observed variables. The interaction between genotype and fertilization notably affected harvest time and the percentage of filled and empty grains.

The average plant height of the double haploid lines (87.26–99.60 cm) was significantly lower than the check Inpari 45 variety (114.68 cm) (Table 2). However, the Inpari 45 variety has fewer generative tillers than the double haploid lines MS36, MS37, MS40, MS41, MS43, MS45, and MS54. The number of generative tillers incurred influences from fertilization, although the number of tillers at 2/3 of the recommended dosages is not significantly different from the recommended dosage treatment. All genotypes feature a dwarf stature, which effectively minimizes lodging risks (Wu *et al.,* 2022). This morphological trait prevents ergonomic strain and potential injuries during harvesting processes (Mulyati *et al*., 2019). The number of generative tillers determines the number of panicles and affects yield. The rice tillering ability varies based on the genotype and environment factor. The low content of nitrogen and phosphate in the soil will hamper the differentiation of buds and reduce the number of tillers (Zhang *et al.,* 2024). Meanwhile, the genotype-dependent response has the control of endogenous hormones, such as cytokinin, gibberellin, abscisic acid, brassinosteroid, and strigolactone that impact the number of tillers (Zhang *et al.,* 2025).

The total grain number of DH lines (162.7–216.9 grains) was higher than Inpari 45 (134.3 grains). The increase in total grain number sustained effects from the number of grains on the secondary branches of the panicle, where proper nitrogen fertilization encourages the differentiation of secondary branches and the development of spikelets in rice panicles (Liu *et al*., 2021). Although the total grain number of Inpari 45 was the lowest, this variety had a significantly higher 1000-grain weight than the double haploid lines and Inpari 42.

The harvest times of double haploid lines range from 121.3 days after sowing (DAS) to 125.0 DAS (Table 3). Several genotypes show differences in harvest age at

Table 1. P-value of genotype, fertilization, and interaction effect.

Character	Fertilizer dosage	Genotypes	Interaction	CV (%)
Generative plant height	0.88	0.0001**	0.97	3.0
Number of productive tillers	0.017*	0.025*	0.173	10.0
Days of harvesting	0.60	<0.0001**	0.009**	0.7
Number of total grains	0.16	0.0001**	0.27	12.8
Percentages of filled grains	0.88	0.001**	0.02*	8.3
Percentages of empty grains	0.85	0.0002**	0.007**	29.7
1000-grain weight	0.55	<0.0001**	0.06+	9.9
Yield	0.06+	0.0002**	0.91	10.3^t

**: Significantly affected (< 1%); *: Significantly affected (< 5%); +: tend to be significantly affected (< 10%); CV: Coefficient of variation; and t: root transformation.

Table 2. Mean plant height, number of generative tillers, total grain number, 1000-grain weight, and productivity.

Treatment	Plant height (cm)	Productive tillers/hill	Grains/panicle	1000-grain weight (g)	Yield (t/ha)
Fertilizer dosage					
1/3 dosage	93.88	12.8	164.5	19.67	3.44
2/3 dosage	93.95	14.3	180.6	20.20	3.99
Recommended Dosage	94.26	15.3	204.4	20.97	4.28
LSD 5%	-	1.3	-	-	0.71
Genotype					
MS36	90.31	14.5	171.3	18.15	3.74
MS37	91.65	15.2	191.9	19.48	3.74
MS38	93.12	13.3	187.2	21.04	4.07
MS40	93.20	14.6	185.1	18.36	3.62
MS41	89.78	14.4	184.7	19.06	3.88
MS42	91.97	14.0	216.9	19.73	4.33
MS43	89.92	14.4	203.0	20.53	3.51
MS44	92.24	13.8	188.8	19.81	3.47
MS45	91.88	14.1	187.4	21.74	5.10
MS46	99.60	13.7	172.3	22.03	4.13
MS47	96.30	14.0	162.7	20.47	3.94
MS49	95.58	13.8	188.2	20.19	3.28
MS51	91.91	14.0	178.4	19.54	4.01
MS54	87.26	15.5	181.7	18.33	3.93
Inpari 42	95.22	14.1	196.9	19.93	4.84
Inpari 45	114.68	12.8	134.3	26.12	2.92
$LSD_{0.05}$	2.69	1.3	22.0	1.89	0.86

different fertilizer doses. Namely, MS43, MS44, and MS46 show longer harvest times at recommended fertilizer dosages. The time to harvest rice plants gained influence from the time of flowering. According to Ye *et al.* (2019), higher nitrogen fertilization will increase tiller formation, which causes the development of some tillers to be slower than others. This will result in non-uniform flowering, which explains why some genotypes take longer to flower. In contrast, MS36 and MS45 expressed shorter harvesting time under recommended fertilization. According to Baek *et al.* (2026), optimal nitrogen supply triggers earlier flowering by coordinating nutrient signaling with reproductive development. It exhibited the potential for high nutrient responses, high yield, and the early harvesting variety.

