INFLUENCE OF SEEDLING AGE AND NUMBER OF SEEDLINGS PER HILL ON THE PERFORMANCE OF BLACK RICE (*Oryza sativa* L.)

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Dedicated to

My

Loving Parents
and

***Respected Professors**,*

whose hopes, dreams,
and prayers have
guided me through
life.

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CERTIFICATE

*This is to certify that the thesis entitled **"Influence of Seedling Age and Number of Seedlings Per Hill on the Performance of Black Rice (Oryza sativa L.)"** was submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** in **AGRONOMY**, embodies the result of a piece of bona fide research work carried out by **MD. RAKIBUL HASAN**, Registration number: **19-10191,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed during the course of this investigation, has duly been acknowledged.

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INFLUENCE OF SEEDLING AGE AND NUMBER OF SEEDLINGS PER HILL ON THE PERFORMANCE OF BLACK RICE (*Oryza sativa* L.)

ABSTRACT

The experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, from June 2021 to December 2021 to study the growth and yield of black rice (*Oryza sativa* L. *indica*) as affected by seedling age and seedling rate (no. of seedlings hill^{-1}). Black rice was used as the test crop for this experiment. The experiment comprised two factors. Factor A: Seedling age (4 levels); 25 days old seedling, 30 days old seedling, 35 days old seedling, and 40 days old seedling, and Factor B: Seedling rate (no. of seedlings hill^{-1}) (3 levels): 1 seedling hill^{-1}; 2 seedling hill^{-1} and 3 seedling hill^{-1}. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Due to the combination effect of seedling age and seedling rate, the maximum number of effective tillers hill^{-1} (14.00) was found in the treatment combination of 35 days old seedlings transplanted in 2 seedlings hill^{-1} and the minimum number (2.00) in 25 days seedling age with 3 seedlings hill^{-1}. The longest plant height (184.87 cm) was found in the treatment combination D_4S_1(40 days old seedling and 1 seedling hill^{-1}), whereas the shortest plant (161.60 cm) was found in the treatment combination D_1S_3 (25 days old seedling with 3 seedlings hill^{-1}). The maximum number of filled grains panicle^{-1} (353.2) was found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}), and the minimum number (270.73) was found in D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}). The highest grain yield (5.56 t ha^{-1}) was found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}), and the lowest grain yield (2.87 t ha^{-1}) was observed from D_1S_1 (25 days old seedling and 1 seedling hill^{-1}), but the highest straw yield (5.69 t ha^{-1}) was found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}), and the lowest straw yield (3.66 t ha^{-1}) was observed in the treatment combination of D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}). The 35 days old seedlings planted in 2 seedlings hill^{-1} showed a better response in most of the studied parameters.

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LIST OF ABBREVIATIONS

AEZ	Agro-Ecological Zone
BARI	Bangladesh Agricultural Research Institute
SAU	Sher-e-bangla Agricultural University
BBS	Bangladesh Bureau of Statistics
Co	Cobalt
CV%	Percentage of coefficient of variance
cv.	Cultivar
DAE	Department of Agricultural Extension
DAS	Days after sowing
^{0}C	Degree Celsius
et al.	And others
FAO	Food and Agriculture Organization
g	gram(s)
ha^{-1}	Per hectare
HI	Harvest Index
kg	Kilogram
Max	Maximum
mg	Milligram
Min	Minimum
MoP	Muriate of Potash
N	Nitrogen
No.	Number
NS	Not significant
%	Percent
SAU	Sher-e-Bangla Agricultural University
SRDI	Soil Resources and Development Institute
TSP	Triple Super Phosphate
UPOV	Union for the Protection of Plant Varieties
Wt.	Weight

CHAPTER I

INTRODUCTION

One of Bangladesh's primary industries is farming. Agriculture is crucial to their economy. The climate and soil of Bangladesh are ideal for growing rice (*Oryza sativa* L.). Half of the world's population relies on rice as their primary source of nutrition, with over 91% of the world's supply being produced and consumed in Asia (IRRI, 2021). Paddy is grown on 161 million ha worldwide, yielding about 713.8 million tons with average productivity of 4.44 tons per hectare per year (t ha^{-1}). A whopping 612 million metric tons of paddy rice are harvested annually from Asia's 143 million hectares of rice fields (IRRI, 2014). China is the largest rice producer in the world, with a total rice production of 149 million tons in 2021, accounting for about 30% of the world's total production (USDA, 2022). A catastrophic food crisis is imminent if it is impossible to improve rice yields, which have been constant in recent years (Haque and Haque, 2016). Expanding the amount of land used for farming or implementing cutting-edge techniques to boost output per acre will be required to reach the target. In addition to environmental parameters like temperature, sunlight, moisture, soil quality, and nutrient adequacy factors like seedling age, the number of seedlings per hill and population density significantly impact rice yields (Baloch *et al.*, 2002).

Black rice is a variety of pigmented rice. It contains numerous nutritional and bioactive components, including essential amino acids, functional lipids, dietary fiber, vitamins, minerals, anthocyanins, phenolic compounds, γ-oryzanols, tocopherols, tocotrienols, phytosterols, and phytic acid (Ito and Lacerda, 2019). It is also known as purple rice, forbidden rice, heavenly rice, royal rice, king rice, and precious rice. Many assume this rice is a panacea for many culinary diseases because of its high nutritional value and curative effect. This rice is supposed to prolong life, hence it is also known as longevity rice. This rice includes various varieties with a long history of cultivation in Southeast Asian countries like China, India, and Thailand. (Sompong *et al.*, 2011).

Colored rice could be a good source of antioxidants for foods with functional properties (Yawadio *et al.*, 2007). Black rice became a functional food in Japan because of its high polyphenol and anthocyanin content (Itani and Ogawa, 2004). A demand for black rice as an organic food coloring additive was predicted by Chaudhary (2003) prior to the appearance of colored rice's health benefits. This demand was made achievable, at least in part, by the rise in black rice production.

The growth and development of rice as well as the yield of grain are greatly influenced by the age of rice seedlings. Because of its significant impact on tiller production, grain formation, and other yield-contributing characteristics, seedling age before transplanting is a crucial consideration (Liu *et al.,* 2017; Aslam *et al.,* 2015) Bangladeshi farmers generally employ old seedlings while transplanting and pay little attention to the seedlings' age. Because the farmers are unaware of this factor, using over-aged seedlings significantly reduces crop output and decelerates agricultural performance overall (Liu *et al.,* 2017; Shrestha *et al.,* 2019) Age of seedlings at transplanting of a specific variety during a specific season is a very important criterion for the best output (Tian *et al.,* 2022).

Along with this, the number of seedlings hill^{-1} is an essential factor in the growth and yield of rice. Optimal population density and leaf area influence the availability of sunlight and nutrients for growth and development. Competition within the hill is an integral part of the physical environment, and the competition by neighbors often accentuates the complexity. Both these factors contribute to determining yield. As growth proceeds, intra-plant competition becomes progressively more operative until flowering and seed setting occurs. A load of panicles is as significant as to lead to competition among the panicles themselves, thereby reducing the efficiency of seed production in the individual inflorescence. The ultimate result was the lowest yield. If a single seedling is utilized, there is a possibility of missing hills. Alternatively, if more than the optimal number of seedlings are used hill^{-1}, seedlings will be misused, resulting in excessive use of seeds. Seedling vitality contributes to subsequent growth (Herliana *et al.*, 2019).

After transplanting, the rice's tillering, yield, and quality are examined. Rice growth and yield depend on timely cultivation and cultivar growth duration, which is influenced by the number of seedlings hill^{-1} (Mishra and Salokhe, 2008).

Considering the phenomena mentioned above, this study was undertaken with the following objectives:

i. Determine the optimal number of seedlings hill^{-1} to increase black rice production
ii. Identify the optimal seedling age for maximizing black rice yield
iii. Assess the interaction between seedling age and the number of seedlings hill^{-1}

CHAPTER II

REVIEW OF LITERATURE

Horizontal expansion of rice area and rice yield per unit area should be increased to meet the ever-increasing food demand in the country, but this will require the adoption of new technology such as high management package, high yielding cultivar, higher input use, etc. Agricultural practices significantly impact the growth and development of all crops, including rice. Age and growth rate of seedlings are the two most important factors. Numerous studies evaluating the effects of seedling age and seedling rate on the performance of rice have been conducted. Among the variables mentioned above, some recent information on rice seedling age and the seedling rate has been examined under the following headings:

1. Influence of seedling age on the growth and yield of rice

While conducting an experiment, Kawatra *et al.* (2021) found that transplanting the rice nursery at the optimum age resulted in higher yields. However, if older seedlings must be transplanted, productivity can be increased through the foliar application of either Kinetin 30 ppm or TRIA 1 or TRIA 2 ppm on the nursery (1 week prior to transplanting) and/or crop (1 week after transplanting). The primary function of TRIA is to increase the number of tillers, whereas kinetin enhances crop seed filling.

Zhimomi *et al.* (2021) conducted a field study undertaken during the Kharif season of 2014 at the Agronomy research farm of Nagaland University. The study indicated that plant height, LAI, and the number of tillers per hill increased at 30, 60, 90, and 120 DAT. Dry matter accumulation was higher for $20 \times 20\ cm^2$ spacing treatment on a unit area basis, but $40 \times 40\ cm^2$ spacing treatment was superior per plant basis. The straw yield was shown to be inversely related to the grain yield.

Cao (2021) Conducted a field trial in Wuxue County, Hubei Province, China. Four middle-season rice studies were carried out in farmers' fields between 2016 and 2018. This study examines the yield responses to the two strategies of modifying seedling age. Among eight cultibars, only one demonstrated a consistent yield reduction in elderly seedlings compared with young seedlings. For the remainder of cultibars, seedling age had mixed effects on yield. The yield response to seedling age mostly depends on changes in heat stress during panicle development and flowering caused by varied seeding or transplanting dates and different crop durations. Transplantation of old seedlings for up to 40 days did not necessarily affect the yield of middle-season rice in central China as long as heat stress during panicle growth and flowering could be avoided by selecting acceptable types with proper sowing or transplanting dates.

Lile (2021) investigated FARO 44's germination rate was greater than 7-day-old seedlings and more effectively than seedlings transplanted at earlier ages. The N fertilizer rate has no effect on the germination of rice seeds. Applying 0 kg to 60 kg N ha^{-1} at one and two months of storage improved the germination of seven-day-old seedlings of both kinds and might be suggested for optimal germination in rice.

Tadesse (2021) reported that Rice produced by transplanting seedlings at the optimal age reached maturity substantially earlier than rice produced by sowing dry seeds directly. All yield component enhancements of plants grown from transplanted seedlings resulted in considerably enhanced grain production and economic advantage compared to direct sowing. This experiment has demonstrated that transplanting seedlings rather than directly spreading dry seed results in much higher grain yields and more economic benefits in rice cultivation.

El-Rahem and Abo-Marzoka (2020) studied the effect of three rice cultibars on three seedling ages (20, 25, and 30 days after planting) and three transplanting spaces (15, 20, and 25× 20 cm) and their interactions on growth characters, yield, and attributes. Younger seedlings (20 days old) produced the highest mean values significantly for all studied characteristics. In general, the Sakha108 rice cultivar is best suitable with a seedling age of 20 days and plant spacing of 25 × 20 cm under transplanting.

Sultana *et al.* (2020) concluded that Binadhan-15 could be successfully cultivated for maximum yield with 75 kg ha^{-1} N and 15-day-old seedlings alone or in combination with recommended TSP, MOP, and gypsum fertilizers to ensure optimal nutrient requirements for commercial rice cultivation. Because fertility status and seedling age selection may vary from region to region, further research must be conducted immediately. Farmers may be advised to apply 75 kg of nitrogen and 15-day-old seedlings to increase rice grain yield.

Kaur and Dhillon (2020) conducted a field experiment among cultibars PR 126 and PR 127, rice cultivar PR 122 showed significantly higher growth parameters, yield parameters, and 8.3% and 14.1% higher grain yield, respectively. Planting 30-day-old seedlings of the rice cultivar PR 122 demonstrated its superiority in producing a higher yield. Among the different ages of seedlings, 30-day-old seedlings had higher values for growth parameters, yield parameters, and grain yield by 10.1% and 18.4%, compared to 40 and 50-day-old seedlings, respectively.

Patel *et al.* (2019) reported that a significant decrease in the number of filled grains $panicle^{-1}$, the number of panicles/m^2, and the test weight might be associated with a decreasing trend in grain yield when sowing is delayed.

Lampayan *et al.* (2019) showed that in Lao PDR, grain yield was significantly affected by the interaction between seedling age and variety. The seedling density treatments (one, three, and five seedlings $hill^{-1}$), regardless of variety, had significant effects on tillering dynamics but not grain yield. Utilizing varieties with a greater propensity for tillering mitigated the effects of delayed transplanting on crop performance. The late planting of seedlings increased total water productivity, but the delay in harvesting could reduce irrigation water productivity.

Kumar *et al.* (2019) conducted a field experiment was undertaken to evaluate the influence of seedling age and nitrogen levels on gold hybrid rice. The experiment used a split-plot design with three seedling ages and four nitrogen levels. The highest grain yield (5374 kg ha^{-1}) was reported with 15 days seedling, which was similar to 20 days seedling. Among nitrogen levels, 150 kg N ha^{-1} had the highest grain yield (6050 kg ha^{-1}) and harvest index (45.21%), whereas 180 kg N ha^{-1} had the best straw production (7439 kg ha^{-1}).

According to Koudjega *et al.* (2019), seedling age and varied urea supergranule, deep implantation times impact rice development, yield, and nitrogen usage efficiency. Rice growth, yield, and nitrogen utilization efficiency declined as seedling age, and USG treatment duration increased. Application of USG between 7 and 14 DAT on rice transplanted between 10 and 14 days produced the best results. To boost rice yields when 21 days to 28-day-old seedlings must be transplanted, USG should be given between 7 and 14 DAT rather than 0 or 21 DAT.

According to Thapa *et al.* (2019), the highest yield is produced by transplanting younger seedlings regardless of nursery management. The seedlings obtained from high seeding densities should not be transplanted at an older age, as this dramatically reduces rice production. Younger seedlings with a low sowing density and the proper amount of nitrogen are more productive.

Raut *et al.* (2019) Effect of age of seedling, quantities, and techniques of fertilizer administration on growth, output, and quality of rice (*Oryza sativa* L.) During both years, the 20-day-old seedling exhibited considerably superior growth characteristics, yield attributes, grain and straw yield (q ha^{-1}) compared to the 30-day-old and 40-day-old seedlings, in descending order.

Sultan *et al.* (2018) conducted a field experiment during the Kharif seasons of 2016 and 2017 to evaluate the Effect of seedling age, levels, and methods of fertilizer application on the growth, yield and quality of rice (*Oryza sativa* L.). 20 days seedling produced considerably higher growth character, yield attributes, grain and straw yield (q ha^{-1}) than

30 days and 40 days seedling during both years. Significantly greater growth, yield attributes, grain, and straw yields (q ha^{-1}) were reported in treatment K_4 (K_2 + Zn, B, and Cu spray) followed by K_3 (K_1 + Zn, B and Cu spray) over both years. While fertilizer treatment strategies did not affect tillers $hill^{-1}$, panicle $hill^{-1}$, unfilled grains $panicle^{-1}$, and test weight in both years.

According to Paul *et al.* (2018), the effect of nursery seeding density, age of seedling, and number of seedlings $hill^{-1}$ on short-duration transplant *aus* rice yield components and yield (cv. Parija). The treatments 40 g seed m^{-2} 30-day old seedlings 4 seedlings $hill^{-1}$ separately affected total tillers $hill^{-1}$, effective tillers $hill^{-1}$, grains $panicle^{-1}$, and sterility percentage. 40 g seed m^{-2}, 30-day old seedlings, and four seedlings $hill^{-1}$ produced the maximum grain yields of 3.28, 3.35, and 3.5 t ha^{-1}. Using 40 g seed m^{-2}, 30-day-old seedlings, and four seedlings $hill^{-1}$ could boost the yield components and grain production of short-duration transplanted Aus rice (cv. Parija). Short-duration transplanted *aus* rice (cv. Parija) can be grown with 40 g seed m^{-2} and 40-day-old seedlings at 4 seedlings $hill^{-1}$ for optimal grain yield.

Dhillon *et al.* (2021) experimented at Punjab Agricultural University, Ludhiana, India, to study the effect of seedling age on growth, phenology, and thermal energy usage of various rice genotypes. The frequency of dry weather conditions, which corresponded with the grain growing season, was advantageous for the rice crop, as demonstrated by its yield and features. With increasing seedling age, rice grain and straw output continually dropped.

According to Amin and Haque (2009), the overall performance (growth, yield, and yield contributing characters) of all varieties with different seedling ages used in the experiment, it is possible to conclude that 35-day old seedlings were superior to those of relatively younger (15 and 25 day old) and older (45 day old) seedlings.

According to Ahmed *et al.* (2007), except for panicle length, spikelets $panicle^{-1}$, and straw yield, the variety had a substantial effect on the other examined parameters, of the results of the experiment. Sonarbangla-1 provided the highest grain yield and the lowest straw yield, whereas BRRI dhan29 produced the lowest grain yield and the highest straw yield.

Except for panicle length, 1000-grain weight, and straw yield, cultivation method also significantly influenced the analyzed parameters. The maximum grain yield and straw yield were produced by nursery seedlings, while the lowest grain yield and straw yield were produced by SRI.

Chaudhary (2003) conducted an experiment using 2, 4, and 6 seedlings hill^{-1} to determine their impact on the yield components of BR 23 and Pajam rice varieties during the aman season. They reported that 6 seedlings from hill^{-1} produced the most grain and straw.

2. Influence of Seedling no. hill^{-1}

Among the several agronomic methods, the quantity of seedlings is one of the most significant production drivers. This chapter discusses the research findings regarding the number of seedlings hill^{-1} on rice's growth, yield, and contributing qualities.

