

Growth evaluation of F₁ progenies with its parents (Inpago 5(♀) and Inpara 8(♂)), and BC₁F₁ backcross generation development

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ABSTRACT

Oryza sativa is a promising agricultural crop and an important food source for Indonesians. The study aimed to assess the growth of Progenies F₁ and its parents, then backcross F₁×Inpago 5 to obtain Progenies BC₁F₁. This study used a randomized block design (RBD) with three groups, each with five replications. Each replication included three plant units for agronomic character observation. Backcross with three replications, each containing 15 plants from each parent F₁ (♂) and Inpago 5 (♀). The study's findings revealed that both parents' genetics influenced vegetative growth, specifically plant height and total number of tillers in F₁. Inpago 5 (recipient parent) had the highest plant height and the earliest flowering age. Inpara 8 (donor parent) outperforms Inpago 5 and F₁ in terms of number of tillers, number of productive tillers, weight of filled grain, number of grains, number of empty grains, weight of empty grains, weight of filled grain, percentage of filled grain and percentage of empty filled grain, weight of 1000 grains, and dry weight of stover. Then, F₁ on generative variables had moderate values for the number of filled grains, weight of filled grains, percentage of number of filled grains, number of empty grains, weight of empty grains, percentage of number of empty grains, and harvest age. F₁ was determined by the segregation of gene characteristics from its parents. Backcrossing produced 1,448 grains of grain and 1,938 empty grains from a total of 3,386 castrated and pollinated rice flowers. The cross success rate was 42.76%.

Keywords: dual tolerance, drought, introgression, QDTY, Sub-1

INTRODUCTION

Oryza sativa is a potential key agricultural product and food source for Indonesians. In 2023, Indonesia produced 53.98 million tons of dry milled rice and harvested 10.21 million hectares (CSA, 2023). In 2024, Indonesia is expected to produce 52.66 million tons of dry milled rice across a harvest area of 10.05 million hectares (CSA, 2024). Rice production declines due to climate change, which increases floods and droughts. Early drought followed by submergence significantly reduces yield (Revannaswamy et al., 2024). Swamp land rice is vulnerable to rainfall variability, often facing submergence in the vegetative stage and

drought in the generative stage (Irmawati et al., 2015). Due to the delay in flowering and ripening days and grain quantity, this twofold stress has an impact on plant phenology (Wening et al., 2020).

Submergence stress causes metabolic disorders, oxygen deprivation under anaerobic conditions, and inhibited root growth, disrupting photosynthesis (Wang et al., 2024). Rice with the Sub1 gene slows development when submerged to conserve energy reserves (Hasmeda et al., 2022). Rice's survival tactics under submerged conditions include internal aeration and growth control (Oladosu et al., 2020). The Sub1 gene enables rice to tolerate submergence by limiting shoot elongation, conserving energy, and improving recovery (Anumalla et al., 2025).

Shoot growth is reduced during flooding to conserve energy for the 10–14 day submerged period. (Shrirashmi et al., 2024). Drought stress is a significant issue in rice farming, generating morphological, physiological, and biochemical alterations that severely limit plant growth and productivity (Jarin et al., 2024).

Drought stress limits growth by reducing biomass accumulation, chlorophyll content, cell turgor, and leaf water potential (Miftahudin et al., 2020). The study's findings revealed that introgressing Sub1 into rice lines with drought resistance QTL (qDTY; QTL=quantitative trait loci) can result in the establishment of high-yielding rice lines that are resistant to drought and submergence.

Sub1 enhances post-drought recovery during the vegetative stage by reducing leaf water loss and lipid peroxidation, increasing ABA expression, and suppressing ROS production, thereby improving oxidative stress tolerance (Amjad et al., 2022). Tolerant genotypes can maintain or enhance biomass as well as root growth when stressed (Singh et al., 2014). The interrogation of Sub-1 and QDY has been found to improve survivability. Sub-1 also plays an important function in drought resistance (Asmuni et al., 2021). In prior research, F₁ offspring were produced by crossing the Inpago 5 variety with the Inpara 8 variety, which had the Sub-1 gene and was resistant to submersion stress during the vegetative stage (Suwignyo et al., 2021). Inpago 5 is the most yielding and drought-tolerant variety during the generative phase (Rusdan, 2020). A backcross population is created by crossing the recipient parent (RP) with the donor parent to produce F₁ accessions, which are subsequently crossed with the RP to form the first backcross generation (BC₁F₁). Backcross children carrying the target trait must be chosen based on the phenotype of each cross evaluation (Hasan et al., 2015). Backcrossed lines had much higher submergence stress tolerance and recovery rates than their parents and were used in recombinant selection (Adriansyah et al., 2021). Backcross lines showed improvements in agronomic parameters such as the number of tillers, percentage of filled grain, productive tillers, and percentage of tiller numbers (Adriansyah et al., 2022). Thus, crossing

