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Research article

Assimilate Partitioning and Agronomic Performance of Floating Rice in Flood-Prone Ecosystems of Indonesia

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Abstract

Rice cultivation in flood-prone areas often results in a decrease in yield and crop failure. The Floating Rice Field (FRF) method is a strategy to increase plant resilience while improving rice production in flood-prone areas. The choice of the right seedling makes it easier for plants to adapt to the FRF method, improving physiological traits, growth, and yield. The aim of this research was to investigate the effects of seedling age on the agronomic performance and assimilate partitioning of rice planted using the FRF method in the flood-prone areas. A field experiment was conducted in Pangandaran, Indonesia. The study was arranged as a 2x2 factorial randomized complete block design with seedling age (14 DAS and 21 DAS) as the first factor and rice variety (Inpari 3 and Inpari 30 Ciherang Sub 1) as the second factor with four replications. There was no interaction between seedling age and rice variety for all parameters observed. Seedling age significantly affected total chlorophyll, plant height, number of grains per panicle, percentage of filled grain, and harvest yield. Furthermore, rice variety only affected plant height and harvest yield. Although 21 DAS resulted in higher plants, 14 DAS showed better physiological performance and productivity. Specifically, 14 DAS seedlings had higher total chlorophyll content, more grains per panicle, a greater percentage of filled grain, and higher harvest yield. The Inpari 3 rice variety produced lower plant growth and harvest yield than Inpari 30 Ciherang Sub 1 rice variety. In correlation analysis, total chlorophyll content caused an increase in the percentage of filled grain and harvest yield (r= 0.53 and r= 0. 28), while plant height caused a decrease in harvest yield (r= -0.30).

Keywords: agronomic traits; assimilate; chlorophyll; flood-prone; floating rice field

1. Introduction

Flood-prone agricultural land is due to various factors such as small soil pores and poor drainage (Rupngam & Messiga, 2024). Climate change has worsened flooding conditions in agricultural areas, especially those near the coast (Magnan et al., 2022). As we know, climate change causes sea levels to rise and causes abiotic stresses such as flooding and salinity (Bayabil et al., 2021). In addition, agricultural areas close to large rivers are often

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affected by water overflows and cause flooding. Chen et al. (2021a) reported that in Asian countries, the number of flood-prone agricultural areas reached more than 22 million hectares. In Indonesia, many flood-prone agricultural areas extend across extensive swamplands, measuring approximately 13.28 million hectares. Of this, approximately 8.88 million hectares suitable for agriculture, yet only 1.55 million hectares currently support paddy cultivation (Hairani et al., 2024).

Flood-prone agricultural areas can be used for rice production amidst high land conversion. However, these lands have several constraints, such as limited O_2 in the soil due to waterlogging and variations in water level with uncertain times. These constraints cause plant growth disorders and decrease rice yield or crop failure (Gui et al., 2024). Bui et al. (2019) reported that waterlogging in rice plants generally causes shoot elongation, which impacts limited stored carbohydrates. Furthermore, the limited exchange of O_2 and CO_2 gases causes a decrease in the photosynthesis rate (Yang et al., 2017), disruption of ATP synthase activity (Kaur et al., 2020), degradation of natural pigments (Gan et al., 2020), and decrease in plant biomass which lead to low grain filling rates (Panda & Barik, 2021).

Previous studies utilized flood-tolerant rice varieties, which demonstrated improved survival and yield under flooding conditions, to enhance rice production in flood-prone areas (Anandan et al., 2015). Proud et al. (2023) carried out the fertilization balancing under wet-dry irrigation application so plants could grow and develop optimally (Liang et al., 2022). However, in submergence conditions, these technologies are impossible to apply. Therefore, the floating rice field (FRF) can be a strategy for rice cultivation in flood-prone areas. Pangandaran Regency is one of the areas where agricultural land is often flooded due to overflow of the Citarum river and sea tides. The water level in this area can reach 1.5 m and cause crop failure (Nasrudin et al., 2025a).