According to Nisa *et al.* (2022), the influence of salt on the growth and yield of black rice during seedling. As a functional food, black rice (*Oryza sativa* L. *Jeliteng*) has a higher nutritional value than other forms of rice. Black rice can be grown in coastal agricultural areas that are susceptible to salinity issues. Increasing soil salinity concentrations raised the levels of Na^+ and K^+ in plant leaves, while decreasing stomatal opening breadth, plant height, and weight per 100 grains. In the later growth stage, salinity in the seedling stage increased transpiration rate, stem fresh weight, the proportion of green leaves, and the harvest index compared to non-saline nursery seedlings. However, the productivity of seedlings from saline and non-saline nurseries did not differ.

Widian *et al.* (2021) Physical mutations caused by gamma-ray irradiation may be used to increase the genetic variety of plants. The purpose of this study is to assess the effect of gamma-ray irradiation on the growth of six M1-generation black rice accessions. This study utilized six Tasikmalaya accessions (PH, PH2, PH3, PH5, PH7, and PH8) without 0 Gy irradiation and with 200 Gy of M_1-generation gamma-ray irradiation. Gamma-ray irradiation was found to reduce germination parameters, seedling height, and flowering age. There were decreases and increases in the characteristics of root length, plant height, number of productive tillers, number of unproductive tillers, and total number of tillers for some of the accessions.

According to Herliana *et al.* (2019), The finest organic fertilizer is chicken manure, which increases yield by 5.15 t ha^{-1} and influences growth parameters (plant height, productive tillers, number of leaves $clump^{-1}$, number of grains $panicle^{-1}$, dry grain weight $clump^{-1}$). The optimal number of seedlings $planting^{-1}$ hole is three, which results in a grain yield of 4.55 t ha^{-1}. The optimal combination of chicken manure treatment and three seeds per planting hole yields 5.38 t of grain ha^{-1}.

Gurjar *et al.* (2018) reported that an 18-day-old seedling seed was used in this investigation. Younger seedlings have a greater capability for nutrient uptake and weed suppression than older seedlings because they can establish themselves earlier and begin growing faster due to greater root growth.

Bhowmik *et al.* (2012) conducted a field experiment was done at the Agronomy Field Laboratory of the Bangladesh Agricultural University in Mymensingh to determine the influence of spacing and number of seedlings $hill^{-1}$ on the performance of Aus rice cv. NERICA 1. Four spacing viz. 25 cm × l5 cm, 20 cm × l5 cm. Twenty centimeters by ten centimeters and fifteen centimeters by fifteen centimeters, as well as four seedlings $hill^{-1}$, numbered 2, 3, 4, and five, were included in the experiment. 20 cm 10 cm spacing produced the greatest number of total tillers m^{-2}, number of effective tillers m^{-2}, number of grains $panicle^{-1}$, grain yield, straw yield, biological yield, and harvest index. The effect of spacing on plant height and 1000-grain weight was not statistically significant. The number of seedlings on $hill^{-1}$ has a substantial impact on plant height. Five seedlings $hill^{-1}$ produced the highest values of total tillers m^{-2}, number of effective tillers m^{-2}, total grains $panicle^{-1}$, grain yield, straw yield, biological yield, and harvest index. The interaction between spacing and seedling density $hill^{-1}$ had a substantial effect on yield and plant characteristics. Interaction between 20 cm and 10 cm and five seedlings $hill^{-1}$ produced the greatest number of effective tillers per square meter, grains per panicle, grain yield, straw yield, and biological yield.

According to Mishra and Salokhe (2008), using vast seedlings will lower panicle quantities, increase the proportion of empty grains, and reduce the weight of 1,000 grains.

Thawait *et al.* (2014) found that transplanting 2-3 seedlings $hill^{-1}$ at a spacing of 25 cm x 25 cm resulted in the greatest plant height (129.64 cm), the number of tillers (15.70 tillers $hill^{-1}$), dry matter accumulation (102.65 g $hill^{-1}$) and yield attributing characters, as well as the greatest grain yield (3.820 tons ha^{-1}) and straw yield (7.791 tons ha^{-1}).

Ehsanullah *et al.* (2012) found that the density of seedlings $hill^{-1}$ significantly impacts rice growth and grain output due to competing effects on both vegetative and reproductive development. The length of panicles, number of branches per panicle, and number of grains per panicle were unaffected by the number of rice seedlings planted $hill^{-1}$. Due to the increased number of panicle-bearing tillers and 1,000- kernel weight, the number of 2, 3, and 4 seedlings in $hill^{-1}$ resulted in the highest rice kernel yield and harvest index.

Miah *et al.* (2004) assessed the effects of planting rates of 1, 2, 3, or 4 seedlings per hill on the yield and yield components of transplanted rice cultibars. BINA dhan4. Planting one and two seedlings $hill^{-1}$ resulted in the greatest plant height and number of productive tillers $hill^{-1}$. The highest number of tillers, leaf area index and total dry matter were observed when four rice seedlings were planted $hill^{-1}$.

Hushine (2004) found that the number of seedlings per hill influenced all agronomic parameters except plant height, number of ineffective tillers $hill^{-1}$, panicle length, number of sterile spikelets per $panicle^{-1}$, and 1000-grain weight. In comparison to 1 and 5 seedlings $hill^{-1}$, three seedlings $hill^{-1}$ produced the greatest number of total tillers $hill^{-1}$, number of effective tillers $hill^{-1}$, number of total spikelets $panicle^{-1}$, number of fertile spikelets $panicle^{-1}$, and grain yield.

Dongarwar *et al.* (2002) investigated hybrid rice KJTRH-1 with three spacings (20 x 20, 20 x 15, and 20 x 20 cm^2) and two levels of seedlings (1 and 2 seedlings $hill^{-1}$). A single seedling was equivalent to two seedlings when planted on $hill^{-1}$.

Islam *et al.* (2002) experimented with fine rice cv. Kalizira included three hill densities, namely 25 cm x 20 cm, 25 cm x 15 cm, and 25 cm x 10 cm, as well as two levels of seedlings hill^{-1}, namely two seedlings hill^{-1} and four seedlings hill^{-1}. The best grain output was seen with a 25 cm × 20 cm spacing and two seedlings hill^{-1}.

In the instance of late transplant *aman* rice, Karmakar *et al.* (2002) found that the number of effective tillers hill^{-1} and straw yield was highest with six seedlings hill^{-1}, whereas panicle length, grains per panicle, and harvest index were highest with two seedlings hill^{-1}

Obulamma *et al.* (2002) experimented with DPRH-1and APHR-2 hybrid rice. Four spacings (15 x 10, 20 x 20, 15 x 15, and 20 x 15 cm^2) and three seedlings per hill were used as treatments (1, 2, and 3 seedlings hill^{-1}). One seedling hill^{-1} had the greatest grain yield, crop growth rate, and net assimilation rate, whereas three seedlings hill^{-1} had the greatest dry matter production and leaf area index.

Kabir (2002) experimented to determine the influence of boro rice variety and seedling density on yield and yield-contributing traits. The experiment included three kinds: Sonar Bangla 1, BINA dhan5, BINA dhan6, and four different numbers of seedlings hill^{-1}, namely 1, 2, 3, and 4. The number of seedlings varied greatly regarding growth and yield characteristics. Two seedlings hill^{-1} produced the maximum grain output (5.37 t ha^{-1}) while a single seedling hill^{-1} produced the lowest grain yield (4.58 t ha^{-1}), which was statistically comparable to 3 seedlings hill^{-1} (4.77 t ha^{-1}) and four seedlings hill^{-1} (4.58 t ha^{-1}) (4.35 t ha^{-1}). Two seedlings hill^{-1} produced the greatest amount of straw (6.52 t ha^{-1}), whereas four seedlings hill^{-1} produced the least amount (5.11 t ha^{-1}).

Biswas and Salokhe (2001) conducted an experiments were undertaken to determine the effect of planting date, tiller separation, and plant density on the yield and yield attributes of parent and clone plants of two transplanted rice types. The photoperiod-insensitive cultivar RD23 produced a greater harvest than the photoperiod-sensitive variety KDML105. The separation of up to four tillers hill^{-1} had no negative effect on the mother crop. In all seasons, the yield of vegetative tillers transplanted with two to four tillers hill^{-1} was comparable to that of the mother crop. The output of vegetative tillers was greater than that of seedlings transplanted at the same time from a nursery. The yield components, i.e., weight of 1000 grains, grains panicle^{-1}, and percentage of filled grains, responded better to early transplanting of KDML105 in the mother crop and vegetative tillers, with the exception of panicle number and panicle length of vegetative tillers with RD23. In some flood-prone lowlands where the transplanted crop is harmed by natural hazards, the results indicate that vegetative propagation employing tillers separated (maximum 4 hill^{-1}) from the previously established transplanted crop is advantageous for increased productivity.

Shrirame *et al.* (2000) conducted a field experiment on rice cv. During Kharif 1996 in Nagpur, Maharashtra, India. TNRH 10, TNRH 13, and TNRH 18 were cultivated at a density of 1, 2, or 3 seedlings hill^{-1}. Two seedlings hill^{-1} produced a much greater number of tillers and yield of straw than three seedlings hill^{-1}. One seedling hill^{-1} resulted in a significantly greater harvest index (HI). The seedling number hill^{-1} did not influence plant height, the number of functional leaves, leaf area index, or grain yield.

Srivastava and Tripathi (2000) conducted an experiment in which rice cv. Hybrid 6201 and R 320-300 were grown at 20 cm x 15 cm or 15 cm x 10 cm spacing at 1, 2, and 3 seedlings hill^{-1}. They found that R 320-300 grown at 15 cm x 10 cm spacing at two seedlings hill^{-1} produced the highest grain yield of 7.59 t ha^{-1}.

CHAPTER III

MATERIALS AND METHODS

The present investigation entitled "**Influence of Seedling Age and Number of Seedlings Per Hill on the Performance of Black Rice (*Oryza Sativa* L.)"** was carried out during the Aman season of 2021 (June- December/2021) at the Agronomy field of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207. The details of materials used, experimental procedures followed, and techniques adopted during the investigation are described in this chapter. Climatic and edaphic conditions prevailing during crop season, selection of site, cropping history of the field, and other experimental details are also presented.

1. Site description

1.1 Geographical location

The experimental area was situated at $23^0$77′ latitude and $90^0$33′E longitude at an altitude of 8.6 meters above sea level.

The experimental field was attached to the main irrigation channel connecting to the farm water source for quick, regular, and timely irrigation. A proper drainage facility was also provided to remove excess water during the experimental period.

1.2 Agro-ecological region

The experimental field belongs to the Agroecological zone of "The Madhupur Tract," AEZ-28. This region of complex relief represents the red lateritic soil of the Madhupur area. The soil of this region has a clayey texture and contains a large quantity of iron and aluminum. The experimental site is shown in the map of AEZ of Bangladesh in Appendix I.

1.3 Climate and weather conditions

The climate is sub-tropical, with high temperature, high relative humidity, and heavy rainfall. It falls in the southwest monsoon region; generally, the monsoon starts in mid-

June and continues up to October. The mean average annual rainfall is 2730 mm, of which nearly 80-90 % is received between June and October.

The meteorological data related to the weather conditions of the experimental site prevailing during the Aman season, 2021, concerning rainfall, relative humidity, and temperature obtained from the Bangladesh Meteorological Department, is presented in Appendix III and IV.

1.4 Rainfall

The monsoon shower was cumbersome during the year of experimentation. A total rainfall of 1535 mm was recorded during the cropping period. Out of which 383 mm of rainfall was recorded during the seedling stage, 947 mm of precipitation occurred between active tillering and the maximum tillering stage of rice. However, 175 mm of rain was recorded between panicle initiation and to panicle emergence stage of the crop. A little rainfall occurred between the milk to maturity stages, and heavy rain occurred during the maturity stage.

1.5 Temperature

Temperature is one of the significant meteorological variables influencing plants' germination, growth, and development in a given agro-climatic condition. The mean maximum temperature ranged from 26.5 ºC to 31.5 ºC, and the mean minimum temperature went from 14.5 ºC to 26.5 ºC during the experimental period of 2021.

1.6 Relative humidity

The relative humidity varied between 75% to 85% during the experimental period in 2021. It attained the maximum level during the vegetative phase. Minimum relative humidity was recorded during the maturity period of the crop.

1.7 Soil

The soil of the experimental site belongs to the general soil type, Shallow Red Brown Terrace Soils, under Tejgaon Series. Topsoils are clay loam in texture, olive-gray with standard fine to medium distinct dark yellowish-brown mottles. Soil pH ranges from 5.5 to 5.7. The flat experimental area had available irrigation and drainage system and was above flood level.

1.8 Cropping history of the experimental field

The production potential of the experimental field can be judged by its cropping history. The details of the cropping history of the experiment field for preceding crops of the experimentation are given in Table 1.

Table 1. Cropping history of the experimental plot

Year	Crops		
2018-2019	Boro rice	Fallow	Aman rice
2019-2020	Boro rice	Fallow	Aman rice
2020- 2021	Boro rice	Fallow	Aman rice

It may be a concern that mainly only rice was taken in the plots before the start of the experiment.

2. Details of the experiments

2.1 Treatments

Two sets of treatments included in the experiment were as follows:

Factor A: Seedling age

1. D_1 (25 days old seedlings)
2. D_2 (30 days old seedlings)
3. D_3 (35 days old seedlings)
4. D_4 (40 days old seedlings)

Factor B: Number of seedling(s) hill^{-1}

1. S_1 (1 Seedling hill^{-1})
2. S_2 (2 Seedlings hill^{-1})
3. S_3 (3 Seedlings hill^{-1})

2.2 Experimental Design

The experiment was laid in a Randomized Complete Block Design (RCBD) with three replications. There were 12 treatment combinations. The total numbers of unit plots were 36. The size of the unit plot was 3.0 m × 1.8 m. The distances between plot to plot and replication to replication were .75 m. The layout of the experiment is shown in Appendix II.

2.3 Crop/Planting Material

Two rice varieties, Black Rice, were used as planting material.

2.4 Salient features of Black Rice

Black Rice (*Oryza sativa* L. *indica*) takes about 145 days to mature. It attains a plant height of 185 cm. The grain is very long, slender, aromatic, and white. 1000-grain weight is about 29 g. The average grain yield is about 4.5 t ha^{-1}.

3. Crop management

3.1 Seed sprouting

Seeds were soaked in water in a bowl for 24 hours. Seeds were taken out of the water and kept tightly in gunny bags. The seeds started sprouting after 48 hours and were suitable for sowing in 72 hours.

3.2 Preparation of seedbed

A general procedure was followed for planting seedlings in the seedbed. The seedbed was made by repeatedly puddling with a plow and a ladder. The weeds were removed, and the beds were gently irrigated if necessary. No fertilizer was used in the nursery bed.

3.3 Seed sowing

The seeds were divided into four installments. The first consignment was sown on 1st July 2021, and the rice seeds of the 2nd installment were soaked. After planting the seedlings of the first installment, the seeds of the second installment were sown on 08/08/2021. The seeds of the third installment were soaked on the day of sowing the seeds of the second installment. Thus, the third and fourth installment seeds were sown in the seedbed on 11/08/2021 and 16/07/2021, respectively, to raise seedlings for transplanting. The sprouted seeds were sown as uniformly as possible.

3.4 Preparation of experimental land

The experimental field was first ploughed on 2nd August 2021 with the help of a tractor-drawn disc plough; later on, 06 August 2021, the land was irrigated and prepared by three successive ploughings and cross ploughings with a tractor-drawn plough and subsequently leveled by laddering. The previous crop's weeds and other plant residues were removed from the field. Immediately after the final land preparation, the field layout was made on 07 August 2021, according to experimental specifications. Individual plots were cleaned and finally leveled with the help of a wooden plank so that no water pocket could remain in the puddled field.

3.5 Fertilizer application

The experimental field was fertilized with 17, 37.46, and 7.23 kg ha^{-1} of P_2O_5, K_2O, and S applied in the form of triple super phosphate (TSP), muriate of potash (MOP), and gypsum, respectively. The amounts of TSP, MOP, and gypsum were applied as basal doses during final land preparation and mixed properly by a tractor-drawn plough with soil. Urea was top-dressed in three installments, after seedling recovery, during the vegetation stage, and seven days before panicle initiation as per requirement for treatment as 50 g urea $plot^{-1}$ for 98 kg N ha^{-1}.

3.6 Transplanting of seedlings

Twenty-five days, 30 days, 35 days, and 40 days old seedlings were uprooted from the seedbed carefully on 10^{th} August 2021 and were kept in soft mud in the shade. The seedbeds were wet by applying water on the previous day before uprooting the seedlings to minimize mechanical injury to the roots. Seedlings were transplanted with 20 cm × 15 cm spacing on the well-puddled plots. Each plot contained 20 rows containing nine hills of rice seedlings.

3.7 Intercultural operations

3.7.1 Gap-filling

Gap filling was done twice to maintain a uniform plant population. The first gap-filling was done at 10 days after transplanting, and the second gap-filling was done at one week after the first gap-filling.

3.7.2 Weeding

The crop was infested with some weeds during the early stage of crop establishment. Hand weeding was done to reduce crop competition with weeds. First, weeding was done at 20 days after transplanting, followed by second weeding at 30 days after the first weeding. The third weeding was done at 15 days after the second weeding.

3.7.3 Application of irrigation water

Irrigation water was added to each plot as required. All plots were irrigated, maintaining a water level of about 5 cm. Irrigation frequency was reduced after panicles and the grain filling stage emerged. The field was kept dried for ten days before harvesting.