drought- and submergence-tolerant rice is a successful technique for combining multiple adaptive characteristics. The objective of this research was to examine the growth evaluation of F₁ progenies and their parents (Inpago 5 (♀) and Inpara 8 (♂)) and BC₁F₁ offspring with dual drought and submerged stress tolerance features.

MATERIALS AND METHODS

Preparation

Preparation comprises the following: preparation of planting media, planting materials, seedbeds, planting, plant maintenance, backcrossing, and harvesting. Soil samples were collected from non-tidal swampland in the Agriculture Faculty's observation area at Universitas Sriwijaya, Indralaya. Plant materials include F₁, Inpago 5, and Inpara 8 seeds.

Backcrossing

Backcrossed F₁ (♂) rice with Inpago 5 (♀) rice and obtained BC₁F₁ progenies in the Greenhouse of the Agronomy Study Program, Faculty of Agriculture, Sriwijaya University. Backcrossing using F₁ (♂) offspring with Inpago 5 (♀). F₁ was the result of crossing Inpago 5 (♀) rice with Inpara 8 (♂) rice as the donor parent of the Sub1 (♂) gene.

Variables observed in the Growth evaluation

Variables observed include yield component and crossing variables. Plant height, number of tillers per clump, number of productive tillers per clump, number of grains per panicle, number of full grains per clump, number of empty grains per clump, weight of grain per panicle (g), weight of 1000 grains of grain (g), Weight of filled grain per clump, weight of empty grain per clump, wet weight (g), dry weight (g), percentage (%) of filled grain per clump, percentage of empty grain per clump, flowering age, harvest age, and dry weight of stover. The crossing variables include the number of filled grains, the number of vacant grains, the percentage of filled grains, and the percentage of empty grains.

Data Analysis

For agronomic character observations, this study used a randomized block design (RBD)

with three groups, each including five replicates of three treatments. Backcrossing were conducted in three replicates, with 15 plants for each F₁ (♂) and Inpago 5 (♀) parent. The collected data were examined using the analysis of variance (ANOVA) method. If the estimated F value exceeds the F table value at the 5% test level, it indicates that the treatment has a significant effect. To determine differences between treatments, additional testing was performed using the least significant difference (LSD) test method at the 5% test level with SAS software. Based on the results of the diversity of growth evaluation and backcrosses of F₁, Inpara 8, and Inpago 5 during generative growth, it showed no significant effect on the variables of the number of grains per hill, the number of grains per panicle, the number of filled grains, the weight of 1000 grains, and the dry weight of the stover. However, the treatment significantly affected the number of productive tillers, flowering age, harvest age, number of empty grains (grains), weight of filled grains (g), weight of empty grains, percentage of filled grains, and percentage of empty grains (%) version 9.0.

RESULTS

Number of Tillers

Statistically, the number of tillers differed considerably at 28 DAT and 42–56 DAT (Table 3). Inpara 8 had the largest average number of tillers, at 9 (Table 3). Based on the diversity analysis of growth evaluation and the results of the F₁, Inpago 5, and Inpara 8 crossings during vegetative growth, it had no significant effect on

plant height variables but did significantly affect the number of tillers at 28 Days after transplanting (DAT).

This suggests that genetic variations between genotypes had little influence on vertical development during the early vegetative phase, implying that plant height remained largely steady among genotypes under similar environmental conditions. However, the considerable variance in tiller count suggests that tiller production is a more sensitive indicator of genetic and physiological variations during vegetative development. A considerable increase in tiller number at 28, 42, and 56 DAT suggests hybrid vigor (heterosis) in the F₁ generation for the vegetative stage (Table 1).