Several studies examining the application of FRF are still limited. Haque et al. (2016) reported that flood-prone areas in Bangladesh were utilized as floating gardens to produce horticultural commodities. In Myanmar, Intha farmers are famous for their floating agricultural island for cultivating tomatoes and some fruits (Oo et al., 2022). Furthermore, Nguyen and Pittock (2016) reported that several countries such as Bangladesh, Myanmar, Vietnam, Cambodia, Thailand, and various countries in West Africa have implemented floating systems for agricultural production, including rice commodities. In Indonesia, FRF can increase plant adaptation to abiotic stress (Irianto et al., 2021). Other studies reported that FRF could increase rice growth and productivity by up to 50% compared to planting under flooding conditions (Irianto et al., 2018). Mujiyo et al. (2022) reported that applying FRF in Bojonegoro Regency minimized the loss of rice yield in flood-prone areas due to overflowing of the Bengawan Solo River. The composition of planting medium in soil and rice husks resulted in the highest harvest yield compared to soil with organic fertilizer or soil with rice husks and organic fertilizer.

The application of FRF in flood-prone areas involves the use of rafts made of bamboo and planting medium such as cocopeat, leaf litter, and mud with a height of 5 cm. Furthermore, floats are installed to support the raft so that it follows the rise and fall of the water. The shallow planting medium in FRF requires that the transplanted rice seedlings have been able to adapt to the environment. In addition, strong wind can cause rice plants to fall, grow inadequately, and disrupt physiological activity. This condition reduces biomass accumulation, causing the sink received by the grain to be low and productivity to decrease (Wu et al., 2019). Therefore, the right seedling age is needed for plants to grow and develop optimally. Afrinda and Kurniasih (2021) reported that young seedlings of age 14 DAS gave better vegetative growth and chlorophyll content, but older seedlings (28 DAS) were more tolerance to abiotic stress. Other studies reported that rice planted hydroponically at the age of 13-20 DAS showed an increase in photosynthesis rate, biomass production, and harvest yield compared to 27 DAS (Li et al., 2016).

Superior varieties can be used in this FRF method so that rice plants can optimally produce. Nasrudin et al. (2025b) reported that the Banyuasin variety produced the highest chlorophyll content and harvest index for rice grown on organic matter under abiotic stress. Another variety potentially used for rice cultivation in FRF is Inpari 3. Inpari 3 has a potential yield of 7.52 tons ha^{-1}, and it can be planted on irrigated land at an altitude of 600 m above sea level (masl) (Ministry of Agriculture-Indonesia, 2015). According to the problems described previously, a study regarding seedling age planted usings the FRF method is needed. A similar study has not been found, and other studies examining FRF are still limited. Therefore, in this study, a strategy to mitigate rice crop failure in flood-prone areas using FRF was investigated. A field experiment to reveal and investigate the effects of seedling age on agronomic performance of rice planted using the FRF method in the flood-prone area of Pangandaran Regency was conducted.

2. Materials and Methods

2.1 Study area and experimental design

The field experiments were carried out at flood-prone rice fields in Karangjaladri village, Pangandaran Regency (7°41'37.7"S 108°30'49.9"E) from May to October 2022. The study site was 1 km from the coastline which can be seen in Figure 1. The experiment was arranged as a 2x2 factorial randomized complete block with two factors and four replications. Seedling ages was the first factor, consisting of 14 and 21 days after sowing (DAS). Rice variety was the second factor, consisting of Inpari 3 and Inpari 30 Ciherang Sub 1. Inpari 3 has a harvest age of 110 days, a plant height of 95-100 cm, upright flag leaves, and a potential yield of 7.52 t ha^{-1}. It is suitable for irrigated rice fields at altitudes up to 600 m above sea level. In comparison, Inpari 30 Ciherang Sub 1 has a harvest age of 111 days, a plant height of 101 cm, upright flag leaves, and a higher potential yield of 9.6 t ha^{-1}. It is suitable for planting in both irrigated rice fields and flood-prone areas.