3.7.4 Plant protection measures

Plants were infested with rice stem borer (*Scirphophaga incertulas*) and leaf hopper (*Nephotettix nigropictus*) to some extent which was successfully controlled by applying Furadan @ 10 ml/10 liter of water for five decimal lands on 30th September and by Actara @ 10 ml/10 liter of water on 07th October and 21st October 2021. Tilt 250 EC @ 2ml/Liter was sprayed on paddy fields to prevent Blight (*Rhizoctonia solani*) on 1st November 2021. The crop was protected from birds and rats during the grain-filling period. Rats are controlled with field traps and poison bait. The field was covered by a net and kept appropriately watched, especially during the morning and afternoon, to prevent birds.

3.8 Harvesting

The crop was harvested depending on the maturity of the plant. Harvesting was done by serrated-edged sickles manually from each plot. Harvesting was started at 120 days and continued up to 130 days. The crop's maturity was determined when 80% of the grains matured. Five pre-selected hills were harvested from each plot from which different data were collected, and 1 m^2 area from the middle portion of each plot was separately harvested and bundled, properly tagged, and then brought to the threshing floor for recording grain and straw yield.

3.9 Threshing

Threshing was done plot-wise by a pedal thresher. The grains were cleaned and sun-dried to a moisture content of 12%. The straw was also sun-dried properly. Finally, grain and straw yields $plot^{-1}$ were determined and converted to ton ha^{-1}.

4. Recording of data

The data collection was started 30 days after transplanting and continued every 15 days at intervals until the emergence of panicles. The following data were determined during the experiment.

A. Crop growth characters

- i. Plant height (cm) at 15 days intervals and at harvest.
- ii. Number of tillers $hill^{-1}$ at 20 days interval and at harvest
- iii. Fresh weight of plant at 45, 60, 75 DAT and at harvest
- iv. Dry weight of plant at 45, 60, 75 DAT and at harvest

B. Yield and yield contributing characters

- i. Number of effective tillers $hill^{-1}$
- ii. Number of ineffective tillers $hill^{-1}$
- iii. Number of filled grains $panicle^{-1}$
- iv. Number of unfilled grains $panicle^{-1}$
- v. Number of total grains $panicle^{-1}$
- vi. Weight of 1000-grain (g)
- vii. Grain yield (t ha^{-1})
- viii. Straw yield (t ha^{-1})
- ix. Biological yield (t ha^{-1})
- x. Harvest index

5. Detailed procedures for recording data

A brief outline of the data recording procedure followed during the study is given below:

5.1 Crop growth characters

5.1.1 Plant height (cm)

Five plants from each plot were randomly selected and marked for recording the plant height which was taken at 30, 45, 60, 75 DAT, and at harvest. The height of the five tagged paddy trees in the net plot area was measured from the base of the tree to the tip of the flag leaf, and the height of the tree was taken up to the tip of the panicle after heading and harvesting. The plant height was expressed as the average plant height in centimeters.

5.1.2 Number of tillers hill^{-1}

The number of tillers on hill^{-1} was counted at 30, 45, 60, 75 DAT, and at harvest from five randomly pre-selected hills and was expressed as the number hill^{-1}.

5.1.3 Dry weight of plant (gm)

The plants of 2 hills plot^{-1} uprooted from the second line were oven-dried until they reached a constant weight, and then the weight was measured by a digital weighing machine and finally calculated as g hill^{-1}. From which the weight of dry matter hill^{-1} was estimated at 45, 60, 75 DAT, and at harvest.

5.2 Yield and yield contributing characters

5.2.1 Effective tillers hill^{-1}

The tiller which bore the panicle was considered an effective tiller. The number of effective tillers of 5 selected hills was recorded and finally averaged for counting the effective tillers number hill^{-1}.

5.2.2 Ineffective tillers hill^{-1}

The tiller having no panicle was regarded as an ineffective tiller. The number of ineffective tillers of 5 selected hills was recorded and finally averaged for counting the ineffective tillers number hill^{-1}.

5.2.3 Panicle length (cm)

Ten panicles randomly selected from each plot were harvested separately. The length of panicles was measured in centimeters from the basal node of the rachis to the apex of each panicle, and finally, the average length of the panicle was worked out.

5.2.4 Filled grains panicle^{-1}

Grain was considered to be filled if any kernel was present therein. The number of total filled grains present on ten panicles was recorded, and the average value was determined.

5.2.5 Unfilled grains panicle^{-1}

Unfilled grain means the absence of any kernel inside in, and such grain present on each of 10 panicles was counted, and finally, the mean was calculated.

5.2.6 Total grains panicle^{-1}

The sum of the number of filled grains panicle^{-1} and the number of unfilled grains panicle^{-1} gave the total number of grains panicle^{-1}.

5.2.7 Weight of 1000-grain (g)

One thousand cleaned dried seeds were counted randomly from each sample, then oven-dried up to a constant weight, then weighed using a digital electric balance, and the mean weight was expressed in grams.

5.2.8 Grain yield (t ha^{-1})

Harvested bundles of rice plants from the central 1 m^2 of each plot (leaving border areas) were threshed and winnowed separately. After winnowing, the grain was sun-dried plot-wise up to 12% moisture content, and then their weight was recorded by digital electrical balance. The grain yield obtained from the net plot was finally converted into t ha^{-1}.

5.2.9 Straw yield (t ha^{-1})

During harvest, rice straw is a byproduct of rice cultivation. Rice straw is removed together with the rice grains during harvest and depending on whether it was gathered manually or mechanically, it is either piled or thrown throughout the field. Depending on the type and growth, the straw-to-rice ratio ranges from 0.7 to 1.4.

5.2.10 Biological yield (t ha^{-1})

The sum of grain yield and straw yield was regarded as biological yield. The biological yield was calculated with the following formula.

$$\text{Biological Yield (t ha}^{-1}) = \text{Grain Yield (t ha}^{-1}) + \text{Straw yield (t ha}^{-1})$$

5.2.11 Harvest index (%)

It denoted the ratio of economic yield (grain yield) to biological yield (grain yield+ straw yield) and was calculated with the following formula (Donald and Hamblin 1976; Roberts *et al.*,1993)

$$\text{Harvesting Index (\%)} = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100$$

5.3 Statistical analysis of data

The data obtained for different parameters will be statistically analyzed following the computer-based software Statistix V.10 and two-way analysis of variance (ANOVA). Fisher’s least significant difference (LSD) test at the 5% level of significance was applied. Correlation analysis was done considering a 5% level of significance.

CHAPTER IV

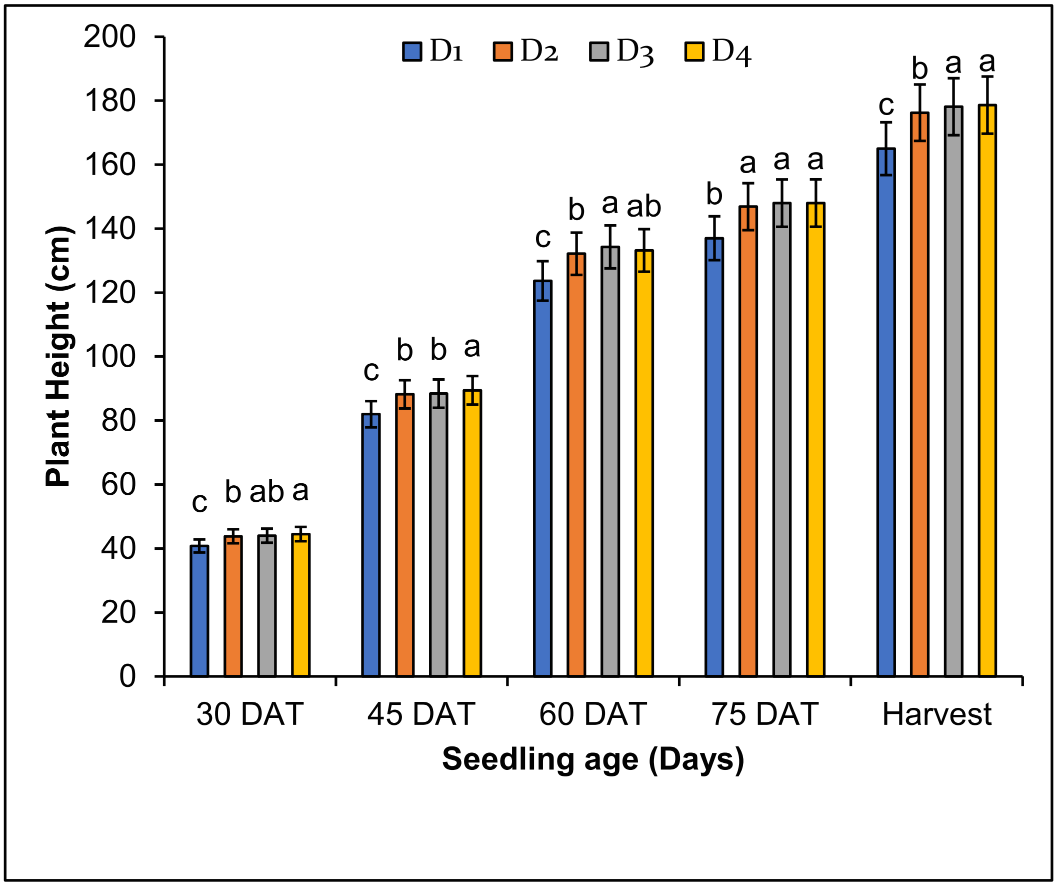
RESULTS AND DISCUSSION

This study aimed to determine the effect of seedling age and Seedling rate (no. of seedlings hill^{-1}) on the course of events and the yield of black rice during the Aman Season. The collection of data on growth characteristics, yield characteristics, and yield. The findings, along with potential interpretations, were presented under the following headings:

1. Plant height

1.1 Seedling age

The height of the black rice plant varied significantly depending on the age of the seedling at 30, 45, 60, 75, and harvest DAT (Figure 1). The results revealed that at 40 DAT, seedlings D_4 (40 days old) had the longest plant (44.49 cm), which was statistically comparable to seedlings D_3 (35 days old) in terms of length (43.98 cm). Similar to this, seedling $D_{1,}$ which was 25 days old, contained the shortest plant, measuring 40.80 cm. Compared to 35, 30, and 25 days old seedlings, respectively. At 45 DAT, D_4 had the numerically highest plant height (89.44 cm), whereas D_1 had the lowest plant height (81.98 cm). At 60 DAT, $D_{3,}$ and $D_{4,}$ respectively, had the highest plant heights (134.28 cm and 133.19 cm), whereas D_1 had the lowest plant height (123.65 cm). At 75 DAT, the highest plant heights were noted in D_4 (147.99 cm), D_3 (147.97 cm), and D_2 (146.87 cm), whereas D_1 (165 cm) seemed to have the lowest plant height. At harvest time, a similar pattern in plant height was also seen. According to Adhikari *et al.* (2013), older seedlings (40 days old) generated taller plants. Forty-day-old seedlings of rice produced the tallest plant compared to seedling aged 30 and 25days. as reported by Cao (2021) and Tadesse (2021). The optimum age of seedlings for growth parameters under the conventional method for transplanting aus, aman, and boro rice were 20-30, 30-40, and 35-45 days, respectively (Amin and Haque, 2009).

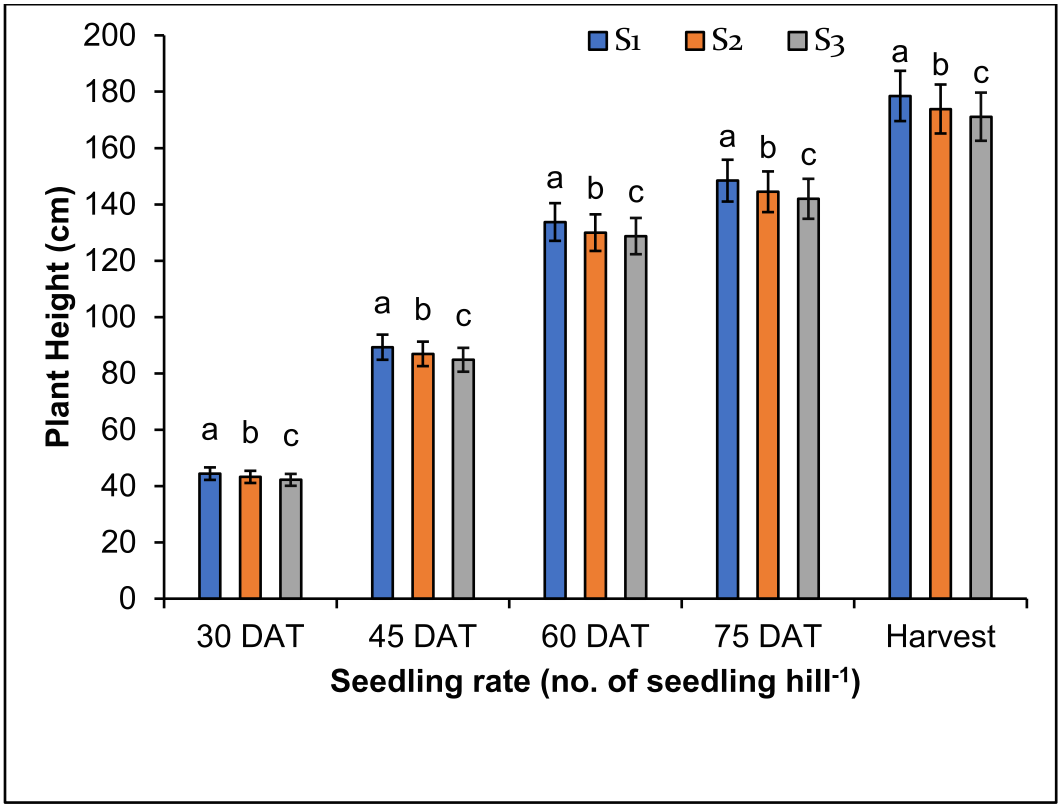


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 1. Effect of seedling age (d) on plant height of black rice

1.2 Number of Seedling hill^{-1}

Due to the various no. of seedlings hill^{-1}, there were statistically significant differences in the plant height of black rice at 30, 45, 60, 75, and Harvest DAT (Figure 2). S_1 (1 seedling hill^{-1}) had the tallest plant height (44.39 cm) at 30 DAT, while S_3 (3 seedlings hill^{-1}) had the shortest plant height (42.19 cm). S_1 (1 seedling hill^{-1}) had the tallest plant at 45 DAT (89.29 cm), while S_3 (3 seedlings hill^{-1}) had the shortest plant (84.82 cm). At 60 DAT, S_1 (1 seedling hill^{-1}) had the tallest plants (133.74 cm), while S_3 (3 seedlings hill^{-1}) and S_2 (2 seedlings hill^{-1}) had statistically comparable short plants (128.736 and 129.96 cm, respectively). At 75 and Harvesting time DAT, the maximum plant height for S_1 (1 seedling hill^{-1}) was (148.42 cm) and (178.50 cm) respectively, and the minimum plant height for S_3 (3 seedlings hill^{-1}) and S_2 (2 seedlings hill^{-1}) was (171.13 cm) and (141.98 cm), respectively. Joshi *et al.* (2021) reported that the highest plant height, test weight, etc., during rice cultivation from transplanting was recorded for one seedling $hill^{-1}$. Adhikari *et al.* (2013) reported that lower seeding density led to taller plants, more productive tillers per square meter, less sterility, and greater grain production. Krishna *et al.* (2008) reported that wider spacing of 40 × 40 cm was found to have a significant influence on growth parameters.



Here, S_1 = 1 Seedling $Hill^{-1}$, S_2 = 2 Seedling $Hill^{-1}$, S_3 = 3 Seedling $Hill^{-1}$. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 2. Effect of seedling rate (no. of seedlings $hill^{-1}$) on plant height of black rice

1.3 Combination effect of seedling age and seedling rate (no. of seedlings $hill^{-1}$)

The combination effect of seedling age and seedling rate produced statistically significant differences in plant height of black rice at 30, 45 DAT, and harvest, but non-significant at 60 and 75 DAT (Table 2) as well as At 30 DAT, the tallest plant (46.44 cm) was found in the treatment combination D_4S_1(40 days old seedling and 1 seedling $hill^{-1}$). In contrast, the shortest plant (39.67 cm) was found in the treatment combination D_1S_1 (25 days old seedling and 3 seedlings hill^{-1}). At 45, 60, 75, and harvest DAT, the treatment combination D_4S_1 (40 days old seedling and 1 seedlings hill^{-1}) produced the tallest plant (93.33, 137.28, 145.57, and 184.87 cm, respectively), whereas the treatment combination D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}) produced the shortest plant (79.611, 121.22, 133.56, and 161.6 cm) respectively. Adhikari *et al.* (2013) found that an interaction study between the two factors revealed that a 40-day-old seedling with a low seeding density generated the tallest plant in both the drought season of 2009 and the high-yielding season of 2010.