This suggests that genetic variation among the genotypes significantly influenced reproductive development and yield components more than it affected grain number or total biomass accumulation. The considerable influence observed in blooming and harvest age implies that each genotype has different genetic processes governing maturity duration and reproductive transition, which could be valuable for choosing lines adapted to specific environments (Table 2).

Plant Height

Plant height did not differ considerably amongst rice plants. Plant height increased steadily each week until 70 days following planting (Figure 1). From 28 to 70 days after planting, Inpara 8 outperformed the F₁ and Inpago 5 treatments in average height.

Table 1. The calculated F value and coefficient of variation of all observed vegetative variables of F₁, Inpago 5, and Inpara 8

Variables	F value				Coefficient of Variation (%)
	Treatment		Group		
Plant Height					
28 DAT	1.56	ns	0.91	ns	8.52
42 DAT	4.97	ns	0.11	ns	4.88
56 DAT	1.16	ns	1.96	ns	2.58
70 DAT	1.58	ns	3.31	ns	3.26
Number of Tillers					
28 DAT	73.68	**	1.68	ns	10.37
42 DAT	12.72	*	0.03	ns	0.03
56 DAT	16.43	*	1.17	ns	7.88

Note: * = significant at the level $p < 0.05$; ** = very significant at the level $p < 0.01$; ns = not significant

Table 2. The calculated F value and coefficient of variation of all observed generative variables of F₁, Inpago 5, and Inpara 8

Variables	F value				Coefficient of Variation (%)
	Treatment		Group		
Number of Productive Tillers	34.94	**	1.97	ns	8.39
Flowering Age (Days)	63.92	**	0.22	ns	0.98
Harvest Age (Days)	277.00	**	0.63	ns	0.42
Wet Weight of Grain (g)	11.56	*	4.87	ns	11.85
Dry Weight of Grain (g)	11.57	*	4.07	*	16.98
Number of Filled Grain (Grains)	2.38	ns	2.48	ns	24.94
Number of Grains per Panicle (Grains)	34.23	ns	3.5	ns	4.16
Number of Filled Grain (Grains)	4.59	ns	1.64	ns	16.47
Number of Empty Grain (Grains)	18.35	**	1.83	ns	15.91
Weight of Filled Grain (g)	556.48	**	26.23	**	1.03
Weight of Empty Grain (g)	40.89	**	2.21	ns	8.19
Percentage of Filled Grain (%)	87.15	**	0.62	ns	3.08
Percentage of Empty Grain (%)	87.15	**	0.62	ns	5.58
Weight of 1000 Grains (g)	0.31	ns	9.46	*	0.75
Dry Weight of Biomassa (g)	1.96	ns	1.08	ns	16.33

Note: * = significant at the level $p < 0.05$, ** = very significant at the level $p < 0.01$, ns = not significant

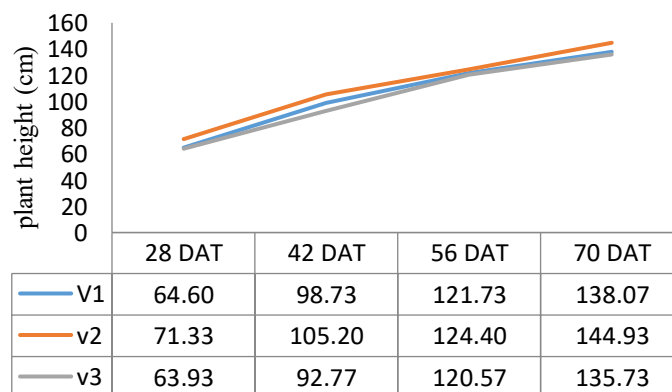


Figure 1. Average height of rice at 28 HST to 70 HST of F₁, Inpago 5, and Inpara 8. Note : DAT (Days after transplanting), V₁ : F₁, V₂ : Inpago 5, and V₃ : Inpara 8