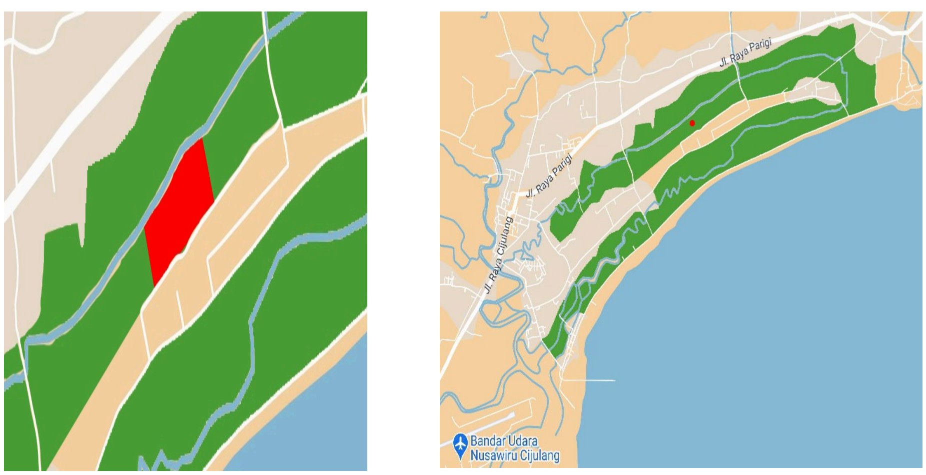

Figure 1. The experiment area in Pangandaran, the red color indicates the study site.

2.2 Procedures

FRF is constructed of bamboo with a length of 5 m and a width of 2 m. A total of four points on the raft bottom are installed with jerry cans with a volume of 25 L as floats so that the movement of the FRF can adjust to the rice and fall of the water level. The planting medium contains cocopeat, mud, and leaf litter with a maximum height of 5 cm. An illustration of the FRF is in Figure 2.

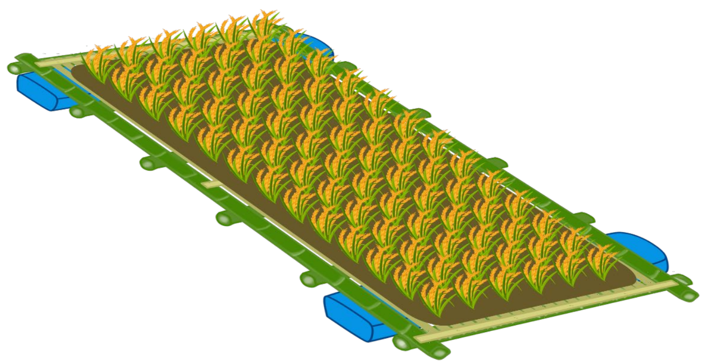

Figure 2. Illustration of FRF used in this study

The rice seed varieties were sown on land and maintained until the seedling age based on treatment was acquired. Rice seedlings in the 21-DAS were transplanted seven days earlier than those in the 14-DAS. The seedlings were transplanted to FRF in the morning using a planting distance of 25 cm x 25 cm. Each hole was filled with two seedlings. The maintenance carried out included chemical control of plant pest disease. Foliar fertilization was carried out using Gandasil-D, which contained 20% N, 15% P2O5, 15% K2O, 1% MgSO4, and several micronutrients, including Mn, B, Cu, Co, and Zn, at a concentration of 30 g L^{-1}. Fertilization was carried out every two weeks from the age of 2 weeks after planting (WAP) until entering the generative phase. The rice was harvested when 90% of the grains were physiologically ripe, which was indicated by the yellowing of the grains and the drying of the leaves. Harvest process was done manually using a sickle in the morning. Furthermore, the grains were then dried under the sun and taken to the laboratory to observe the yield and yield component variables.

2.3 Agronomic traits and assimilate partitioning variables

The variables observed included chlorophyll content, measured at the early heading stage (8 WAP). Determination of chlorophyll content was conducted using the Arnon (1949) method. Leaf samples of 1 g were pounded using a mortar until smooth. As much as 20 mL of 80% acetone was added and stirred until homogenous and filtered using Whatman No. 40 filter paper. Four mL of the filtrate was pipetted into a cuvette and the absorbance at 645 nm and 663 nm was measured using a UV-VIS 752AP spectrophotometer. The calculation of total chlorophyll content was performed using equation 1.

$$\text{The total chlorophyll (mg g-1)} = (17.5 \times A645) + (7.18 \times A663) \quad (1)$$