Table 2. Combination effect of seedling age and seedling rate on plant height of black rice

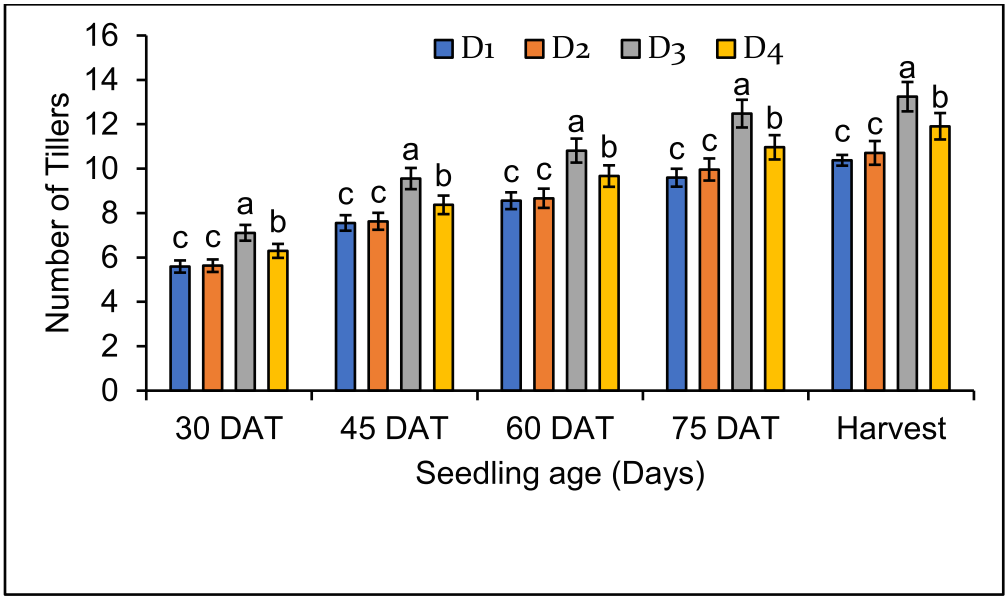
D S	Plant Height				
	30 DAT	**45 DAT**	**60 DAT**	**75 DAT**	**Harvest**
D_1S_1	41.56 ±0.35 f	83.72 ±0.64 f	126 ± 0.27 e	140.44 ± 0.87 f	168 ± 0.71 f
D_1S_2	41.18 ±0.22 f	82.61 ± 0.28 f	123.72 ± 0.80 e	137.01 ± 0.70 g	165.4 ± 0.57 f
D_1S_3	39.67 ± 0.00 g	79.61 ± 0.08 g	121.22 ± 0.42 f	133.56 ± 1.10 h	161.6 ± 0.43 g
D_2S_1	44.67 ± 0.33 b	89.89 ± 0.52 b	135.3 ± 0.77 ab	149.39 ± 0.97 bc	180.17 ± 1.47 bc
D_2S_2	43.11 ± 0.95 de	87.00 ± 1.42 de	129.89 ± 2.08 d	145.67 ± 2.18 de	173.35 ± 3.00 e
D_2S_3	43.67 ± 0.29 cd	87.72 ± 0.70 cd	131.22 ± 1.37 d	145.56 ± 1.10 de	175.23 ± 1.33 de
D_3S_1	44.89 ± 0.19 b	90.19 ± 0.31 b	136.39 ± 2.33 ab	150.89 ± 0.96 ab	180.97 ± 2.15 b
D_3S_2	44.33 ± 0.29 bc	88.89 ± 0.64 bc	134.22 ± 0.96 bc	147.44 ± 1.03 cd	178.83 ± 0.78 bc
D_3S_3	42.72 ± 1.23 e	86.11 ± 1.72 de	132.22 ± 1.26 cd	145.57 ± 2.40 de	174.57 ± 2.10 e
D_4S_1	46.44 ± 0.59 a	93.33 ± 1.09 a	137.28 ± 0.93 a	152.94 ± 0.67 a	184.87 ± 1.32 a
D_4S_2	44.33 ± 0.73 bc	89.17 ± 0.95 bc	132 ± 0.71 cd	147.78 ± 0.96 cd	177.87 ± 1.32 cd
D_4S_3	42.70 ± 0.35 e	85.83 ± 0.36 e	130.28 ± 0.98 d	143.23 ± 0.42 e	173.13 ± 0.57 e
LSD	0.959	1.784	2.521	2.573	3.117

Here, dissimilar letter differs significantly at 0.05 and 1 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling hill^{-1}, S_2 = 2 seedling hill^{-1}, S_3 = 3 seedling hill^{-1}

2. Number of tillers hill^{-1}

2.1 Seedling age

The number of black rice tillers hill^{-1} at 30, 45, 60, and 75 days after sowing and the harvest DAT differed significantly by seedling age (Figure 3) D_3 (35-day-old seedlings) had the highest number of tillers hill^{-1} (7.11) at 30 DAT, while D_1 (25-day-old seedlings) and D_2 (30-day-old seedlings) had the lowest number of tillers hill^{-1} (5.59), and (5.63) which was statistically equivalent. D_3 had the most tillers hill^{-1} at 45, 60, 75, and harvest DAT (9.56, 10.82, 12.49, and 13.24), while D_1 and D_2 had comparable numbers of tillers hill^{-1} (7.56, 8.5, 9.6, and 10.28). According to Adhikari *et al.* (2013), older seedlings (40 days old) generated taller plants, more productive tillers, more ripe grains, and greater grain and straw production.

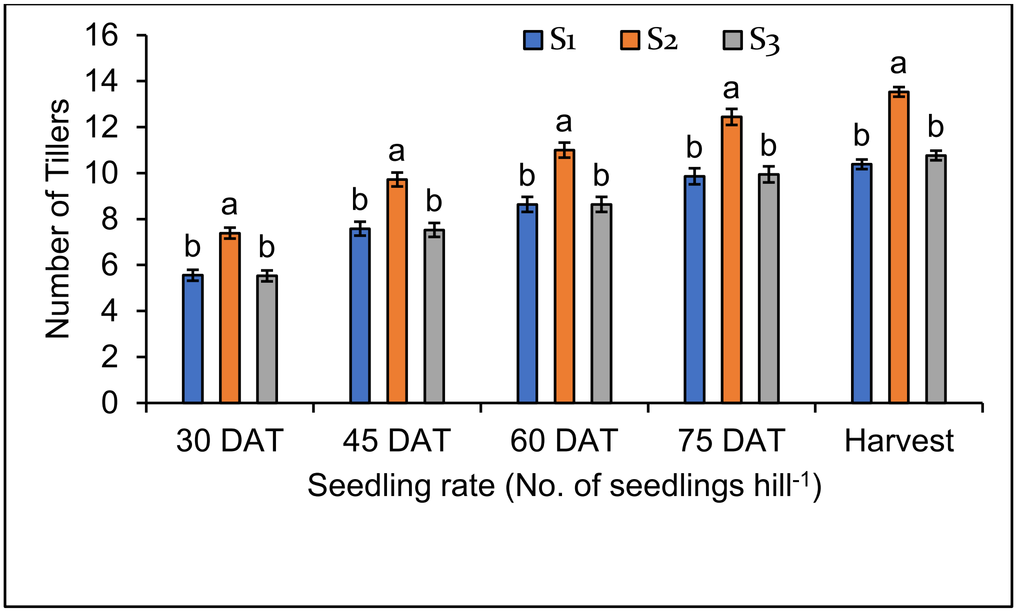


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 3. Effect of seedling age on number of tillers hill^{-1} of black rice

2.2 Seedling rate (no. of seedlings hill^{-1})

Due to the different seedling numbers per hill^{-1}, there were statistically significant differences in the number of tillers per hill^{-1} of black rice at 30, 45, 60, 75 DAT, and at harvest (Figure 4). S_2 (2 seedlings hill^{-1}) had the highest number of tillers hill^{-1} (7.39) at 30 DAT, followed by S_3 (3 seedlings hill^{-1}) and S_1 (1 seedling hill^{-1}) (5.53 and 5.56, respectively). Two seedlings hill^{-1} produced more tillers ha^{-1} than 1 and 3 seedlings hill^{-1}, respectively. S_2 had the greatest number of tillers hill^{-1} at 45, 60, 75, and harvest DAT (9.72, 11, 12,44, and 13.53), whereas S_1 had the lowest number of tillers per hill^{-1} (7.58, 8.63, 9.86, and 10.01), which was statistically equivalent to S_3 (7.53, 8.64, 9.94, and 10.77). Joshi *et al.* (2021) observed that two seedling hill^{-1} produced the maximum plant height, most productive tillers, etc., in rice cultivation from transplanting.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 4. Effect of seedling rate on number of tillers hill^{-1} of black rice

2.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination effect of seedling age and seedling rate was non-significant for the number of tillers hill^{-1} of black rice at ages 30, 45, and 60. Statistically significant differences were observed at 75 DAT and harvest (Table 3). At 30 DAT, the highest number of tillers hill^{-1} (8.33) was observed in the treatment combinations D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}) and D_4S_2 (40 days old seedling and 2 seedlings hill^{-1}) while the lowest number (4.33) was observed in the treatment combination D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}). At 45 DAT, the highest number of tillers hill^{-1} (11.11 and 10) was observed in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}) and D_4S_2 (40 days old seedling and 2 seedlings hill^{-1}), which are statistically equivalent, while the lowest number of tillers hill^{-1} (6, 7, and 7.0) was observed in the treatment combinations of D_1S_3, D_2S_3, and D_4S_1, which are statistically equivalent. At 60 DAT, the highest number of tillers hill^{-1} (12.67 and 11.44) were found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}) and D_4S_2 (40 days old seedling and 2 seedlings hill^{-1}), which are statistically equivalent, and the lowest number (7.0) was found in the treatment combination of D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}), which is statistically equivalent to the treatment combination of D_2S_3 (30 days old seedling and 3 seedlings hill^{-1}) and D_4S_1 (40 days old seedling and 1 seedlings hill^{-1}). At 75 DAT, the highest number of tillers hill^{-1} was observed in the treatment combination D_3S_2 (8.0), which is statistically similar to D_4S_2 (13.11), and the lowest number of tillers hill^{-1} was observed in the treatment combinations D_1S_3 (8.0), D_2S_3 (9.11), and D_4S_1 (9.0). Joshi *et al.* (2021) reported that rice output was increased by transplanting two seedlings per hill instead of one, three, or four seedlings hill^{-1}. As reported by Adhikari *et al.,* (2013), lower seeding density led to taller plants, more productive tillers m^{-2}, less sterility, and greater grain production.

Table 3. Combination effect of seedling age and seedling rate on the number of tillers hill^{-1} of black rice

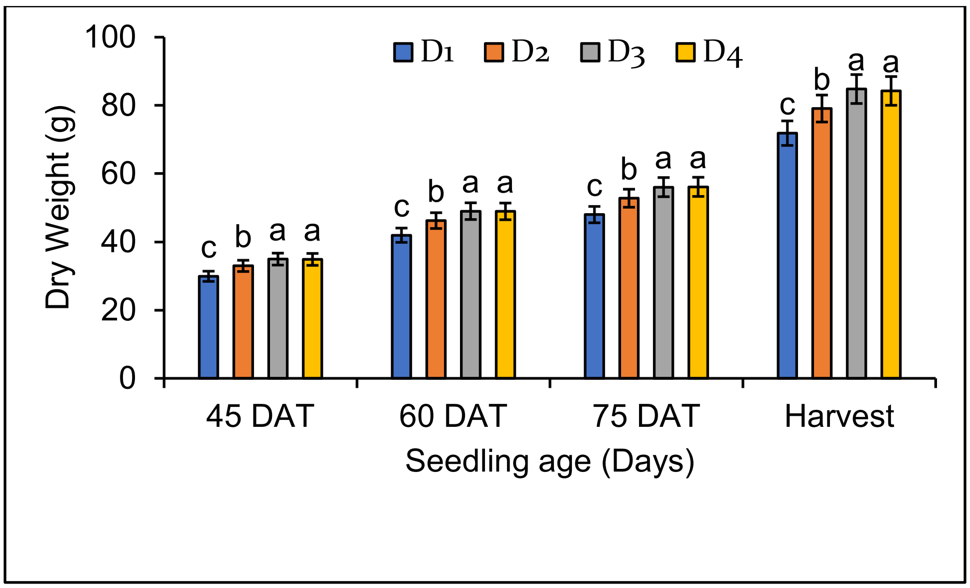
DS	Number of Tillers Hill^{-1}				
	30 DAT	**45 DAT**	**60 DAT**	**75 DAT**	**At harvest**
D_1S_1	5.44±0.16def	7.44±0.14de	8.44 def	9.56±0.16de	10.2±0.16d
D_1S_2	7±0.27bc	9.22±0.14bc	10.222 bc	11.22±0.16c	12.07±0.25c
D_1S_3	4.33±0.27g	6±0.41f	7.000 g	8±0.47f	8.87±0.38e
D_2S_1	5.33±0.72ef	7.33±0.62de	8.333 efg	9.56±0.87de	10±0.71d
D_2S_2	6.56±0.42c	8.56±0.36cd	9.667 cde	11.22±0.42c	12.33±0.25c
D_2S_3	5±0.54fg	7±0.47ef	8.000 fg	9.11±0.68ef	9.8±0.28d
D_3S_1	6.33±0.47cd	8.56±0.49cd	9.778 cd	11.33±0.72c	11.8±0.59c
D_3S_2	8.33±0.72a	11.11±0.95a	12.667 a	14.22±1.23a	15.53±0.25a
D_3S_3	6.67±0.47c	9±0.62bc	10.000 c	11.89±0.87bc	12.4±0.57c
D_4S_1	5.11±0.42fg	7±0.47ef	8.000 fg	9±0.54ef	9.53±0.34de
D_4S_2	7.67±0.47ab	10±0.62ab	11.444 ab	13.11±0.87ab	14.2±0.33b
D_4S_3	6.11±0.16cde	8.11±0.14cde	9.556 cde	10.78±0.42cd	12±0.33c
LSD	0.950	1.213	1.314	1.423	0.829
Pr > F (DS)	0.071	0.071	0.052	0.047	<0.0001

Here, dissimilar letter differs significantly at 0.05 and 1 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1};

3. Dry weight hill^{-1}

3.1 Seedling age

The dry matter hill^{-1} of black rice varied significantly at 45, 60, 75 DAT, and at harvest for various seedling ages (Figure 5). D_1 (25 days old seedling) at 45 DAT had the lowest dry matter hill^{-1} (29.92 g), while D_3 (35 days old seedling) had the highest dry matter hill^{-1} (34.95 g), which was statistically equivalent (34.87 g) to D_4 (40 days old seedling). At 75 DAT, D4 had the highest dry matter hill^{-1} value numerically (56.13 g), D_3 had the highest statistically (56.05 g), and D_1 (25 days old seedling) had the lowest weight (47.99 g). D_3 (35 days old seedlings) had the highest value numerically (84.8 g), which is statistically similar to the D_4 (84.25 g), and D_1 (25 days old seedlings) had the lowest value (71.87 g) at harvest DAT. According to Adhikari *et al.* (2013), older seedlings (40 days old) generated taller plants, more productive tillers, more filled grains, more dry matter, and greater grain and straw production.

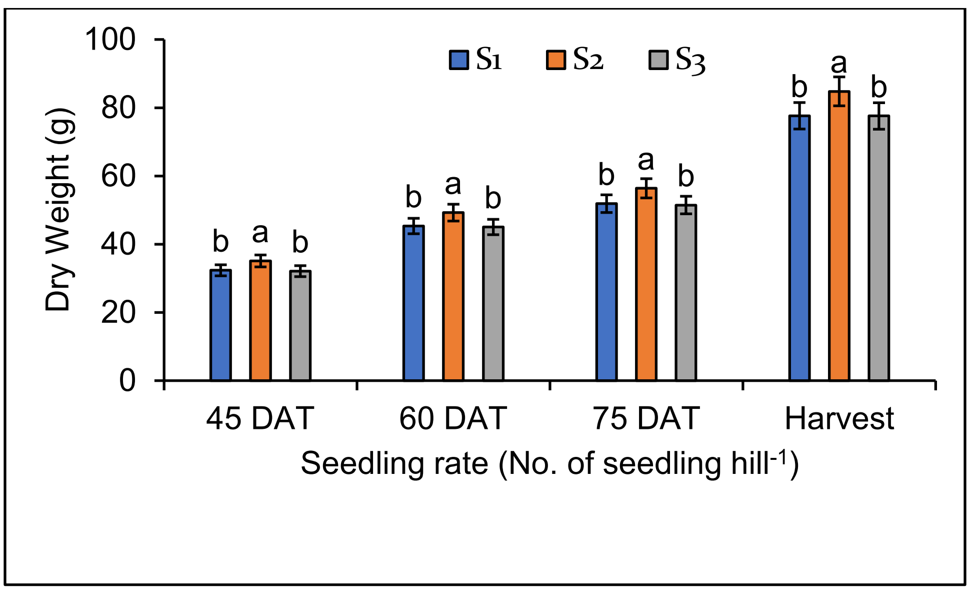


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 5. Effect of seedling age on dry weight (g) of black rice

3.2 Seedling rate (No. of seedlings hill^{-1})

Statistically significant differences in dry matter hill-1 of black rice were observed at 45, 60, 75 DAT, and harvest due to the varying number of seedlings hill^{-1} (Figure 6). At 45 DAT, S_2 (2 seedlings hill^{-1}) had the highest dry matter hill^{-1} (35.09 g), while S_3 (3 seedlings hill^{-1}) and S_1 (1 seedling hill^{-1}) had the lowest dry matter hill^{-1} (32.09 g and 32.34 g, respectively). At 60 DAT, S_2 (2 seedlings hill^{-1}) had the highest dry matter hill^{-1} (49.25 g), whereas S_3 and S_1 had the lowest (45.03 g and 45.33 g, respectively). At 75 DAT, S_2 (2 seedlings hill^{-1}) contained the highest dry matter hill^{-1} (56.38 g), while S_1 (1 seedling hill^{-1}) contained the lowest (51.48 g). At harvest, the highest dry matter hill^{-1} accumulation rate was observed, with S_2 having the highest value (84.70 g) and S_3 (3 seedlings hill^{-1}) having the lowest value (77.58 g), followed by S_1 (77.64 g). Joshi *et al.* (2021) observed that 2 seedlings hill^{-1} had the maximum dry matter content in rice cultivation after transplanting.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 6. Effect of seedling rate on dry weight (g) of black rice

3.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination of seedling age and seedling rate revealed significant differences in black rice dry matter hill^{-1} at 45, 60, 75 DAT, and harvest (Table 4). At 45 DAT, the treatment combination D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}) had the highest dry matter hill^{-1} (37.19 g), which was statistically similar to D_4S_2 (38.0 g), and the treatment combinations D_1S_1 (25 days old seedling and 1 seedling hill^{-1}) and D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}) had the lowest dry matter hill^{-1} (29.23 g and 29.56 g). At 60 DAT, the treatment combination D_4S_2 produced the highest dry matter hill^{-1} (53.27 g), followed by the treatment combination D_3S_2 (52.14 g), and the treatment combination D_1S_3 produced the least dry matter hill^{-1} (41.52 g), which was statistically similar to the treatment combination D_1S_1 (40.82 g). At 75 DAT, the highest dry matter hill^{-1} (61.29 g) was observed in the D_4S_2 treatment combination. In contrast, the lowest (46.82 g) was observed in the D_1S_1 treatment combination, which was statistically equivalent to the D_1S_3 treatment combination. The treatment combinations D_4S_2 (92.21 g) and D_3S_2 (91.33 g) yielded the highest dry matter hill^{-1} at harvest, while D_1S_1 and D_1S_3 yielded the least (70.5 g and 71.07 g, respectively). According to Adhikari *et al.* (2013), older seedlings (40 days old) generated taller plants, more productive tillers, more filled grains, more dry matter, and greater grain and straw production. Joshi *et al.* (2021) observed that two seedlings hill^{-1} had the maximum dry matter content in rice cultivation after transplanting.