Table 3. Number of tillers pada evaluasi of F₁, Inpago 5, and Inpara 8

	Number of Tillers		
	28 DAT	42 DAT	56 DAT
V ₁	2.20 _b	5.00 _b	6.40 _b
V ₂	2.87 _b	5.33 _b	6.93 _b
V ₃	5.67 _a	7.73 _a	9.00 _a
BNT _{5%}	0.84	1.64	1.33

Note: V₁: F₁, V₂: Inpago 5, V₃: Inpara 8, Means followed with the same letters within rows are not significantly different based on the LSD at $p < 0.05$

Number of Productive Tillers, Flowering Age (Days) and Harvest Age (Days)

Statistically, the number of productive tillers, flowering age, and harvest age all had a significant impact on each rice. Inpara 8 had the most productive tillers, averaging 10.13, while F₁ had the fewest, averaging 5.93. Inpara 8 had the longest flowering age, averaging 77.67, while Inpago 5 had the shortest, an average of 70.93. Inpago 5 had the highest harvest age, averaging

124.87, while Inpara 8 had the smallest harvest age, an average of 115.20 (Table 4).

This study shows that Inpara 8 has higher vegetative vigor and tillering capacity, both essential for prospective yield development. The reduced number of tillers in F₁ may indicate partial dominance or unstable genetic segregation. The intermediate flowering time of F₁ reflects a mix of both parental traits, allowing for considerable flexibility. Inpara 8 finishes its growth cycle faster. In contrast, Inpago 5's longer

growth time allows for sustained photosynthetic activity and biomass accumulation.

Wet Weight of Grain (g), Dry Weight of Grain (g), Number of Grains per Clump (Grains), and Number of Grains per Panicle (Grains)

Statistically, both the wet and dry weights of grain had a significant effect on each plant. Inpara 8 had the largest wet weight of grain, averaging 29.60, while F₁ had the lowest weight, averaging 18.63. Inpara 8 had the largest dry weight of grain, averaging 16.63, while F₁ had the lowest, averaging 1240.20. The amount of grains per hill and per panicle had no significant impact on either plant. Inpara 8 had the most grains per hill, with an average of 1867.80, while F₁ had the least weight, averaging 1240.20. Inpara 8 had the most grains per panicle, averaging 200.17, while F₁ had the fewest, an average of 150.89 (Table 5). These findings show that Inpara 8 is more efficient at partitioning and translocating assimilates to grains during the reproductive stage, resulting in greater dry matter accumulation. Inpara 8's increased grain mass suggests greater sink capacity and photosynthetic activity compared to Inpago 5 and F₁. The poorer performance of F₁ in both grain weight and grain number parameters may indicate that the heterosis effect was not completely realized in the first filial generation.

Number of Filled Grain (Grains), Number of Empty Grain (Grains), Weight of Filled Grain (g), and Weight of Empty Grain (g)

Statistically, the quantity of empty grains, weight of filled grains, and weight of empty grains varied substantially between plants. The Inpago 5 treatment had the most empty grains 658.50, while Inpara 8 had the fewest 297.67. Inpara 8 had the highest filled grain weight 56.03, while Inpago 5 had the lowest weight 43.49. The quantity of grains did not differ considerably between the plants. The Inpara 8 treatment had the most full grains 1008.30, whereas Inpago 5 had the fewest 712.00. The Inpago 5 treatment had the highest empty grain weight, averaging 8.59, while Inpara 8 had the lowest, averaging 3.62 (Table 6). Overall, the results show that Inpara 8 had the best features in terms of filled grain weight, while Inpago 5

performed poorly. The F₁ hybrid had intermediate results, indicating partial inheritance of beneficial features from both parents.

Percentage of Filled Grain (%), Percentage of Empty Grain (%), Weight of 1000 Grains (g), and Dry Weight of Biomassa (g)

Statistically, the percentages of filled and empty grain had a significant effect. Inpara 8 had the largest proportion of full grain, averaging 74.92, while Inpago 5 had the lowest percentage, an average of 53.567. Inpago 5 had the highest percentage of empty grain, with an average weight of 1000 grains, and the stover's dry weight had no significant effect. Inpara 8 had the highest 1000 grain weight, averaging 24.97, while F₁ had the lowest weight, an average of 24.49. Inpara 8 had the highest biomass dry weight, averaging 27.19, while F₁ had the lowest, averaging 21.07 (Table 7). The results revealed that the percentages of filled and empty grains varied dramatically among the three genotypes, showing a major genetic influence on grain-filling capacity. Inpara 8 had the highest proportion of filled grains and the lowest percentage of empty grains, indicating better fertilization effectiveness and assimilate transfer than Inpago 5 and F₁. Although the weight of 1000 grains and dry biomass did not differ considerably, Inpara 8 consistently had the highest numerical values for both parameters, indicating superior physiological performance and resource use. Thus, Inpara 8 showed excellent reproductive and developmental traits.