Table 3. Interaction of genotype and fertilizer dosage for days to harvesting, percentages of filled grains, and percentages of empty grains.

Genotype	Days to harvesting (days)			Filled grains (%)			Empty grains (%)		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
MS36	124.7	122.7	122.3	73.7	72.3	80.7	26.3	27.7	19.3
MS37	122.3	122.7	122.3	79.0	76.0	78.7	21.0	24.0	21.3
MS38	121.3	121.7	121.7	80.0	75.3	82.3	20.0	24.7	17.7
MS40	122.3	121.3	121.3	70.0	76.3	69.7	30.0	23.7	30.3
MS41	121.7	122.0	120.7	79.3	68.3	66.7	20.7	31.7	33.33
MS42	121.7	122.0	122.3	74.7	73.7	78.3	25.3	26.3	21.7
MS43	122.3	123.3	124.3	75.0	78.0	69.3	25.0	22.0	30.7
MS44	121.3	121.7	123.3	76.7	80.3	78.3	23.3	19.7	21.7
MS45	123.3	121.7	121.3	76.0	81.3	91.3	24.0	18.7	8.7
MS46	121.3	123.3	123.7	71.3	75.3	67.6	28.7	24.7	32.3
MS47	122.3	123.0	123.7	73.3	78.0	76.0	26.7	22.0	24.0
MS49	123.3	122.0	123.0	67.3	81.3	67.3	32.7	18.7	32.7
MS51	122.7	121.7	123.3	72.7	79.3	81.3	27.3	20.7	18.7
MS54	124.7	124.0	124.0	70.3	76.3	79.3	29.7	23.7	20.7
Inpari 42	124.0	124.0	124.0	77.3	72.3	77.0	22.7	27.7	23.0
Inpari 45	125.0	124.0	123.7	71.0	73.0	63.0	29.0	27.0	37.0
$LSD_{0.05}$ interaction	1.4			10.1			10.1		

Note: P1 = 1/3 dosage of fertilizer; P2 = 2/3 dosage of fertilizer; and P3 = Recommended dosage.

The MS45 genotype has the highest percentage of filled grains under recommended fertilizer application rates, similar to that of the 2/3 of the recommended dosage. Other genotypes show no significant difference in the grain-filling percentage across different fertilizer application rates. The opposite response resulted in the percentage of unfilled grains. According to Huang *et al.* (2019), genotypes respond to the dosage of fertilization by determining the physiological mechanisms, i.e., increased nitrogen remobilization, efficient nitrate assimilation, and robust sink capacity. These conditions will lead the genotypes to respond positively to low nitrogen conditions in maintaining growth and productivity. In comparison, genotypes with less efficient nitrogen remobilization and lower sink capacity will show a reduction in seed filling, biomass, and yield under limited nitrogen availability.

Inpari 42 and its DH lines exhibit shorter, denser panicles than the Inpari 45 variety. The *dep1* allele is reported to be associated with the more upright and denser panicle architecture and identified as a fundamental resource for GSR development (Xu *et al.,* 2015; Yu et al., 2022). The *dep1* gene has pleiotropic effects on nitrogen use efficiency, as shown by the increase in stomatal conductance at lower N fertilization (Li *et al.,* 2023b), the better canopy structure, and the formation of more vascular tissues (Li *et al.,* 2023a).

The productivity of double haploid lines showed a higher value on the recommended fertilization dosage, but it was not significantly different from the productivity under 2/3 dosage fertilization (Table 2). Results at two-thirds of the recommended rate revealed an average yield reduction of 0.29 t/ha or 6.75%, with a 33% reduction in fertilizer application. Therefore, reducing the fertilization dosage to 2/3 of the recommended dosage will not significantly reduce productivity. MS38, MS42, MS45, MS46, and MS51 gave high productivity similar to Inpari 42 and higher than Inpari 45. Further selection continued based on each genotype's performance at 2/3 of the recommended fertilizer dosage to identify the best genotypes with high productivity at lower fertilizer rates.

The tolerance index is one of the selection criteria used to identify genotypes that are tolerant to low fertilization conditions based on their productivity. The tolerance index has been applicable as an indicator of selection under low nitrogen conditions in

Table 4. Average tolerance index of double haploid lines at 2/3 dosage fertilization.