Table 4. Combination effect of seedling age and seedling rate on dry weight of black rice

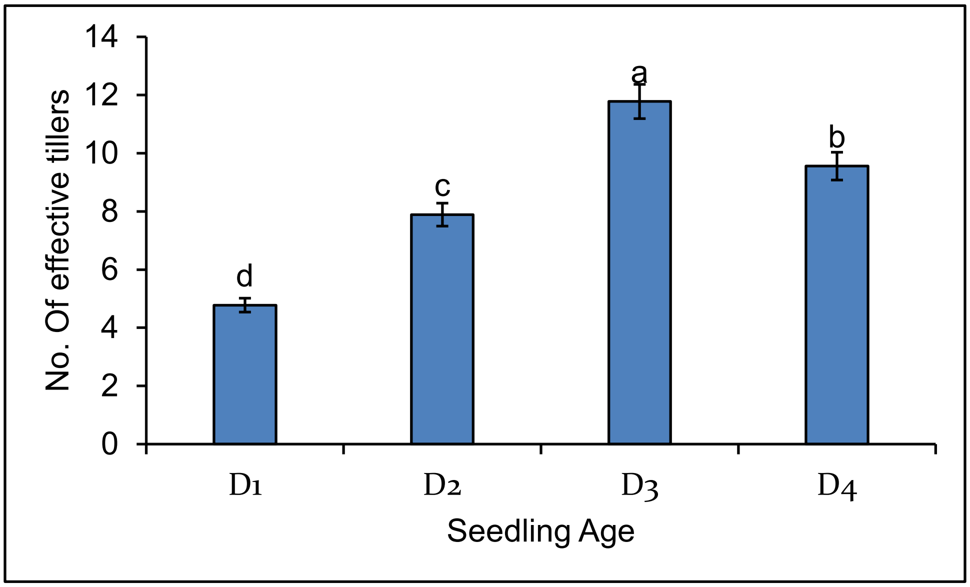
DS	Dry weight (g)			
	45 DAT	**60 DAT**	**75 DAT**	**At harvest**
D_1S_1	29.228±0.58f	40.817±0.72f	46.819±0.88g	70.5±1.4g
D_1S_2	30.97±0.26e	43.527±0.27e	49.659±0.36f	74.033±0.33f
D_1S_3	29.557±0.33f	41.522±0.33f	47.497±0.38g	71.067±0.54g
D_2S_1	32.28±0.4d	45.247±0.58d	51.666±0.58e	77.333±0.61e
D_2S_2	34.194±0.64b	48.052±0.75b	54.896±0.85c	81.6±0.76b
D_2S_3	32.417±0.36d	45.413±0.46d	51.826±0.6e	78.333±0.65de
D_3S_1	34.081±0.14b	47.747±0.23b	54.581±0.22c	81.8±0.08b
D_3S_2	37.192±0.24a	52.137±0.48a	59.684±0.43b	91.333±0.73a
D_3S_3	33.589±0.38bc	47.132±0.61bc	53.878±0.72cd	81.267±0.46b
D_4S_1	33.778±0.13b	47.489±0.35b	54.422±0.32c	80.91±0.34bc
D_4S_2	38±0.44a	53.278±0.59a	61.278±0.48a	92.213±1.03a
D_4S_3	32.822±1.07cd	46.052±1.33cd	52.692±1.55de	79.633±1.24cd
LSD	0.995	1.291	1.454	1.600
Pr > F (DS)	0.000	0.000	<0.0001	<0.0001

Here, dissimilar letter differs significantly at 0.05 and 1 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling $Hill^{-1}$, S_2 = 2 Seedling $Hill^{-1}$, S_3 = 3 Seedling $Hill^{-1}$

4. Effective tillers hill^{-1}

4.1 Seedling age

The number of effective black rice tillers per hill^{-1} varied significantly with seedling age (Figure 7). D_3 (35-day-old seedling) had the greatest number of effective tillers hill^{-1} (11.78), while D_1 (25-day-old seedling) had the least (4.78). According to Adhikari *et al.* (2013), older seedlings (40 days) produced taller plants, more productive tillers, more full grains, more dry matter, and greater grain and straw production.

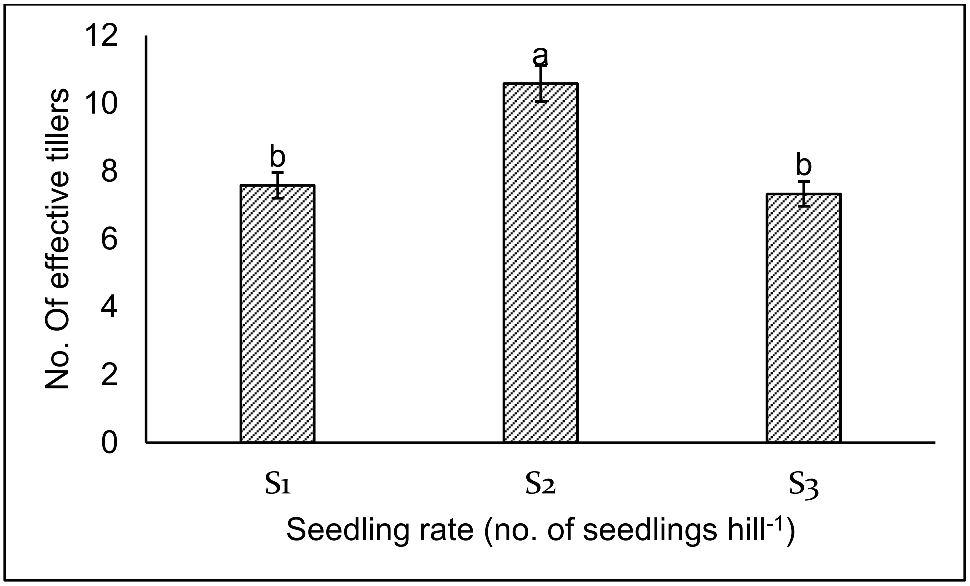


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 7. Effect of seedling age on effective tillers hill^{-1} of black rice

4.2 Seedling rate (no. of seedlings hill^{-1})

Due to the different seedling rates, there were statistically significant differences in the number of effective black rice tillers hill^{-1} (Figure 8). S_2 (2 seedlings hill^{-1}) had the highest number of effective tillers hill^{-1} (10.58), followed by S_3 (7.33) (3 seedlings hill^{-1}) and S_1 (7.59). S_3 had the lowest number of effective tillers hill^{-1} (7.33). The number of effective tillers produced by 2 seedlings hill^{-1} was greater than that of 3 seedlings hill^{-1} and 1 seedling hill^{-1}, respectively. Joshi *et al.* (2021) reported that the rice cultivation from transplanting 2 seedlings hill^{-1} compared to 1, 3, and 4 seedlings hill^{-1} gave the highest effective tillers and yield.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 8. Effect of seedling rate on effective tillers hill^{-1} of black rice

4.3 Combination effect of seedling age and seedling rate

Significant differences were observed in the number of effective tillers hill^{-1} of black rice due to seedling age and seedling rate (Table 5). The highest number of effective tillers hill^{-1} (14.0) was observed in the treatment combination D_3S_2 (35-day-old seedling and 2 seedlings hill^{-1}), and the lowest number was observed in the treatment combination D_1S_3 (2.0) (25 days old seedling and 3 Seedlings hill^{-1}). Adhikari *et al.* (2013), older seedlings (40 days) produced taller plants, more productive tillers, more full grains, more dry matter, and greater grain and straw production. Joshi *et al.* (2021) reported that rice cultivation from transplanting 2 seedlings hill^{-1} compared to 1, 3, and 4 seedlings hill^{-1} gave the highest effective tillers and yield.

Table 5. Combination effect of seedling age and seedling rate on effective tillers hill^{-1} of black rice

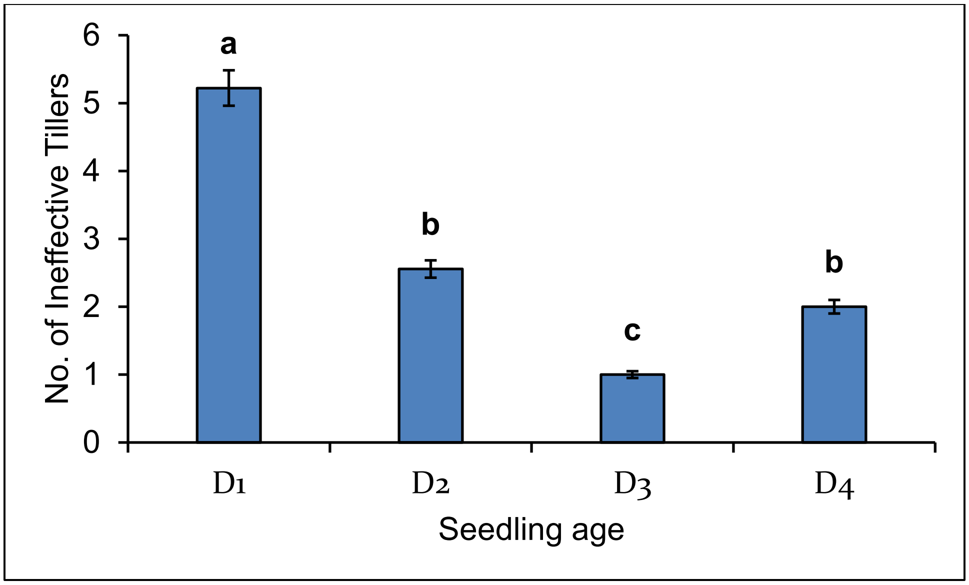
Seedling age × Seedling rate	Effective tillers
D_1S_1	5.667±0.47e
D_1S_2	6.667±0.47de
D_1S_3	2±0f
D_2S_1	7±0.82d
D_2S_2	9.667±0.47c
D_2S_3	7±0.82d
D_3S_1	10.667±0.47c
D_3S_2	14±0.82a
D_3S_3	10.667±0.47c
D_4S_1	7±0d
D_4S_2	12±0.82b
D_4S_3	9.667±0.47c
LSD	1.192
Pr > F (DS)	<0.0001

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}

5. Ineffective tillers hill^{-1}

5.1 Seedling age

The number of ineffective tillers hill^{-1} of black rice at different ages and seedling rates varied significantly (Figure 9). The results revealed that D_1 (25-day-old seedling) had the highest number of ineffective tillers hill^{-1} (3.08), while D_3 (35 days old seedling) had the lowest number (1.0). Adhikari *et al.* (2013), older seedlings (40 days) produced taller plants, more productive tillers, more filled grains, more dry matter, and greater grain and straw production.

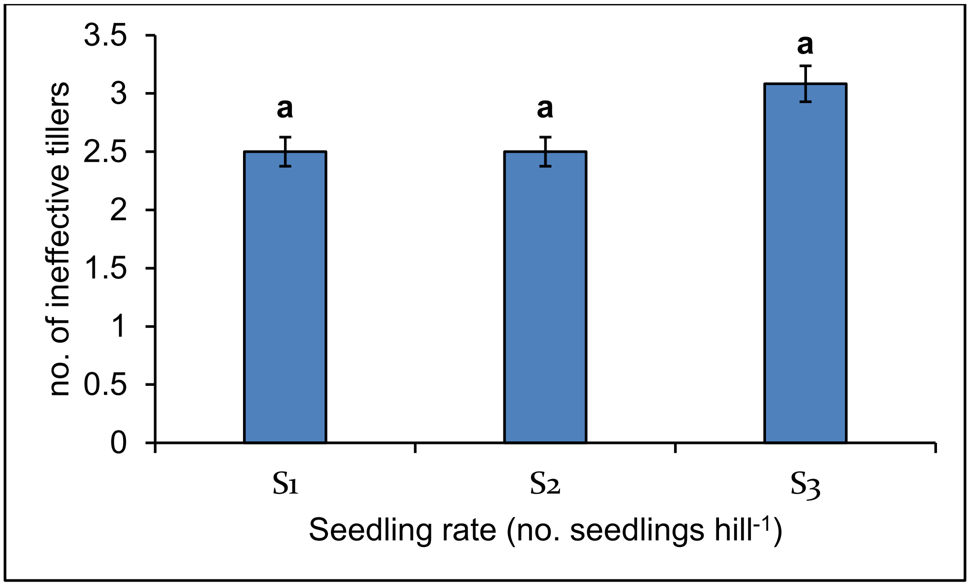


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 9. Effect of seedling age on ineffective tillers hill^{-1} of black rice

5.2 Seedling rate (no. of seedlings hill^{-1})

Due to the number of seedlings hill^{-1}, there were statistically significant differences in the number of ineffective black rice tillers hill^{-1} (Figure 10). S_3 (3 seedlings hill^{-1}) had the highest number of ineffective tillers hill^{-1} (3.08), which was statistically comparable (2.5 and 2.5) to S_1 (1 seedling hill^{-1}) and S_2 (2 seedlings hill^{-1}). Dhungana *et al.* (2021) discovered that transplanting with too many seedlings hill^{-1} increased the number of ineffective tillers, whereas transplanting with a single seedling hill^{-1} decreased the number of ineffective tillers.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 10. Effect of seedling rate (no. of seedlings hill^{-1}) on ineffective tillers hill^{-1} of black rice

5.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The effect of seedling age and seedling rate on the number of ineffective tillers hill^{-1} of black rice exhibited non-significant differences (Table 6). The highest number of ineffective tillers hill^{-1} (6.33) was observed in the treatment combination D_1S_3 (25-day-old seedling and 3 seedlings hill^{-1}), while the lowest number (0.66, 1.0, 1.33, 1.67, 2.0, and 2.33) was observed in the treatment combinations D_3S_1, D_3S_2, D_3S_3, D_4S_2, and D_4S_3, respectively. Dhungana *et al.* (2021) found that transplanting with younger seedlings and more seedlings per hill increased non-effective tillers but transplanting with one seedling per hill and older seedlings decreased non-effective tillers.

Table 6. Combination effect of seedling age and seedling rate on ineffective tillers hill^{-1} of black rice

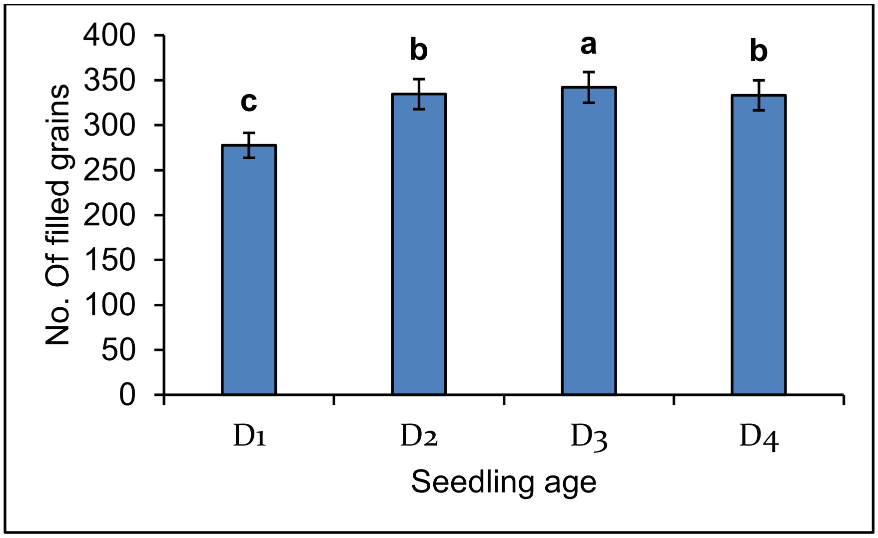
Seedling age × Seedling rate	Ineffective tillers
D_1S_1	4.33±0.47b
D_1S_2	5±0.82b
D_1S_3	6.33±0.47a
D_2S_1	2.67±0.47c
D_2S_2	2.33±0.47cd
D_2S_3	2.67±0.47c
D_3S_1	0.67±0.47f
D_3S_2	1±0.82ef
D_3S_3	1.33±0.47def
D_4S_1	2.33±0.47cd
D_4S_2	1.67±0.47cdef
D_4S_3	2±0.82cde
LSD	1.192
Pr > F (DS)	0.168

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}

6. Filled grains panicle^{-1}

6.1 Seedling age

For various seedling ages, the number of filled grain panicles^{-1} of black rice varied significantly (Figure 11). The results revealed that D_3 (35-day-old seedlings) had the highest number of filled grains (341.96), while D_1 (25-day-old seedlings) had the lowest number (277.50). Compared to younger seedlings, Adhikari *et al.* (2013) found that older seedlings (40 days) generated taller plants, more productive tillers, more filled grains, more significant dry matter, and greater grain and straw production.