Observed Variables in Backcrossing Number of Filled Grains and Number of Empty Grains

All of the crossed rice yielded 1448 full grains and 1938 empty grains from 3386 castrated and pollinated rice blossoms. The effectiveness of fertilization and grain filling in backcross generation was moderate. The comparatively high frequency of empty grains in the backcross generation could be attributable to a variety of physiological and genetic causes. Incomplete fertilization or incompatibility between parental lines may have lowered embryo development success rates. Environmental stress during flowering, such as variable temperature or humidity, may also have affected pollen viability

and stigma receptivity, resulting in inadequate fertilization (Figure 2).

Percentage of Filled Grain and Percentage of Empty Grain

The percentage of filled grain or successful crossbreeding was 42.76% of the grains created, while the percentage of empty grain was 57.24% of the grains that did not form. Furthermore, reduced assimilate transfer during the grain-

filling stage may have led to empty grain production, as developing seeds compete for available carbohydrates. These data indicate that, while the backcrossing method produced viable grains, more improvements in genetic compatibility, flowering synchrony, and nutrient allocation efficiency are required to improve reproductive success and yield stability of the progenies (Figure 2).

Table 4. Number of productive tillers, flowering age (days), and harvest age (days) of F₁, Inpago 5, and Inpara 8

	Number of Productive Tillers	Flowering Age (Days)	Harvest Age (Days)
V ₁	5.93 _b	74.00 _b	120.33 _b
V ₂	6.93 _b	70.9 _c	124.87 _a
V ₃	10.13 _a	77.67 _a	115.20 _c
BNT _{5%}	1.46	1.66	1.14

Note: V₁: F₁, V₂: Inpago 5, V₃: Inpara 8, Means followed with the same letters within rows are not significantly different based on the LSD at $p < 0.05$

Table 5. Wet weight of grain (g), dry weight of grain (g), number of grains per clump and number of grains per panicle (grains) of F₁, Inpago 5, and Inpara 8

	Wet Weight of Grain (g)	Dry Weight of Grain (g)	Number of Grains per Clump	Number of Grains per Panicle (Grains)
V ₁	18.63 _b	8.85 _b	1240.20 _a	150.89 _c
V ₂	22.97 _b	10.85 _b	1370.30 _a	182.94 _b
V ₃	29.60 _a	16.63 _a	1867.80 _a	200.17 _a
BNT _{5%}	6.37	4.66	843.90	16.78

Note: V₁: F₁, V₂: Inpago 5, V₃: Inpara 8, Means followed with the same letters within rows are not significantly different based on the LSD at $p < 0.05$

Table 6. Number of filled grain (Grains), number of empty grain (Grains), weight of filled grain, and weight of empty grain (g) of F₁, Inpago 5, and Inpara 8

	Number of Filled Grain (Grains)	Number of Empty Grain (Grains)	Weight of Filled Grain (g)	Weight of Empty Grain (g)
V ₁	729.00 _a	433.33 _b	49.79 _a	6.83 _b
V ₂	712.00 _a	658.50 _a	43.49 _c	8.59 _a
V ₃	1008.30 _a	297.67 _b	56.03 _b	3.62 _c
BNT _{5%}	304.90	167.06	1.09	1.55

Note: V₁: F₁, V₂: Inpago 5, V₃: Inpara 8, Means followed with the same letters within rows are not significantly different based on the LSD at $p < 0.05$

Table 7. Percentage of filled grain (%), percentage of empty grain (%), weight of 1000 grains (g), and dry weight of biomass (g) of F₁, Inpago 5, and Inpara 8