Assimilate partitioning was determined by using plant biomass from each plant organ (shoot, root, and grain). The shoot and root were dried in an oven (Memmert type UN23) at 80^{o}C for 48 h, while the grain was dried at a temperature of 40^{o}C for 24 h until it reached a water content of 14%. Furthermore, the plant biomass was weighed using a digital scale with an accuracy of 500 g x 0.01. The data was expressed in histogram with standard deviation. Root length was measured using a ruler from the base of root to the longest tip root. The leaf area observation was conducted by placing the leaves on white cardboard, measuring their dimension with a meter ruler, and then taking a picture using a camera. The resulting image was then measured using Image J version 1.54 g. Calibration was required before using ImageJ so that its size matched the actual leaf image. Plant height was determined by a meter ruler measuring from the base of the stem to the tip of the highest shoot observed when the plant was 2 to 10 WAP at intervals of once every two weeks.

Yield and yield components were observed in the laboratory. Panicle length was measured with a ruler. The number of grains per panicle was determined using a hand counter. The percentage of filled grains was determined by counting the number of filled grains in one clump, the total number of grains in the clump and then performing the calculation according to equation 2. These parameters were measured in each treatment plot using five clumps as samples. Harvest yield was estimated by harvesting all plants from a 10 m^2 area within each treatment plot at physiological maturity. The harvested grains were threshed, cleaned, and dried to approximately 14% moisture content before being weighed. Grain weight from the sampled area (in kg) was converted to yield in t ha^{-1} using equation 3.

Percentage of filled grain (%) = (the number of filled grain)/(a total grain) x 100% (2)

Harvest yield (t ha^{-1}) = grain weight from sample (kg)/sample area (m^2) x 10,000 (3)

2.4 Statistical analysis

All data were analyzed using the F test. The effect due to treatment was done using a Posthoc Duncan's multiple range test (DMRT) (α= 5%). The Pearson correlation was used to determine the relationship between variables observed. The data were then presented in the Table, graphs, and histograms form with standard deviation values. The data were analyzed using Statistical Tools for Agricultural Research version 2.0.1 and Microsoft Excel.

3. Results and Discussion

The treatments involving seedling age and rice variety showed no significant effect on rice leaves under FRF (Table 1). While seedling age typically has minimal influence on leaf expansion, this study found that younger seedlings demonstrated better adaptability to field conditions. Effective seedling adaptation enhances water and nutrient uptake from the planting medium, thereby supporting cell division and the growth of plant organs (Wen-jun et al., 2023). Additionally, the Inpari 3 rice variety exhibited optimal adaptability to the FRF environment, leading to the development of broader leaves. Generally, the ability of plants to adapt to environmental constraints is regulated by genetic factors (Bin et al., 2020). Leaves are essential plant organs that play a crucial role in photosynthesis as they contain chlorophyll and various structures that facilitate this process (Lv et al., 2023). Broader leaves can capture more photons from sunlight, which are then utilized in the photosynthesis process (Töpfer, 2021).

Table 1. The effects of seedling age on leaf area, total chlorophyll content, and root length in the two rice varieties at the early heading stage.

Treatments	Leaf Area (cm^2)	Total Chlorophyll ($mg\ g^{-1}$)	Root Length (cm)
Seedling ages			
14 DAS	481.10	44.21[b]	23.70
21 DAS	407.12	57.57[a]	27.10
Rice varieties			
Inpari 3	520.75	50.13	26.05
Inpari 30 Ciherang Sub 1	367.47	51.43	24.75
ANOVA			
Seedling age (A)	ns	*	ns
VarietY (V)	ns	ns	ns
A x V	ns	ns	ns
CV (%)	18.87	19.19	22.38

Remarks: Difference superscript letters in the same columns means significant difference in the DMRT (α= 0.05). ns means no significant difference.

Rice planted under FRF with varying seedling ages influenced total chlorophyll content. Plants with older seedlings exhibited higher total chlorophyll content. This finding was consistent with the study by Sarma et al. (2023), which demonstrated that older seedlings offered greater tolerance under stress conditions. The formation of chlorophyll is also influenced by the availability of nutrients and water in the planting medium (Oco et al., 2024). According to Hou et al. (2020), essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) play a critical role in chlorophyll synthesis. Despite this, the two rice varieties tested in the present study showed no significant differences in total chlorophyll content. This suggests that rice planted under FRF may not significantly impact chlorophyll degradation caused by environmental factors. Gan et al. (2020) reported that chlorophyll degradation is typically driven by abiotic stress conditions, including flooding, salinity, and drought, which activate the chlorophyllase enzyme.