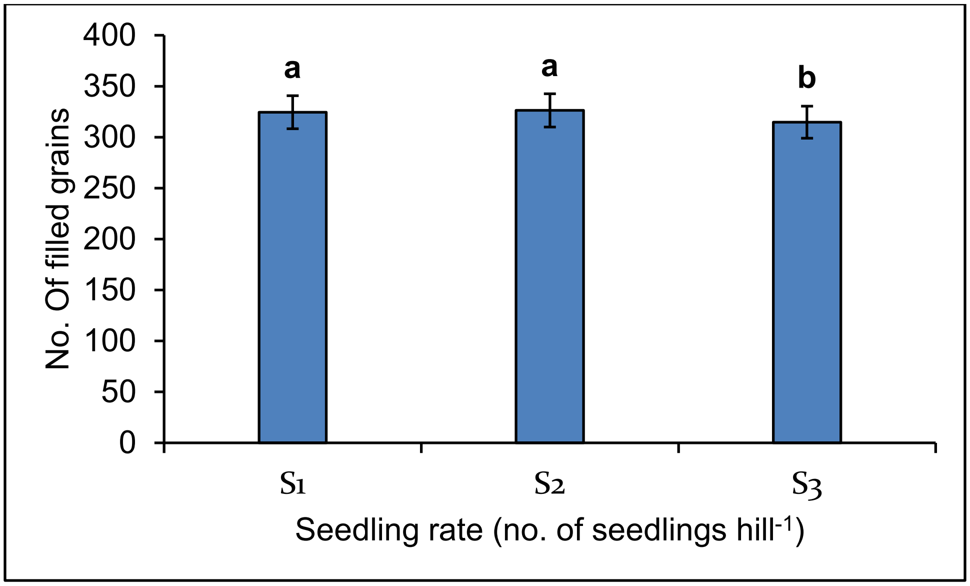


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 11. Effect of seedling age on filled grains of black rice

6.2 Seedling rate (no. of seedlings hill^{-1})

Due to the variation in seedling rate, there were statistically significant differences in the number of filled grain panicle^{-1} of black rice (Figure 12). S_2 (2 seedlings hill^{-1}) contained the most significant number (324.45) of filled grains (326.23), which was statistically comparable to S_1 (1 seedling hill^{-1}), whereas S_3 (3 seedlings hill^{-1}) contained the smallest number (314.67) of filled grains. Dhungana *et al.* (2021) reported that lower seedlings per hill transplanted plant produced a more significant number of grains plant^{-1}. Still, higher seedlings hill^{-1} transplanted plant had fewer grains panicle^{-1}.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 12. Effect of seedling rate (no. of seedlings hill^{-1}) on filled grains of black rice

6.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination effect of seedling age and seedling rate revealed statistically significant differences in the number of filled grains panicle^{-1} of black rice (Table 7). The highest number of filled grains (353.2) was found in the treatment combination D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}), while the lowest number (270.73) was found in the statistically comparable D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}) to D_1S_2 (25 days old seedling and 2 seedlings hill^{-1}) is (278.0). Dhungana *et al.* (2021) demonstrated that transplanting with optimal seedling age and fewer seedlings hill^{-1} increased the number of effective tillers.

Table 7. Combination effect of seedling age and seedling rate on filled grains of black rice

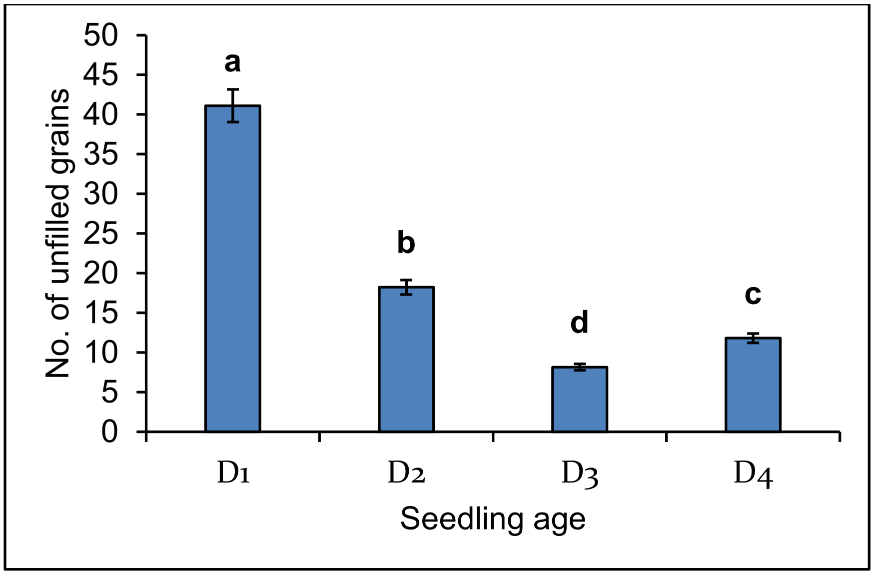
Seedling age × Seedling rate	Filled grains
D_1S_1	283.87 ± 5.88e
D_1S_2	278 ± 10.38ef
D_1S_3	270.73 ± 10.38f
D_2S_1	340.27 ± 3.27b
D_2S_2	335.33 ± 4.53bc
D_2S_3	327.8 ± 3.3cd
D_3S_1	334.73 ± 1.59bc
D_3S_2	353.2 ± 2.57a
D_3S_3	337.93 ± 1.79bc
D_4S_1	338.93 ± 2.6bc
D_4S_2	338.4 ± 3.1bc
D_4S_3	322.2 ± 4.81d
LSD	11.052
Pr > F (DS)	0.039

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}

7. Unfilled grains panicle^{-1}

7.1 Seedling age

Significant differences were observed in the number of unfilled grains of black rice based on seedling age (Figure 13). The results revealed that D_1 (25-day-old seedling) had the highest number of unfilled grains (41.11), while D_3 (8.16) had the lowest number of unfilled grains (35 days old seedling). According to Adhikari *et al.* (2013), younger seedlings (20 days) produced more unfilled grains panicle^{-1}, but older seedlings (40 days) produced comparatively fewer unfilled grains panicle^{-1}.

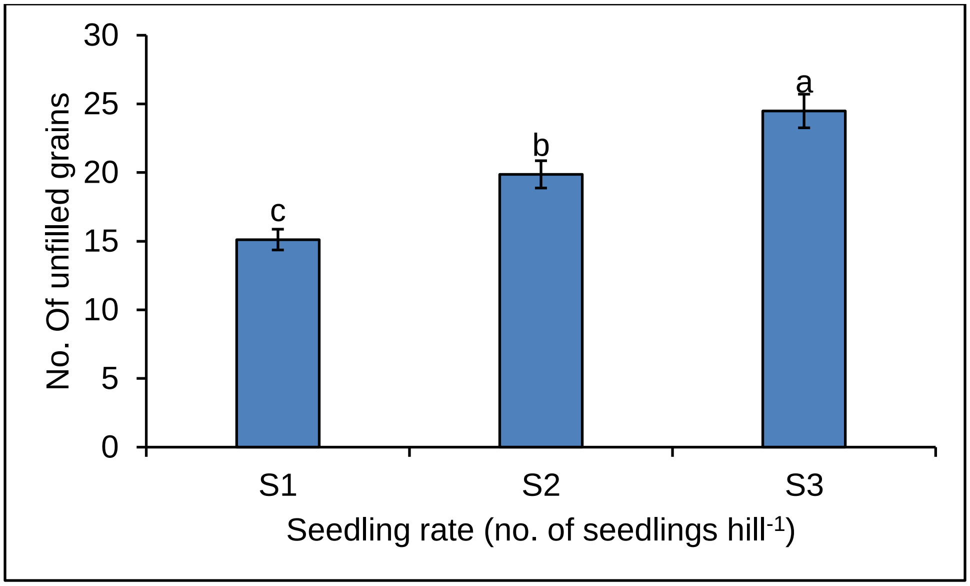


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 13. Effect of seedling age on unfilled grains of black rice

7.2 Seedling rate (No. seedlings hill^{-1})

Due to the different number of seedlings hill^{-1}, there were statistically significant differences in the number of unfilled grains panicle^{-1} of black rice (Figure 14). S_3 (3 seedlings hill^{-1}) contained the highest number of unfilled grains (24.48), while S_1 (1 seedling hill^{-1}) had the lowest number (15.12). Joshi *et al.* (2021) observed that rice cultivation with more seedlings hill^{-1} produced more unfilled grains panicle^{-1} than rice cultivation with fewer seedlings hill^{-1}.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 14. Effect of seedling rate (no. of seedlings hill^{-1}) on unfilled grains of black rice

7.3 Combination effect of seedling age and seedling rate

The combination effect of seedling age and seedling rate revealed significant differences in the number unfilled grains per panicle of black rice (Table 8). The treatment combination D_1S_3 (25-day-old seedling and 3 seedlings hill^{-1}) produced the highest number of unfilled grains (52.33), while the lowest numbers (6.88, 7.73, 9.8, 9.93, and 11.53) were observed for D_3S_1, D_3S_2, D_4S_1, D_4S_2, D_4S_3, and D_4S_2 respectively. According to Adhikari *et al.* (2013), younger seedlings (20 days) produced more unfilled grains panicle^{-1}, but older seedlings (40 days) grew comparably fewer unfilled grains panicle^{-1}. Joshi *et al.* (2021) observed that rice cultivation with more seedlings hill^{-1} produced more unfilled grains panicle^{-1} than rice cultivation with fewer seedlings hill^{-1}.

Table 8. Combination effect of seedling age and seedling rate (no. Of seedlings hill^{-1}) on unfilled grains of black rice

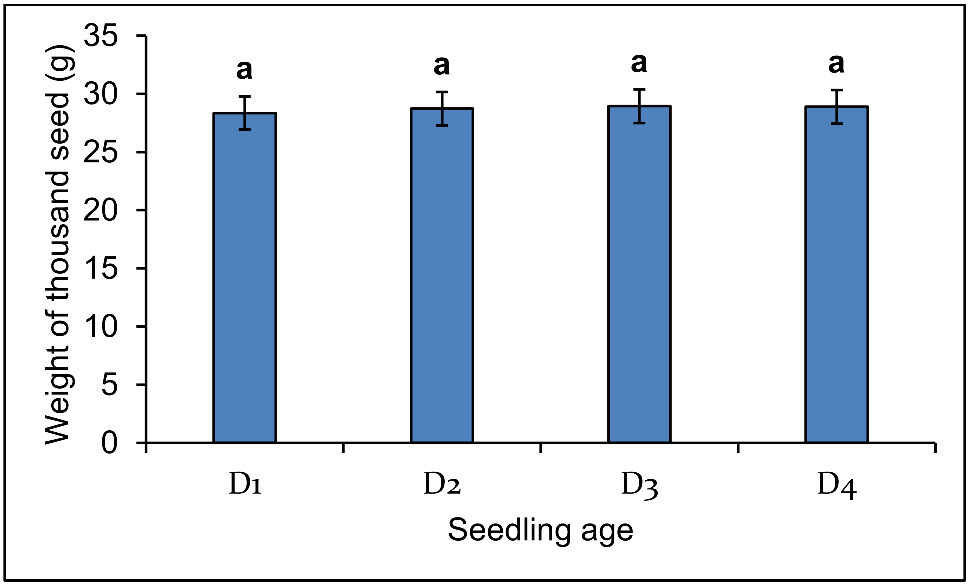
Seedling age × Seedling rate	Unfilled grains
D_1S_1	29.67 ± 6.74 c
D_1S_2	41.33 ± 3.79 b
D_1S_3	52.33 ± 2.54 a
D_2S_1	14.2 ± 0.85 ef
D_2S_2	18.87 ± 3.35 de
D_2S_3	21.6 ± 1.84 d
D_3S_1	6.8 ± 0.86 g
D_3S_2	7.73 ± 0.82 g
D_3S_3	9.93 ± 1.39 fg
D_4S_1	9.8 ± 1.45 fg
D_4S_2	11.53 ± 2.85 fg
D_4S_3	14.07 ± 1.54 ef
LSD	5.883
Pr > F (DS)	0.002

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}

8. Weight of 1000-grain

8.1 Seedling age

There was no significant difference in the weight of 1000 grains of black rice at different seedling ages (Figure 15). The maximum weight of 1000-grain (28.94 g) was recorded in treatment D_3 (35-day-old seedlings), and the remaining treatments were statistically comparable (28.354, 28.724, and 28.88 g in treatments D_1, D_2, and D_4, respectively). Adhikari *et al.* (2013) also recorded a similar increment in the weight of 1000-grain.

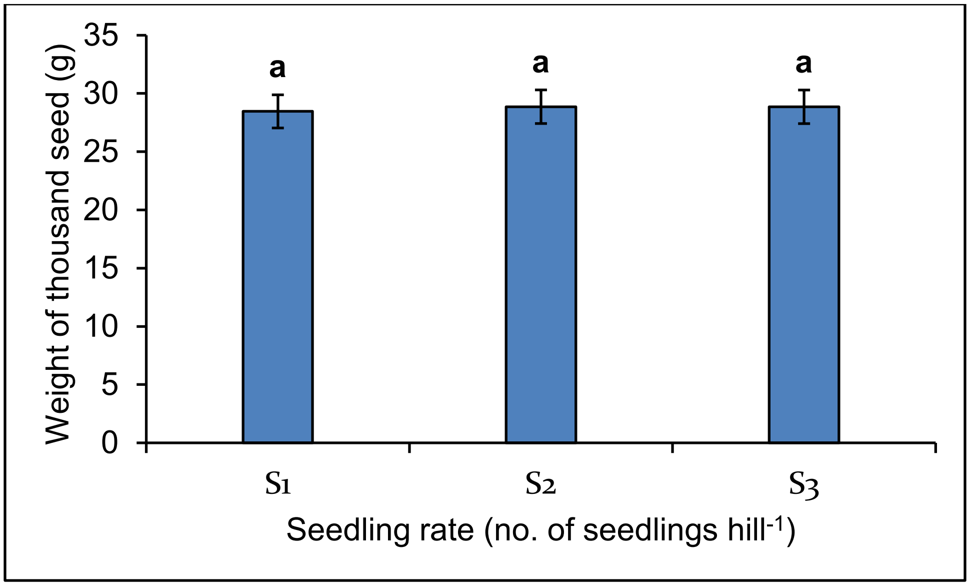


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 15. Effect of seedling age on weight of 1000 seed of black rice

8.2 Seedling rate (no. of seedlings hill^{-1})

Due to the different number of seedlings hill^{-1}, there were statistically non-significant differences in the weight of 1000 grains of black rice (Figure 16). S_2 (2 seedlings hill^{-1}) had the highest 1000-grain weight (28.863 g), which was statistically similar to S_3 (28.855 g) and S_1 (28.46 g). Adhikari *et al.* (2013) similarly observed a similar increase in the weight of one thousand grains. Joshi *et al.* (2021) found that rice cultivation with more seedlings hill^{-1} decreased grain weight panicle^{-1}.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 16. Effect of seedling rate (no. of seedlings hill^{-1}) on weight of thousand seeds of black rice

8.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

Significant differences were observed in the weight of 1000 grains of black rice due to the combined effect of seedling age and seedling rate (Table 9). The treatment combination D_3S_2 (35 days old seedling and 2 seedling hill^{-1}) resulted in the heaviest 1000-grain weight (30.67 g), while D_1S_2 resulted in the lightest 1000-grain weight (27.79 g) (25 days old seedling and 2 seedlings hill^{-1}). Adhikari *et al.* (2013) similarly observed a comparable increase in the weight of one thousand grains. Joshi *et al.* (2021) found that rice cultivation with more seedlings hill^{-1} decreased grain weight panicle^{-1}.

Table 9. Combination effect of seedling age and seedling rate on 1000 seed weight (g) of black rice

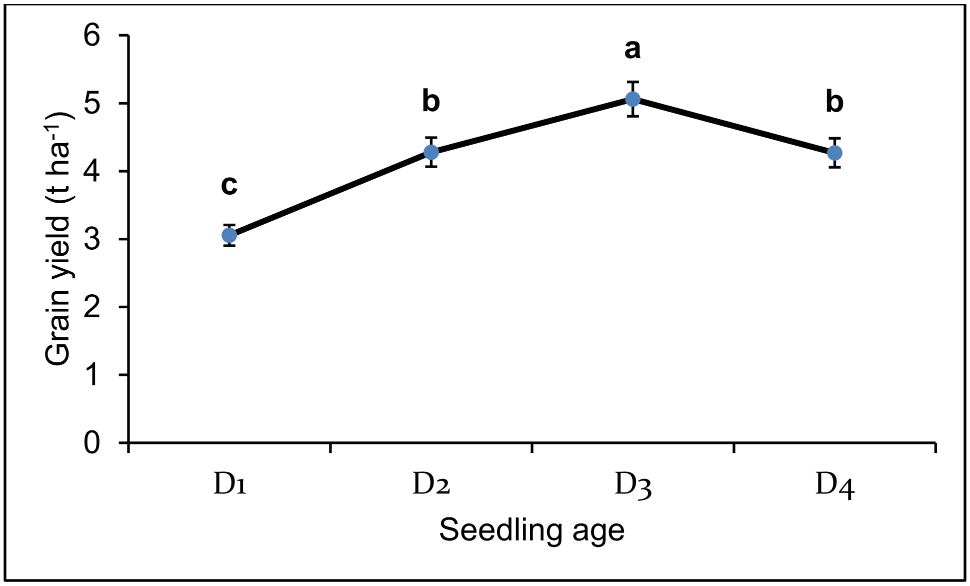
Seedling age × Seedling rate	1000-seed weight (g)
D_1S_1	28.6 ± 1.09 ab
D_1S_2	27.8 ± 0.5 b
D_1S_3	28.67 ± 1.22 ab
D_2S_1	27.94 ± 0.76 b
D_2S_2	29.08 ± 0.3 ab
D_2S_3	29.15 ± 0.44 ab
D_3S_1	28.07 ± 0.49 b
D_3S_2	30.67 ± 3.17 a
D_3S_3	28.07 ± 0.24 b
D_4S_1	29.23 ± 1 ab
D_4S_2	27.9 ± 0.8 b
D_4S_3	29.52 ± 1.22 ab
LSD	2.475
Pr > F (DS)	0.185

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}

9. Grain yield

9.1 Seedling age

The grain yield of black rice varied significantly according to the age of the seedlings (Figure 17). The results revealed that D_3 (35-day-old seedling) produced the highest grain yield (5.06 t ha^{-1}), and D_1 (25 days old seedling) had the lowest grain yield (3.05 t ha^{-1}). Adhikari *et al.* (2013) reported that older seedlings (40 days) produced taller plants, more productive tillers, more filled grains, higher dry matter, and a higher grain and straw yield.