	Percentage of Filled Grain (%)	Percentage of Empty Grain (%)	Weight of 1000 Grains (g)	Dry Weight of Biomass (g)
V ₁	64.87 _b	35.13 _b	24.49 _a	21.07 _a
V ₂	53.57 _c	46.43 _a	24.69 _a	26.15 _a
V ₃	74.92 _a	25.08 _c	24.97 _a	27.19 _a
BNT _{5%}	4.49	4.49	1.70	9.18

Note: V₁: F₁, V₂: Inpago 5, V₃: Inpara 8, Means followed with the same letters within rows are not significantly different based on the LSD at $p < 0.05$

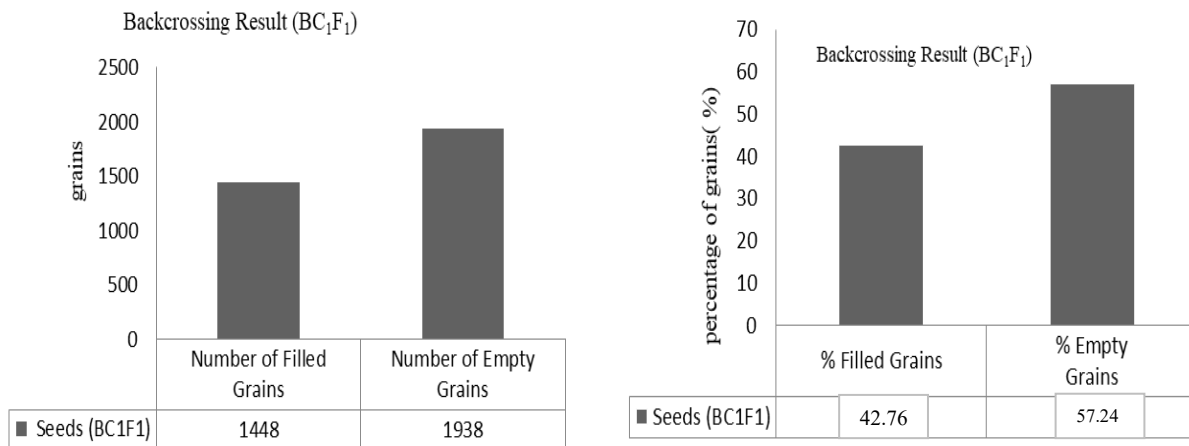


Figure 2. Number and % of filled grains empty grains from backcrossing result

DISCUSSION

Agronomic Characteristics

Current rice breeding progress is centered on reaching appropriate rice height, making plant height an important factor in plant breeding efforts. This is because plant height determines the amount of lodging a plant exhibits. The average plant height at 70 days following planting ranged between 135.73 and 144.93 cm (Figure 1). IRRI (2013) defines upland rice plant height using the Rice Standard Evaluation System as short (<90 cm), medium (90–125) cm, and tall (>125 cm). The average observed plant height ranged from 135.73 to 144.93 cm, demonstrating that tall plants are susceptible to lodging if not supported by a strong stem structure (Aswidinnoor et al., 2023).

The average F₁ value for plant height was lower than those for Inpago 5 and Inpara 8. Short plants are a standard for rice quality. Plants with too tall stems are prone to topple over, whereas shorter plants are typically more resistant to wind or rain pressure (Djurhuus et al., 2025). The F₁ mean was lower than that of Inpago 5 and Inpara 8, showing that the crosses produced offspring with more moderate stem size, which supports possible lodging resistance. Modern breeding tries to optimize plant height to balance growth and stress resistance by applying genetic haplotypes that govern plant height, so ensuring optimal production while avoiding excessive lodging (Quan et al., 2024).

Table 3 shows the average number of tillers per rice plant. The number of tillers per rice plant is divided into three categories: few (<10),

moderate (11–15), many (16–20), and very many (>20). The observations indicate that the total number of tillers observed falls into the low tiller group (<10). The quantity of tillers is heavily influenced by genetic and environmental factors like as rainfall, cultivation practices, planting distance, and nutrient availability. The quantity of tillers is determined by the formation and growth of tiller shoots (Quan et al., 2024).