The water and nutrient absorption in plants is significantly influenced by the root system. However, seedling age and rice variety were found to have no significant effect on root length (Table 2). This outcome was likely due to the shallow nature of the planting medium in FRF, which is typically only 5 cm. Such shallowness was shown to constraint root organ development (Islam et al., 2023). Nevertheless, if the planting medium provides the required nutrients, plants can still sustain their nutrient needs to support cell growth and overall development (Inzaghi et al., 2022). Although root growth was limited, plants absorbed sufficient water and nutrients to maintain key metabolic functions, including photosynthesis.

Photosynthesis, a critical metabolic process in plants, enables the production of assimilates (Tao et al., 2023). These assimilates are subsequently translocated to various plant organs, including grains, which serve as permanent sinks (Fukai & Mitchell, 2024). In rice plants, assimilates are distributed to the roots, shoots, and grains. The assimilated partitioning in rice cultivated under floating field conditions is illustrated in Figure 3. Based on Figure 3a, the assimilates produced through photosynthesis in Inpari 3 were distributed predominantly into the shoots (45.23%), followed by the grains (27.64%) and

Table 2. The seedling ages affect panicle length, number of grains per panicle, percentage of filled grains, and rice yield in two rice varieties.

Treatments	Panicle Length (cm)	Number of Grains per Panicle	Percentage of Filled Grains (%)	Harvest Yield (t ha^{-1})
Seedling ages				
14 DAS	22.56	98.04^{b}	84.32^{b}	3.03^{b}
21 DAS	23.00	108.57^{a}	92.76^{a}	3.98^{a}
Rice varieties				
Inpari 3	22.94	105.17	89.83	3.17^{q}
Inpari 30 Ciherang Sub 1	22.63	101.13	87.26	3.83^{p}
ANOVA				
Seedling age (A)	ns	*	*	**
Varieties (V)	ns	ns	ns	*
A x V	ns	ns	ns	ns
CV (%)	2.87	7.69	8.04	15.46

Remarks: the number followed by the difference letters in the same columns means significant difference in the DMRT (α= 0.05).

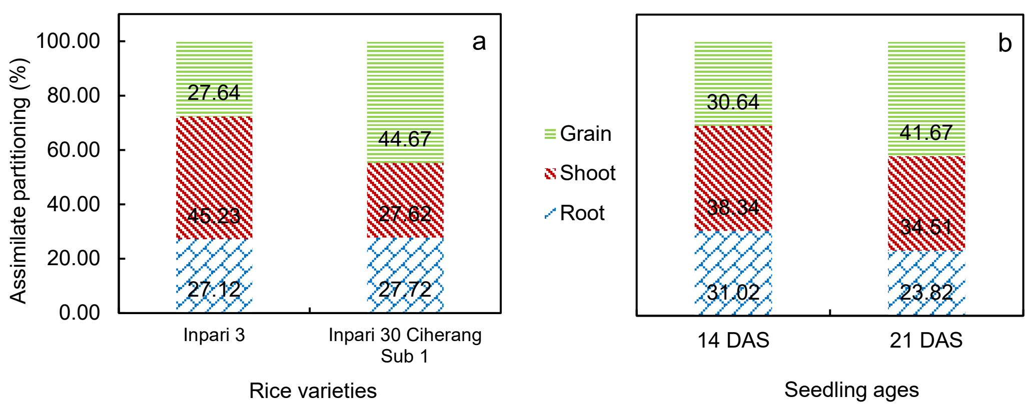

Figure 3. (a). Assimilate partitioning in rice varieties; (b). Assimilate partitioning with different seedling ages

roots (27.12%). Conversely, in the Inpari 30 Ciherang Sub 1, assimilates were primarily allocated to the grains (44.67%), with the roots (27.72%) and shoots (27.62%) receiving slightly lower proportions. These findings suggest that the Inpari 3 tends to store more assimilates in the shoots, whereas the Inpari 30 Ciherang Sub 1 prioritizes reproductive organs for storage. Genetic differences influence a plant's ability to allocate assimilates to various organs. The distribution of assimilates by several factors, including genetics, nutrients particularly nitrogen-and the balance between root and shoot growth was previously determined (Paul, 2021). As further elaborated by Bouteillé et al. (2012), the genetic makeup of a plant determines the growth and development characteristics of its organs, particularly its roots and shoots. The development of these organs enhances the plant's capacity to fix carbon and absorb nutrients, enabling optimal photosynthesis (Andrews & Raven, 2022).