Genotype	YS	YP	GMP	YSI	SSI	YI	MP	TOL	STI
MS36	4.27	3.59	3.91	1.19	-2.82	1.07	3.93	-0.69	0.83
MS37	3.75	4.08	3.91	0.92	1.18	0.94	3.92	0.33	0.83
MS38	4.09	4.82	4.44	0.85	2.23	1.02	4.46	0.73	1.08
MS40	3.62	3.83	3.72	0.94	0.82	0.91	3.72	0.21	0.75
MS41	4.27	3.95	4.10	1.08	-1.19	1.07	4.11	-0.32	0.92
MS42	4.09	4.59	4.33	0.89	1.58	1.02	4.34	0.49	1.02
MS43	3.82	3.67	3.74	1.04	-0.57	0.96	3.75	-0.14	0.76
MS44	3.38	3.96	3.66	0.85	2.16	0.85	3.67	0.58	0.73
MS45	4.84	5.64	5.22	0.86	2.09	1.21	5.24	0.80	1.48
MS46	4.95	4.45	4.70	1.11	-1.65	1.24	4.70	-0.50	1.20
MS47	4.04	3.92	3.98	1.03	-0.44	1.01	3.98	-0.12	0.86
MS49	3.51	3.54	3.52	0.99	0.15	0.88	3.53	0.04	0.68
MS51	3.91	4.75	4.31	0.82	2.60	0.98	4.33	0.84	1.01
MS54	3.66	4.50	4.06	0.81	2.77	0.92	4.08	0.85	0.90
Inpari 42	4.73	5.86	5.27	0.81	2.83	1.18	5.30	1.12	1.51
Inpari 45	2.98	3.41	3.18	0.87	1.86	0.75	3.1	0.43	0.55

Note: YS = Yield on 2/3 fertilizer dosage (t/ha); YP = Yield on recommended dosage (t/ha); GMP = Geometric mean productivity; YSI = Yield stability index; SSI = Stress susceptibility index; YI = Yield index; MP = Mean productivity; TOL = Tolerance index; and STI = Stress tolerance index.

wheat (Tyagi *et al.*, 2020) and sorghum (Ararisa *et al.*, 2024). The YI tolerance index indicates a similar ranking pattern of productivity values at 2/3 of the recommended dosage, with the highest value belonging to MS46 and the lowest to Inpari 45 (Table 4). The GMP, MP, and STI tolerance indices provided a similar ranking pattern to productivity at optimal conditions, with the highest value belonging to Inpari 42 and the lowest to Inpari 45. Higher values and lower rankings indicate better tolerance. Meanwhile, in SSI and TOL values, which disclosed reversed rankings compared with other indices, lower values and higher rankings indicate better tolerance. SSI values less than one imply better tolerance.

Determining the most effective indices as selection criteria for identifying desirable DH lines was successful with the Spearman correlation among all the tolerance indices, calculating yield under 2/3 dosage fertilizer and the recommendation environment. All the tolerance indices showed a strong and high correlation with the yield in stress conditions, except for the TOL index (Figure 1). The STI, MP, YI, and GMP also expressed a high and strong correlation with the yield under the recommended fertilizer. According to Ararisa *et al.* (2024), the MP, GMP, and STI tolerance indices are efficient tolerance indices for use under environmental stress conditions, with the STI tolerance index showing stable values under both stress and non-stress conditions. Bhandari *et al.* (2024) also found these indices offer a comprehensive evaluation, where STI balances yield and stress tolerance, GMP ensures consistency, and MP reflects average performance. They facilitate stable selection across optimal and stress conditions. In this study, the tolerance indices showing a significant positive and strong correlation with productivity under low fertilization conditions and optimum conditions are STI, MP, YI and GMP. The use of these indices in selection will reflect genotype tolerance under low fertilization dosages and yield stability under low and optimal fertilization conditions.

The Multi-Trait Genotype–Ideotype Distance Index (MGIDI) is a selection method with a distance approach between genotypes and ideal ideotypes expected by breeders. This selection method seemed better in determining the selected genotype based on many characters because it can avoid multicollinearity problems. Likewise, the strength and weakness graph can help decide the selected genotype based on the strength and weakness of its characters (Olivoto *et al.*, 2022). Breeders can utilize multiple traits and

Table 5. Principal component, eigenvalues, variance, and cumulative variance in MGIDI.