Not all rice tillers will become productive. Total tillering affects the number of productive tillers. Differences in the number of tillers produced during the vegetative phase are impacted more by the plant's genetic features or by the sensitivity of the variety and promising line to environmental conditions. Nonproductive tillers are one of the factors influencing yield. The more non-productive tillers there are, the more humid the microclimate becomes, making pests and diseases more likely to thrive. The Inpara 8 treatment had the most productive tillers, with an average of 10.13; the F₁ treatment had the fewest, with an average of 5.93 (Table 4). The number of productive tillers determines the number of grains per plant, and consequently the production yield; the more productive tillers, the higher the output (Purwanto et al., 2023).

The number of grains per panicle is an indicator of rice plant yield; the more grains per panicle, the higher the yield. The average number of complete grains in the observations ranged between 712.00 and 1008.30 grains. The Inpara 8 treatment yielded the most loaded grains. In general, the number of grains per panicle is determined by two elements: genetics, such as the number of leaves, and environmental factors,

such as low temperatures and limited light availability during panicle formation. According to agronomic evaluation, the number of productive tillers, panicle length, and percentage of full grain all have a significant impact on grain yield per panicle (Das et al., 2022). Pests and diseases can cause a decrease in the amount of complete grains in certain plants. Pest and disease attacks can contribute to whole grain loss, resulting in discolored and chalky rice (Chen et al., 2021). The average weight of whole grain ranged between 43.49 and 56.03 g. The Inpara 8 treatment had the highest average whole-grain weight, at 56.03 g. Grain weight is heavily regulated by post-flowering factors such as leaf number, photosynthate availability, and weather. This will alter the amount of carbohydrates produced by photosynthesis, as well as the grain's shape and size. The form of the grain influences the resulting grain weight (Elvina et al., 2023). Round and large grains will have a higher weight than oval and flat grains. Grain weight is greatly influenced by the efficiency of grain filling after flowering. Varieties with tolerance to water stress are able to maintain photosynthates during the grain filling phase, resulting in higher grain weight (Amjad et al., 2022).

The average weight of empty grain ranges between 3.62 and 8.59. Inpago 5 has the largest empty grain weight 8.59 g, while Inpara 8 has the lowest weight 3.62 g (Table 6). The number of empty grains is regulated by both hereditary and non-genetic causes, and emptiness in new rice varieties is generated by an imbalance between sink and supply. The rice grain is the economically valuable section of the rice plant. The rice plant's efficacy is determined by the grain weight to total biomass ratio, which is regulated by photosynthesis results absorbed into the grain (Kumar et al., 2018).

Inpara 8 had the highest average 1000-grain weight at 24.97. The data is shown (Table 6) The 100-grain weight is proportional to the quantity and size of grains; the larger the grain size, the higher the 100-grain weight. The greatest 1000-grain weight of Inpara 8 grain has a favorable correlation with grain size and yield (Mohanavel et al., 2024). Large grain size is a trait of excellent cultivars that promotes high yield since

it shows good carbohydrate buildup (Wu et al., 2021).

F₁ progeny from crossings between various lines exhibit heterosis for several agronomic parameters, including plant height, stalk height, number of productive tillers, grain count per panicle, and grain weight per hill. The size of the growth varies. Heterosis in F₁ rice is caused by heterozygosity, which combines complementary alleles from both parents. Selecting genetically compatible parental pairings increases the likelihood of obtaining F₁ with high vigor (Gu et al., 2023). Changes in each component are determined by the combination of parental abilities and genetic background (Tao et al., 2016). Rice breeding selects homozygous individuals with the desired gene combination to ensure stability in the next generation, despite the fact that F₁ is typically heterozygous (Zhou et al., 2012).

Allelic recombination causes significant phenotypic segregation in F₁, leading to varied trait distribution. This shows that high F₁ yields do not necessarily sustain without a selection procedure (Dan et al., 2015). Stress can cause heterosis in F₁, but this is not always the case. The stability of tolerance is determined by the parents' genetic features as well as the complexity of the tolerance trait (polygenic). In addition, genes and the environment play important roles (Gu & Han, 2024). The agronomic resemblance of offspring to male or female parents is determined by genetic factors such as additivity, dominance, and epistasis. If a trait is governed by additive genes, the kids will typically fall somewhere between the male and female parents. If dominance exists, offspring will be more similar to the parent with the dominant allele (Shen et al., 2014).