Seedling age also significantly influenced the development of roots and shoots, subsequently affecting the production and allocation of assimilates. As shown in Figure 3b, rice seedlings aged 14 days after sowing (DAS) allocated assimilates primarily to shoots (38.34%), followed by roots (31.02%) and grains (30.64%). In contrast, seedlings aged 21 DAS directly allocated assimilates mainly to grains (41.67%), followed by shoots (34.51%) and roots (28.82%). These findings indicated that younger seedlings allocated more assimilates to vegetative organs, whereas older seedlings prioritized generative organs for assimilating storage. Li et al. (2016) reported that younger rice seedlings exhibited better root development compared to older seedlings as older seedlings age tended to inhibit root growth and regeneration (Wang et al., 2024). Additionally, the shoots of younger seedlings undergo faster cell regeneration, promoting the growth of more shoots and tillers (Zohaib et al., 2024). Moreover, transplanting older seedlings resulted in a faster initial increase in plant height but subsequently restricted tiller development, which ultimately reduced the number of panicles (Lee et al., 2021).

Plant height reflects the increase and expansion of cells, which is affected by various factors supporting rice cultivation, including genetic and environmental conditions (Chen et al., 2021b). As shown in Figure 4a, both rice varieties exhibited substantial growth in plant height across all observation periods. The Inpari 30 Ciherang Sub 1 variety produced taller plants compared to the Inpari 3 variety, likely due to differences in genetic traits and environmental interactions. According to Zhao et al. (2022), plant height is affected by genetics, hormonal regulation, and environmental equilibrium, which all contribute to internode elongation.

Furthermore, Figure 4b illustrates that rice plants, regardless of seedling age, exhibited plant heights that increased at each observation under FRF. Rice transplanted at 14 and 21 DAS showed no significant differences in plant height. Typically, younger seedlings possess a higher capacity for cell division, which contributes to accelerated and more optimal plant growth (Zhao et al., 2020) and greater efficiency in nutrient absorption (Wu et al., 2018). In contrast, older seedlings tend to experience delays in biomass production, reduced tillering, and an extended harvest period (Cao et al., 2022).

The research indicates that both younger and older seedlings were able to adapt and grow in the planting medium of FRF, and plant height was generally lower than expected under optimal conditions. Environmental factors play a significant role in the growth of rice plants. Sufficient nutrient availability, particularly nitrogen, is crucial for cellular processes that promote plant elongation (Ma et al., 2023). However, rice roots in FRF hampered development and reduced nutrient uptake from the planting medium. Additionally, the proximity of water to the planting medium often results in nutrient leaching, thereby decreasing nutrient availability (Linquist et al., 2014). The reduced availability of nutrients in the planting medium directly affects their uptake and distribution to other plant organs, despite the critical need for macronutrients to support vegetative growth (Sharma et al., 2018).

Plant height reflects the plant's ability to support the growth and development of key organs such as leaves, stems, and panicles, which contribute to overall biomass and yield potential. These structural components play a critical role in photosynthesis and assimilate productions. The assimilates produced are then translocated to sink organs to