Principal component	Eigenvalue	Variance (%)	Cumulative variance (%)
PC1	4.83	53.63	53.63
PC2	1.92	21.33	74.96
PC3	1.05	11.66	86.63
PC4	0.87	9.69	96.31
PC5	0.18	2.05	98.37
PC6	0.13	1.42	99.78
PC7	0.02	0.20	99.99
PC8	0.00	0.01	100.00
PC9	0.00	0.00	100.00

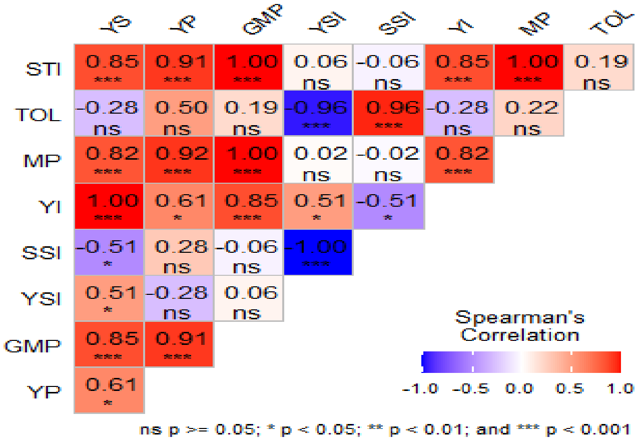

Figure 1. Spearman's correlation for tolerance indices and productivity. YS = Yield on 2/3 fertilizer dosage (t/ha); YP = Yield on recommended dosage (t/ha); GMP = Geometric mean productivity; YSI = Yield stability index; SSI = Stress susceptibility index; YI = Yield index; MP = Mean productivity; TOL = Tolerance index; and STI = Stress tolerance index.

assign weighting to select genotypes with superior agronomic performance, yield, and stress adaptation (Debnath *et al.,* 2024). PC1 to PC8 can explain 100% of the data diversity, where PC1 to PC3 can explain 86.63% of the diversity in the data and eigenvalues above one (Table 5). According to Olivoto *et al.* (2022), the number of factors to be used in MGIDI follows the number of factors with eigenvalues above one. Therefore, in this study, the variables used in the selection will be reduced to three factors of analysis. These factors calculated MGIDI values. By reducing the variables into this group, the selection can be performed simultaneously across all variables while maintaining a balanced ideotype.

The closer the genotype point is to the outer graph, the smaller the distance between the genotype and the target ideotype. The results show the five best double haploid lines, namely, MS38, MS42, MS45, MS46, and MS51 (Figure 2a). MS38, MS42, MS46, and MS51 show high values for FA3, indicating that these genotypes have strengths related to total grain yield and grain-filling percentage (Figure 2b). MS38, MS45, M46, and MS51 reveal strengths in FA2, which correspond to 1000-grain weight and the number of productive tillers. MS45 and MS42 display high values for FA1 compared with other double haploid lines, indicating that these lines demonstrated better performance in productivity and tolerance index traits.

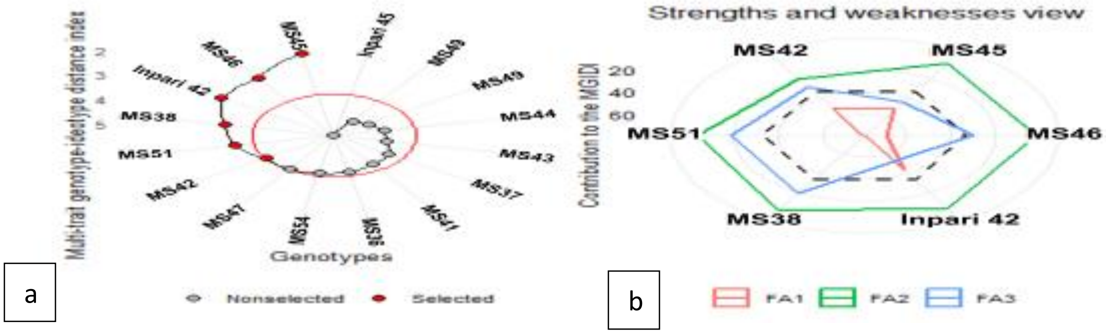

Figure 2. MGIDI selection results (a) Genotype ranking for the selection and (b) The strengths and weaknesses of the selected genotype.

CONCLUSIONS

The rice (*O. sativa* L.) double haploid lines showed the highest productivity under recommended fertilization but were not significantly different from the 2/3 fertilization dosage. Compared with Inpari 45, DH lines displayed shorter plants, higher total grain number, and lower 1000-grain weight. Based on the MGIDI selection, MS38, MS42, MS45, MS46, and MS51 were the best double haploid lines selected, which demonstrated better productivity, yield components, and tolerance index values under the 2/3 fertilizer dosage. These could provide valuable genetic resources for breeding sustainable and low-input rice varieties.

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