The heritability of plant height, productive tillers, panicle weight, and number of grains per panicle suggests that these traits can be utilized as selection criteria in breeding rice that is tolerant to submergence stress (Aparajita et al., 2016). Sub1 helps to slow down chlorophyll breakdown during immersion, allowing plants to photosynthesize while light is still available (Suwetha et al., 2025). Variables in vegetative growth, such as plant height and total number of tillers, reveal that F₁ is influenced by both

parents' DNA. Compared with Inpara 8 and F₁, Inpago 5 (receiving parent) has the greatest plant height and the earliest flowering age. Inpara 8 (donor parent) has the highest values in the variables of number of tillers, number of productive tillers, weight of filled grain, number of grains, number of empty grains, weight of empty grains, weight of filled grain, percentage of filled grain, percentage of empty filled grain, weight of 1000 grains, and dry weight of stover compared to Inpago 5 and F₁. Then F₁ analysis revealed moderate values for the following generative variables: number of filled grains, weight, percentage of filled grains, number of empty grains, weight, percentage of empty grains, and harvest age. This suggests that F₁ showed the segregation of gene characteristics from its parents.

Backcrossing

All crossed rice produced 1448 full grains and 1938 empty grains from a total of 3386 castrated and pollinated rice blossoms. The percentage of successful cross-breeding was 42.76% of the grains produced. Cross-breeding success was determined by flower condition as well as the cross-breeder's precision and ability. Cross-pollination is also influenced by environmental conditions like as high temperature and low humidity, as well as light intensity and wind speed. Rain often occurs during cross-pollination, causing high cross-pollination failure due to high humidity. The success rate for manual backcrossing is typically between 30 and 50%, depending on anthesis synchronization and pollen viability (Mohanavel et al., 2024). The key element impacting this success is the short pollen viability time of approximately 30 minutes following dehiscence, which means that delayed pollination can diminish the success rate (Wu et al., 2021).

High grain yield and low fertile pollen yield are caused by both damaged male and female gametes. If the female gametes are healthy, more viable seeds can be generated. The low success rate of crossbreeding is strongly linked to flower condition. These include flower drop before or after fertilization, insufficient pollen production, non-viable pollen, male sterility, and self-incompatibility. Several factors influence rice

flower crossing and fertilization, including the timing of female receptivity and male anthesis. The pistil receptivity time in rice flowers ranges between 3 and 7 days. Under typical conditions, pollen viability begins to fade within 5 minutes of dehiscence from the anther, and is totally lost within 30 minutes. Other considerations include the crossbreeder's lack of experience, compatibility between the two parents, and the timing of the crossbreeding. Efforts to combine submergence tolerance via the Sub1 gene from Inpara 8 and drought tolerance via Inpago 5 are critical in dealing with climate variability in the swamp ecosystem. Adding Sub1 to the drought tolerance QTL qDTY improves yield stability under stress circumstances (Asmuni et al., 2021).

CONCLUSION

The study's findings revealed that both parents' genetics influenced vegetative growth, specifically plant height and total number of tillers in F₁. Inpago 5 (the recipient parent) had the highest plant height and the earliest flowering age when compared to Inpara 8 and F₁. Inpara 8 (donor parent) has the highest value in the variables of number of tillers, number of productive tillers, weight of filled grain, number of grains, number of empty grains, weight of empty grains, weight of filled grain, percentage of filled grain, percentage of empty filled grain, weight of 1000 grains, and dry weight of stover when compared to Inpago 5 and F₁. F₁ analysis revealed moderate values for the following generative variables: number of filled grains, weight, percentage of filled grains, number of empty grains, weight, percentage of empty grains, and harvest age. This suggests that F₁ showed the segregation of gene characteristics from its parents. F₁ plants were used for the first generation backcross (BC₁F₁). Backcrossing resulted in 1448 full grains and 1938 empty grains from a total of 3386 castrated and pollinated rice flowers. The crossing was successful with 42.76% of the grains produced. The findings (BC₁F₁) were molecularly chosen using the Marker-Assisted Backcrossing (MABC) approach to obtain the best plants with the Sub1 gene and agronomic characteristics most similar to Inpago 5 for further investigation.

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