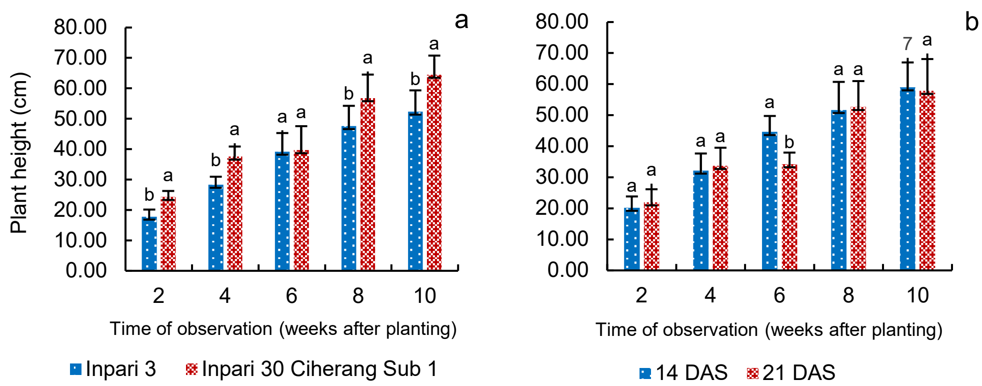

Figure 4. (a) Plant height in rice varieties; (b) Plant height with different seedling ages

support growth and grain filling (He et al., 2024). In rice plants, sinks encompass all organs, including the generative organs, with grains acting as permanent sink (Fei et al., 2024). The quantity of assimilates produced directly influences harvest yield, highlighting the importance of efficient assimilate production and partitioning.

Assimilates stored in rice plants play a role in grain formation and significantly influence various yield components. While the seedling age did not appear to affect panicle elongation, it had a notable impact on key yield components such as the number of grains per panicle, the percentage of filled grains, and rice yield (Table 2). Based on the study by Virk et al. (2021), rice transplanted at a younger age tended to produce longer panicles than older seedlings. However, their study classified seedlings at 21 DAS as young, whereas seedlings at 35 DAS were considered older. In the present study, panicle length was not significantly influenced by seedling age, likely due to both seedling ages examined falling within the range capable of producing panicles of similar length. Panicle length serves as an indicator of spikelet number, which directly influences overall grain yield.

Seedlings transplanted at an excessively young age tend to exhibit suboptimal sucrose storage in grains. This phenomenon reveals the higher number of grains per panicle and increased percentage of filled grains in rice transplanted at 21 DAS compared to 14 DAS. According to Liu et al. (2017), seedlings at 20 DAS produce 19.36% more grains than seedlings transplanted at below 20 DAS or above 30 DAS. This was affected by the source-sink relationship, which reflected the balance between source and sink organs (Gao et al., 2021), as well as the size of the sink, determined by the number of spikelets per panicle that could store sucrose (Wang et al., 2020). Additional factors such as plant age and nutrient availability also play a crucial role in high yielding (Zhou et al., 2024).

Seedlings at 20 DAS demonstrated higher assimilate production capacity from photosynthesis and provided a larger grain storage capacity for sucrose. Conversely, rice transplanted at 14 DAS focused more on allocating sucrose to vegetative organs (Reddy et al., 2021). Consequently, in this study, seedlings at 21 DAS were more effective in producing assimilates, storing sucrose, and enhancing grain filling, resulting in increased yield. The larger number of spikelets capable of assimilating storage and the higher proportion of filled grains contributed significantly to improved rice yield.

Other study results indicated that variety treatment did not affect panicle length, the number of grains per panicle, the percentage of filled grains, and rice yield (Table 2). Both tested varieties were high-yielding rice types with inherent capabilities for superior performance. Liu et al. (2024) reported that high-yielding rice varieties optimized yield potential due to the presence of numerous spikelets per panicle. Moreover, the number of spikelets per panicle and the number of panicles per clump were critical determinants of high yield (Wang et al., 2022). Additionally, the water regime affects the planting medium under floating water and enhances plant metabolic activities and biomass production. The environmental factor likely contributed to the high yield observed in both Inpari 3 and Inpari 30 Ciherang Sub 1 (Zou et al., 2024).