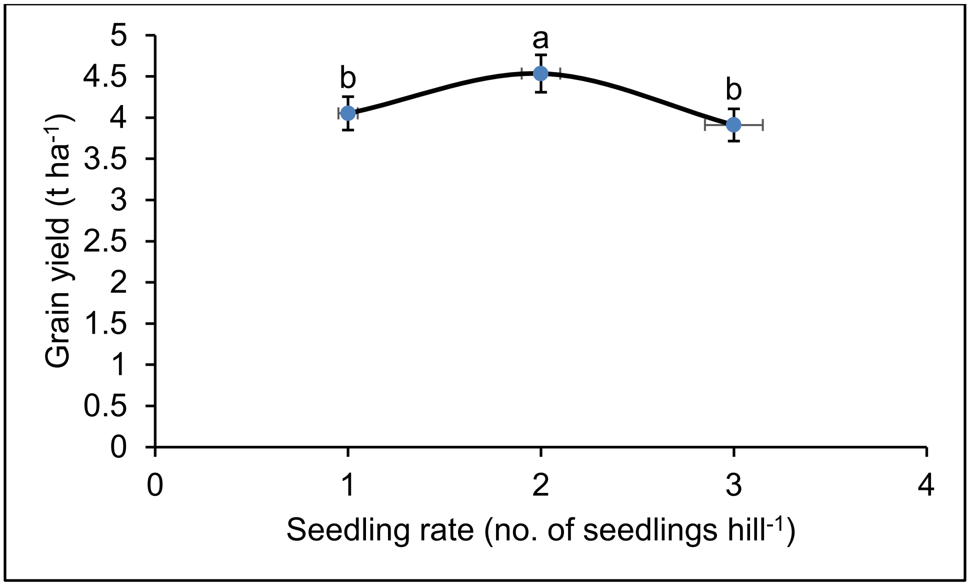


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 17. Effect of seedling age on grain yield of black rice

9.2 Seedling rate (Numbers of seedling hill^{-1})

Due to the different numbers of seedling hill^{-1}, there were statistically significant differences in the grain yield of black rice (Figure 18). S_2 (2 seedlings hill^{-1}) had the highest grain yield (4.54 t ha^{-1}), closely followed by S_1 (1 seedling hill^{-1}) (4.05 t ha^{-1}) and S_3 (3 seedlings hill^{-1}) with the lowest grain yield (3.91 t ha^{-1}). Dhungana *et al.* (2021) reported that the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than those transplanted with four seedlings hill^{-1}. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best grain yield was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed than the other treatments. An increase in grain yield may be due to the generation of more tillers hill^{-1} and whole grains panicle^{-1}, increasing grain yield.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 18. Effect of seedling rate (no. of seedlings hill^{-1}) on grain yield of black rice

9.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination effect of seedling age and seedling rate showed significant differences in the grain yield of black rice (Table 10). The highest grain yield (5.56 t ha^{-1}) was found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}), and the lowest grain yield (2.87 t ha^{-1}) was observed from D_1S_1 (25 days old seedling and 1 seedling hill^{-1}) which is statistically similar to the treatment combinations of D_1S_3 and D_1S_2 (3.09 t ha^{-1} and 3.2 t ha^{-1}) respectively. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best grain yield was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed than the other treatments. An increase in grain yield may be due to the generation of more tillers hill^{-1} and whole grains panicle^{-1}, increasing grain yield. Dhungana *et al.* (2021) reported that the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than those transplanted with four seedlings hill^{-1}.

Table 10. Combination effect of seedling age and seedling rate on grain yield of black rice

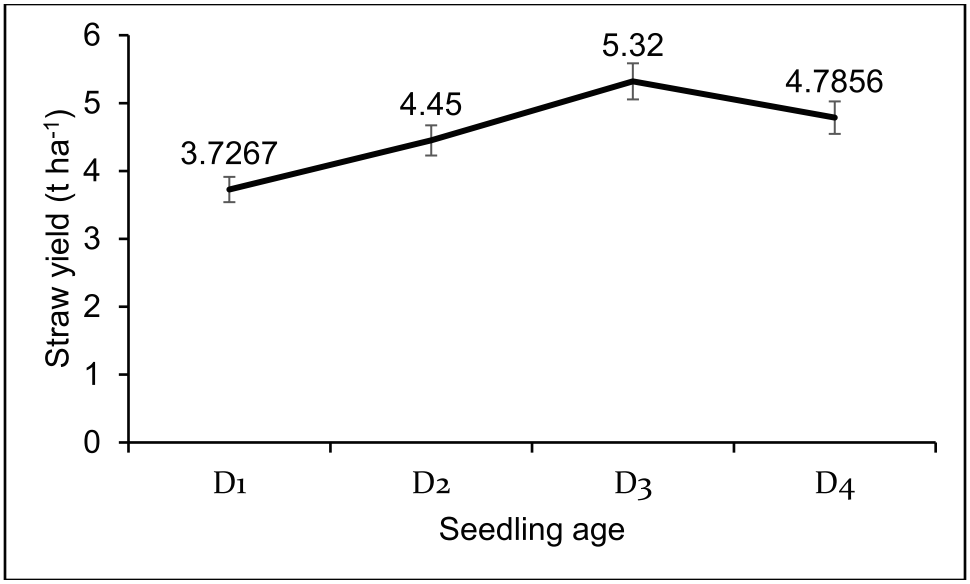
Seedling age × Seedling rate	Grain yield (t ha^{-1})
D_1S_1	2.87 ± 0.06 f
D_1S_2	3.2 ± 0.22 ef
D_1S_3	3.09 ± 0.49 ef
D_2S_1	4.83 ± 0.07 b
D_2S_2	4.69 ± 0.11 bc
D_2S_3	3.317 ± 0.07 e
D_3S_1	4.67 ± 0.13 bc
D_3S_2	5.57 ± 0.17 a
D_3S_3	4.95 ± 0.04 b
D_4S_1	3.83 ± 0.29 d
D_4S_2	4.69 ± 0.21 bc
D_4S_3	4.28 ± 0.19 c
LSD	0.430
Pr > F (D×S)	<0.0001

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling $Hill^{-1}$, S_2 = 2 Seedling $Hill^{-1}$, S_3 = 3 Seedling $Hill^{-1}$

10. Straw yield

10.1 Seedling age

Significant variation was recorded in the straw yield of black rice for different seedling ages (Figure 19). The results revealed that the highest straw yield (5.32 t ha^{-1}) was recorded in D_3 (35 days old seedling), and the lowest straw yield (3.73 t ha^{-1}) was found in D_1 (25 days old seedling). The D_3 (35 days old seedlings) gave a higher straw yield than that of D_4 (40 days old seedlings), D_2 (30 days old seedlings), and D_1 (25 days old seedlings), respectively. Adhikari *et al.* (2013) reported that older seedlings (40 days) produced taller plants, more productive tillers, more filled grains, higher dry matter, and a higher grain and straw yield.

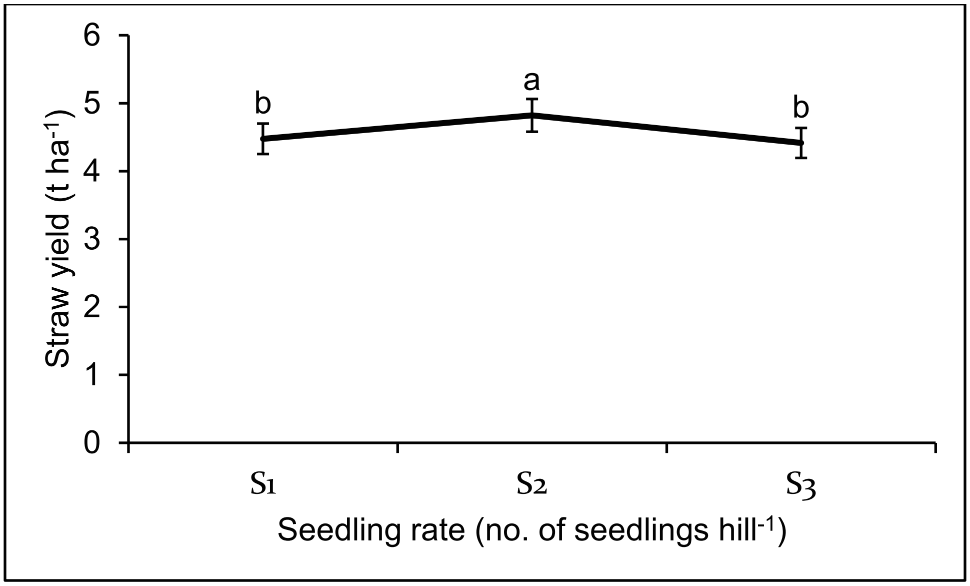


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 19. Effect of seedling age on straw yield of black rice

10.2 Seedling rate (no. of seedlings hill^{-1})

The straw yield of black rice showed statistically significant differences due to the number of seedlings hill^{-1} (Figure 20). The highest straw yield (4.82 t ha^{-1}) was found in S_2 (2 seedlings hill^{-1}), while the lowest straw yield (4.42 t ha^{-1}) was recorded in S_3 (3 seedlings hill^{-1}), which was statistically similar to the (4.48 t ha^{-1}) S_1 treatment. The S_2 (2 seedlings hill^{-1}) gave a higher straw yield than that of S_3 (3 seedlings hill^{-1}) and S_1 (1 seedling hill^{-1}), respectively. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best straw yield was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed the other treatments. An increase in straw yield may be due to the generation of more tillers hill^{-1} and whole grains panicle^{-1}, increasing straw yield. Dhungana *et al.* (2021) reported that the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than those transplanted with four seedlings hill^{-1}.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 20. Effect of seedling rate (no. seedlings hill^{-1}) on straw yield of black rice.

10.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination effect of seedling age and seedling rate showed significant differences in the straw yield of black rice (Table 11). The highest straw yield (5.69 t ha^{-1}) was found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}) and the lowest straw yield (3.66 t ha^{-1}) was observed in the treatment combination of D_1S_3 (25 days old seedling and 3 seedlings hill^{-1}) which was statistically similar to the (3.68 t ha^{-1}, and 3.84 t ha^{-1}) D_1S_3 (25 days old seedlings and 3 seedlings hill^{-1}) and D_1S_2 (25 days old seedlings and 2 seedlings hill^{-1}) treatment combinations, respectively. Dhungana *et al.* (2021) reported that according to the data, the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than the plant transplanted with four seedlings hill^{-1}. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best straw yield was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed the other treatments. An increase in straw yield may be due to the generation of more tillers hill^{-1}.

Table 11. Combination effects of seedling age and seedling rate (no. seedlings hill^{-1}) on the straw yield of black rice

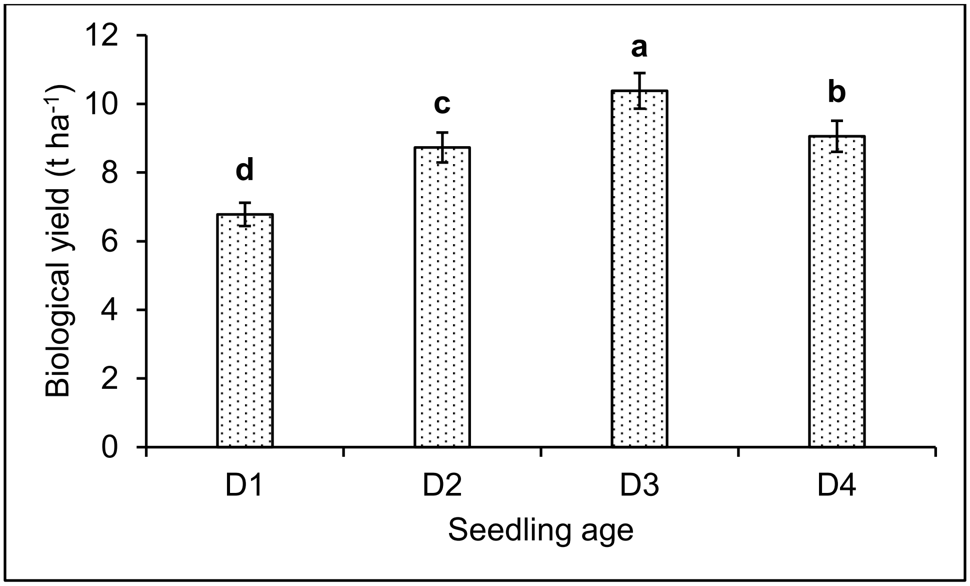
Seedling age × Seedling rate	Straw yield (t ha^{-1})
$D_1 \times S_1$	3.66 ± 0.09 g
$D_1 \times S_2$	3.84 ± 0.06 g
$D_1 \times S_3$	3.68 ± 0.19 g
$D_2 \times S_1$	4.35 ± 0.08 f
$D_2 \times S_2$	4.65 ± 0.08 def
$D_2 \times S_3$	4.34 ± 0.05 f
$D_3 \times S_1$	5.32 ± 0.37 b
$D_3 \times S_2$	5.69 ± 0.21 a
$D_3 \times S_3$	4.94 ± 0.04 cd
$D_4 \times S_1$	4.56 ± 0.09 ef
$D_4 \times S_2$	5.1 ± 0.16 bc
$D_4 \times S_3$	4.69 ± 0.14 de
LSD	0.328
Pr > F (D×S)	0.145

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 seedling hill^{-1}, S_2 = 2 seedling hill^{-1} S_3 = 3 seedling hill^{-1}

11. Biological yield

11.1 Seedling age

Significant variation was recorded in the biological yield of black rice for different seedling ages (Figure 21). The results revealed that the maximum biological yield (10.38 t ha^{-1}) was recorded in D_3 (35 days old seedling), and the minimum biological yield (6.78 t ha^{-1}) was found in D_1 (25 days old seedling). Adhikari *et al.* (2013) reported that the optimum age of seedlings produced taller plants, more productive tillers, more filled grains, higher dry matter, biological yield, and a higher grain and straw yield.

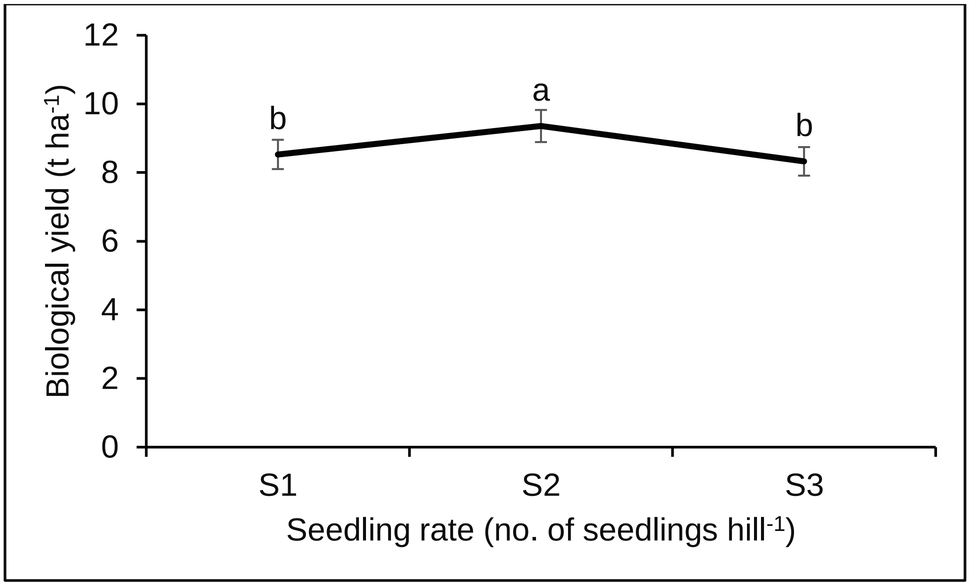


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 21. Effect of seedling age on biological yield of black rice

11.2 Seedling rate (no. of seedlings hill^{-1})

The biological yield of black rice showed statistically significant differences due to the different seedling rates (Figure 22). The highest biological yield (9.36 t ha^{-1}) was found in S_2 (2 seedlings hill^{-1}), while the lowest biological yield (8.33 t ha^{-1}) was recorded in S_3 (3 seedlings hill^{-1}). The S_2 (2 seedling hill^{-1}) gave a higher biological yield than that of S_3 (3 seedlings hill^{-1}) and S_1 (1 seedling hill^{-1}), respectively. Dhungana *et al.* (2021) reported that the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than those transplanted with four seedlings hill^{-1}.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 22. Effect of seedling rate (no. of seedlings hill^{-1}) on the biological yield of black rice

11.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination effect of seedling age and seedling rate showed significant differences in the biological yield of black rice (Table 12). The highest biological yield (11.25 t ha^{-1}) was found in the treatment combination of D_3S_2 (35 days old seedling and 2 seedlings hill^{-1}), and the lowest biological yield (6.53 t ha^{-1}) was observed in the treatment combination of D_1S_1 (25 days old seedling and 1 seedling hill^{-1}) which was statistically similar to the treatment combination of D_1S_3 (6.77 t ha^{-1}) and D_1S_2 (7.04 t ha^{-1}), respectively. Dhungana *et al.,* (2021) reported that the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than the plant transplanted with four seedlings hill^{-1}. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best grain yield was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed than the other treatments. An increase in biological yield may be due to the generation of more tillers hill^{-1}.