Pearson correlation analysis determines the relationship between two variables, with values ranging from -1 to +1. A correlation value of +1 indicates a strong positive linear correlation, -1 indicates a strong negative linear correlation, and 0 indicates no linear correlation between the two variables. Table 3 presents the results of the Pearson correlation analysis, which revealed that leaf area exhibited a strong positive correlation with shoot biomass (r= 0.71), root biomass (r= 0.48), and root length (r= 0.44). This finding indicates that increased leaf area enhanced assimilate production and distribution to sinks such as the shoot and root systems. Additionally, higher chlorophyll content positively correlated with increased filled grains (r= 0.53). Chlorophyll is a component in photosynthesis and facilitates the capture of photons in leaves. The processes of light reactions and the Calvin cycle ultimately drive carbohydrate synthesis. The carbohydrates produced are stored in permanent sinks, such as grains, to promote grain filling. The increase in filled grains was also associated with rice yield (r= 0.53). Correlation analysis was conducted to determine the relationships between variables affected by the applied treatments.

Table 3. The Pearson correlation coefficients among all variables observed for rice planted using different seedling ages under the FRF.

Variable	PH	RL	SB	RB	CT	LA	FG	PY
PH		0.21^{ns}	0.21^{ns}	0.02^{ns}	0.13^{ns}	0.09^{ns}	-0.03^{ns}	-0.30^{*}
RL	0.21^{ns}		0.21^{ns}	0.18^{ns}	0.38^{*}	0.44^{*}	0.12^{ns}	0.26^{*}
SB	0.21^{ns}	0.21^{ns}		0.59^{**}	0.10^{ns}	0.71^{**}	-0.06^{ns}	-0.04^{ns}
RB	0.02^{ns}	0.18^{ns}	0.59^{**}		-0.34^{*}	0.48^{*}	-0.24^{ns}	-0.03^{ns}
CT	0.13^{ns}	0.38^{*}	0.10^{ns}	-0.34^{*}		-0.03^{ns}	0.53^{**}	0.28^{*}
LA	0.09^{ns}	0.44^{*}	0.71^{**}	0.48^{*}	-0.03^{ns}		0.02	-0.02^{ns}
FG	-0.03^{ns}	0.12^{ns}	-0.06^{ns}	-0.24^{ns}	0.53^{**}	0.02^{ns}		0.53^{**}
PY	-0.30^{*}	0.26^{*}	-0.04^{ns}	-0.03^{ns}	0.28^{*}	-0.02^{ns}	0.53^{**}	

Remarks: ns is not significant, ** is significantly correlated at α= 1%, * is significantly correlated at α= 1%, plant height (PH), root length (RL), shoot biomass (SB), root biomass (RB), chlorophyll total (CT), leaf area (LA), filled grain (FG), rice yield (PY).

In general, the appropriate selection of seedling age significantly influenced the growth and yield of rice cultivated using FRF. The FRF method is usually applied in areas with high water availability, such as flood-prone areas or regions near rivers. Proper implementation of the FRF approach requires careful consideration of the planting medium to ensure optimal root development for nutrient uptake. These factors are critical for enhancing production efficiency and supporting national food security.

4. Conclusions

In this study, it was found that the agronomic performance with 21 DAS seedlings age significantly enhanced chlorophyll content and higher levels of partitioning assimilates (which were then translocated to the grain section) compared to 14 DAS seedlings. The increased partitioning assimilated into the permanent sink caused an improvement in the number of grains per panicle, percentage of filled grains, and rice yield. Additionally, the Inpari 30 Ciherang Sub 1 exhibited greater plant height than the Inpari 3. This variety also demonstrated superior assimilate partitioning into the grain section, further contributing to increased rice yield. The analysis revealed that chlorophyll content was positively correlated with the percentage of filled grains (r= 0.53), which, in turn, contributed to higher rice yield (r= 0.53). Furthermore, leaf area positively influenced root length, shoot biomass, and root biomass (r= 0.44; r= 0.71; r= 0483, respectively) due to the translocation of photosynthesis assimilates stored in the shoot and roots.

This study demonstrates that the FRF method, combined with the appropriate selection of seedling age and rice varieties, can produce harvest yields of approximately 3-4 tons ha^{-1}. The root development causes and optimizes growth and productivity. Enhanced root growth directly impacts the plant’s ability to absorb water and nutrients, influencing overall yield outcomes.

5. Acknowledgements

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6. Authors’ Contributions

Nasrudin designed the research and developed the methodology. Monita Dwiyani performed the data analysis and interpretation. Dian Mardiansyah and Riad Taufik contributed to fieldwork and data collection. All authors participated in writing, reviewing, and approving the final manuscript.

7. Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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