Table 12. Combination effect of seedling age and seedling rate on the biological yield of black rice

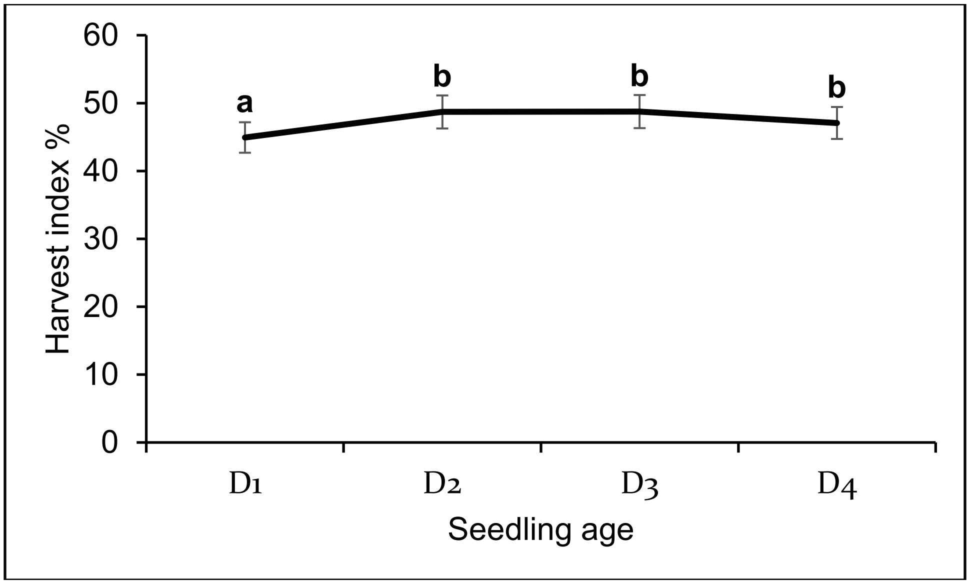
Seedling age × Seedling rate	Biological yield (t ha^{-1})
D_1S_1	6.53 ± 0.1 g
D_1S_2	7.04 ± 0.16 g
D_1S_3	6.77 ± 0.62 g
D_2S_1	9.18 ± 0 d
D_2S_2	9.34 ± 0.19 cd
D_2S_3	7.66 ± 0.12 f
D_3S_1	10 ± 0.25 b
D_3S_2	11.25 ± 0.38 a
D_3S_3	9.89 ± 0.08 bc
D_4S_1	8.4 ± 0.34 e
D_4S_2	9.79 ± 0.29 bc
D_4S_3	8.98 ± 0.06 d
LSD	0.559
Pr > F (DS)	0.000

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 seedling $hill^{-1}$, S_2 = 2 seedling $hill^{-1}$, S_3 = 3 seedling $hill^{-1}$

12. Harvest index

12.1 Seedling age

Significant variation was recorded in harvest index of black rice for different seedling ages (Figure 23). The results revealed that the highest harvest index (48.75 %) was recorded in D_3 (35 days old seedling), which was statistically similar to (48.69 %) D_2 (30 days old seedling) and closely followed by (47.07 %) D_4 (40 days old seedling) and the lowest harvest index (44.93 %) was found in D_1 (25 days old seedling). The D_3 (35 days old seedlings) gave a higher harvest index than 25, 30, and 40-day-old seedlings, respectively. Adhikari *et al.,* (2013) reported that the optimum age of seedlings produced taller plants, more productive tillers, more filled grains, higher dry matter, biological yield, and a higher grain and straw yield.

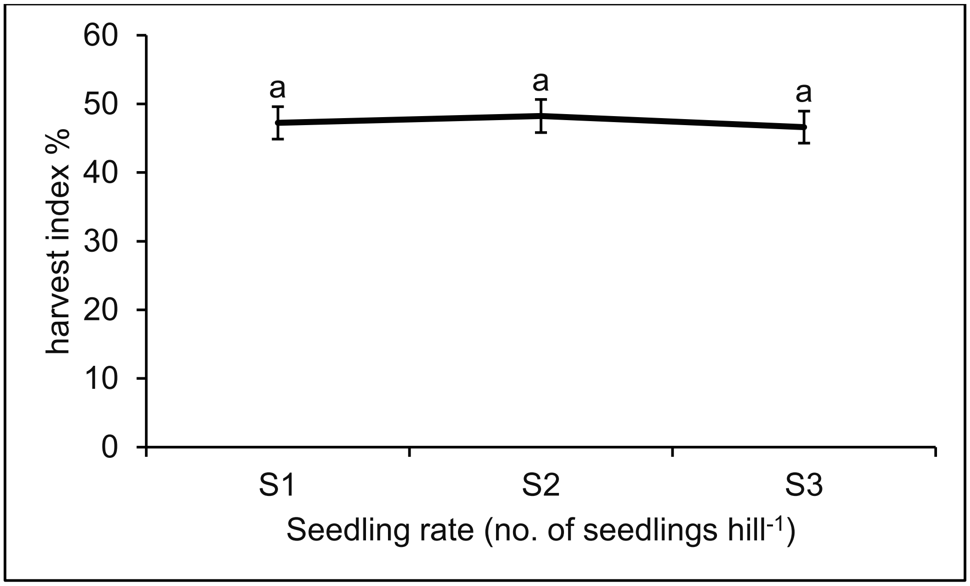


Here, D_1= 25 days, D_2= 30 days, D_3= 35 days, and D_4= 40 days old seedlings.Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test. Bars represent ±SD values of three biological replications

Figure 23. Effect of seedling age on the harvest index (%) of black rice

12.2 Seedling rate (no. of seedlings hill^{-1})

The harvest index of black rice showed statistically non-significant differences due to the different numbers of seedling rates (Figure 24). The numerical maximum harvest index (48.23 %) was found in S_2 (2 seedlings hill^{-1}), which is statistically similar to the S_1 (47.23 %) and S_3 (46.61 %), respectively. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best harvest index was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed than the other treatments. An increase in the harvest index may be due to the generation of more tillers hill^{-1} and full grains panicle^{-1}, increasing grain yield.



Here, S_1 = 1 Seedling Hill^{-1}, S_2 = 2 Seedling Hill^{-1}, S_3 = 3 Seedling Hill^{-1}. Values in a column with letters are significantly different at $p \leq 0.05$ applying Fisher's LSD test Bars represent ±SD values of three biological replications

Figure 24. Effects of seedling rate (no. of seedling hill^{-1}) on the harvest index (%) of black rice

12.3 Combination effect of seedling age and seedling rate (no. of seedlings hill^{-1})

The combination effectof seedling age and seedling rate showed significant differences in the harvest index of black rice (Table 13). The highest harvest index (52.59 %) was found in the treatment combination of D_2S_1 (30 days old seedling and 1 seedling hill^{-1}) which is statistically similar to the treatment combinations of D_2S_2 (50.19%), D_3S_3 (50.03 %), and D_3S_2 (49.39 %) and the lowest harvest index (43.29 %) was observed in the treatment combination of D_2S_3 (30 days old seedling and 3 seedlings hill^{-1}) which is statistically similar to D_1S_1 (43.93 %), D_1S_3 (45.42 %), D_1S_2 (45.43 %), and D_4S_1 (45.59 %) respectively. Dhungana *et al.* (2021) reported that the plant transplanted with two seedlings hill^{-1} produced a more significant economic output than the plant transplanted with four seedlings hill^{-1}. Ahmad and Hasanuzzaman (2012) also reported a similar finding, noting that the best harvest index was recorded in the treatment, including two seedlings hill^{-1}. The transplantation of two seedlings hill^{-1} significantly outperformed the other treatments. An increase in the harvest index may be due to the generation of more tillers hill^{-1} and full grains panicle^{-1}, increasing grain yield.

Table 13. Combination effect of seedling age and seedling rate (no. of seedlings $hill^{-1}$) on harvest index of black rice

Seedling age × Seedling rate	Harvest index (%)
D_1S_1	43.93 ± 0.87 ab
D_1S_2	45.43 ± 2.02 abc
D_1S_3	45.42 ± 3.4 abc
D_2S_1	52.6 ± 0.81 f
D_2S_2	50.19 ± 0.25 ef
D_2S_3	43.3 ± 0.22 a
D_3S_1	46.81 ± 2.4 bcd
D_3S_2	49.4 ± 0.34 def
D_3S_3	50.03 ± 0.17 def
D_4S_1	45.59 ± 1.63 abc
D_4S_2	47.91 ± 1.2 cde
D_4S_3	47.71 ± 1.84 cde
LSD	3.295
Pr > F (DS)	0.000

Here, dissimilar letter differs significantly at 0.05 and 0.01 percent level of probability. D_1 = 25 days, D_2 = 30 days, D_3 = 35 days and D_4 = 40 days old seedlings; S_1 = 1 Seedling $Hill^{-1}$, S_2 = 2 Seedling $Hill^{-1}$, S_3 = 3 Seedling $Hill^{-1}$

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted at the Sher-e-Bangla Agricultural University farm, Dhaka-1207, Bangladesh during the period from June 2021 to December 2021 to study the performance of Black rice as affected by seedling age and seedling rate. Black Rice was used as the test crop for this experiment.

The experiment comprised two factors. Factor A: Seedling age (4 levels); D_1: 25 days old seedling, D_2: 30 days old seedling, D_3: 35 days old seedling and D_4: 40 days old seedling and Factor B: Seedling rate: (3 levels); S_1: 1 seedling hill^{-1}, S_2: 2 seedlings hill^{-1}, S_3: 3 seedlings hill^{-1}.

The experiment was laid out in a randomized complete block design with three replications. Data on different growth parameters, yield attributes, and yield were recorded. At 30 DAT, the longest plant (44.49 cm) was recorded in D_4, and the shortest plant (40.80 cm) in D_1. At 45 DAT, the maximum plant height (89.44 cm) was found in D_4, whereas the minimum plant height (81.98 cm) was in D_1. At 60 DAT, the maximum plant height (134.28 cm) was observed in D_3, while the minimum plant height (123.65 cm) was in D_1. The same trend of plant height was also observed at 75 and harvest DAT. At 30 DAT, the maximum number of tillers hill^{-1} (6.29) was recorded in D_4 and the minimum number (5.59) in D_1. At 45 DAT, the maximum number of tillers hill^{-1} (8.37) was found in D_3, whereas the minimum number (7.56) was in D_1. At 60 DAT, the maximum number of tillers hill^{-1} (10.82) was observed in D_3, while the minimum number (8.56) was in D_1. The same trend of the number of tillers hill^{-1} was also observed at 75 DAT and harvest DAT.

At 45 DAT, the highest dry matter hill^{-1} (34.87 g) was recorded in D_4 and the lowest (29.92 g) in D_1. At 60 DAT, the numerically maximum dry mater hill^{-1} (48.94 g) was found in D_4, whereas the minimum (41.96 g) was observed in D_1. At 75 DAT, the highest dry matter hill^{-1} (56.13 g) was observed in D_4, while the lowest (47.99 g) was recorded in D_1. The maximum number of effective tillers hill^{-1} (11.78) was recorded in D_3, and the minimum number (4.78) in D_1. The maximum number of ineffective tillers hill^{-1} (5.22) was recorded in D_1 and the minimum number (1.0) in D_3. The maximum number of filled grains panicle^{-1} (341.96) was recorded in D_3 and the minimum number (277.53) in D_1. The maximum number of unfilled grains panicle^{-1} (41.11) was recorded in D_1, and the minimum number (8.16) in D_3. The highest weight of 1000 grains (28.94 g) was recorded in D_3, and the lowest weight (28.35 g) in D_1. The highest grain yield (5.06 t ha^{-1}) was recorded in D_3, and the lowest (3.05 t ha^{-1}) in D_1. The highest straw yield (5.32 t ha^{-1}) was recorded in D_3, and the lowest (3.73 t ha^{-1}) in D_1. The highest biological yield (10.38 t ha^{-1}) was recorded in D_3 and the lowest (6.78 t ha^{-1}) in D_1. The highest harvest index (48.75%) was recorded in D_3 and the lowest (44.93%) in D_1. At 45 DAT, the highest dry matter weight hill^{-1} (34.95 g) was recorded in D_3 and the lowest (29.92 g) in D_1. The same trend of data was recorded at 60, 75, and harvest DAT respectively.

In consideration of the Seedling rate at 30 DAT, the maximum plant height (44.39 cm) was found in S_1, while the minimum plant height (42.19 cm) in S_3. At 45 DAT, the maximum plant height (89.29 cm) was recorded in S_1, while the minimum plant height (84.82 cm) in S_3. At 60 DAT, the longest plant height (133.74 cm) was observed in S_1, whereas the shortest plant height (128.74 cm) was in S_3. At 75 DAT, the longest plant (148.42 cm) was recorded in S_1 and the shortest plant (141.98 cm) in S_3. At harvest DAT, the longest plant (178.50) was recorded in S_1 and the shortest plant (171.13 cm) in S_3. At 30 DAT, the maximum number of tillers hill^{-1} (7.39) was found in S_2, while the minimum number (5.53) in S_3 and (5.58) in S_1. At 45 DAT, the maximum number of tillers hill^{-1} (9.72) was recorded in S_2, while the minimum number (7.53) in S_2. At 60 DAT, the maximum number of tillers hill^{-1} (11.0) was observed in S_2, whereas the minimum (8.64) was in S_1. At 75 DAT, the maximum number of tillers hill^{-1} (12.44) was recorded in S_2 and the minimum (9.86) in S_1. At harvest DAT, the maximum number of tillers hill^{-1} (13.53) was recorded in S_2 and the minimum (10.38) in S_1. At 45 DAT, the highest dry matter hill^{-1} (35.09 g) was found in S_2, while the lowest (32.09 g) was in S_3. At 60 DAT, the highest dry matter hill^{-1} (49.25 g) was recorded in S_2, while the lowest (45.03 g) was recorded in S_3. At 75 DAT, the highest dry matter hill^{-1} (56.38 g) was observed in S_2, whereas the lowest dry matter hill^{-1} (51.87 g) was found in S_1. The maximum number of effective tillers hill^{-1} (10.58) was found in S_2, while the minimum number (7.33) was in S_3. The maximum number of ineffective tillers hill^{-1} (3.08) was found in S_3, while the minimum number (2.5) was recorded in S_2. The maximum number of unfilled grains panicle^{-1} (24.48) was found in S_3, while the minimum number (15.12) was in S_1. The highest weight of 1000 grains (28.86 g) was found in S_2, while the lowest (28.46 g) was in S_1. The highest grain yield (4.54 t ha^{-1}) was found in S_2, while the lowest (3.91 t ha^{-1}) was in S3. The highest straw yield (4.82 t ha^{-1}) was found in S_2, while the lowest (4.48 t ha^{-1}) was in S_1. The highest biological yield (9.36 t ha^{-1}) was found in S_2, while the lowest (8.53 t ha^{-1}) was in S_1. The highest harvest index (48.23%) was found in S_2, while the lowest (47.23%) was in S_1.

In the case of the combination effect of seedling age and seedling rate, at 30 DAT, the longest plant (46.44 cm) was found in the treatment combination of D_4S_1 and the shortest plant (39.67 cm) in D_1S_3. At 45 DAT, the longest plant (93.33 cm) was found in the treatment combination of D_4S_1 and the shortest plant (79.61 cm) in D_1S_3. At 60 DAT, the longest plant (137.28 cm) was found in the treatment combination of D_4S_1 and the shortest plant (121.22 cm) in D_1S_3. At 75 DAT, the longest plant (152.94 cm) was found in the treatment combination of D_4S_1 and the shortest plant (133.56 cm) in D_1S_3. At harvest DAT, the longest plant (184.87 cm) was found in the treatment combination of D_4S_1 and the shortest plant (161.60 cm) in D_1S_3. At 30 DAT, the maximum number of tillers hill^{-1} (8.33) was found in the treatment combination of D_3S_2 and the minimum number (4.33) in D_1S_3. At 45 DAT, the maximum number of tillers hill^{-1} (11.11) was found in the treatment combination of D_3S_2 and the minimum number (6.0) in D_1S_3. At 60 DAT, the maximum number of tillers hill^{-1} (12.67) was found in the treatment combination of D_3S_2 and the minimum number (7.0) in D_1S_3. At 75 DAT, the maximum number of tillers hill^{-1} (14.22) was found in the treatment combination of D_3S_2 and the minimum number (8.0) in D_1S_3. At harvest DAT, the maximum number of tillers hill^{-1} (15.53) was found in the treatment combination of D_3S_2 and the minimum number (8.87) in D_1S_3. At 40 DAT, the highest dry matter hill^{-1} (37.192 g) and (38.0 g) were found in the treatment combination of D_3S_2 and $D_4S_{2,}$ while the lowest (29.56 g) in D_1S_3. At 60 DAT, the highest dry matter hill^{-1} (52.137 g) and (53.28 g) were found in the treatment combination of D_3S_2 and $D_4S_{2,}$ while the lowest (41.52 g) was in D_1S_3. At 75 DAT, the highest dry matter hill^{-1} (61.28 g) was found in the treatment combination of D_4S_2, and the lowest (47.49 g) was observed in the treatment combination of D_1S_3. At harvest DAT, the highest dry matter hill^{-1} (92.23 g) and (91.33 g) were found in the treatment combination of D_4S_2 and D_3S_2, while the lowest (71.07 g) in D_1S_3. The maximum number of effective tillers hill^{-1} (14.0) was found in the treatment combination of D_3S_2 and the minimum number (2.0) in D_1S_3. The maximum number of ineffective tillers hill^{-1} (6.33) was found in the treatment combination of D_1S_3 and the minimum number (0.67) in D_3S_1. The maximum number of filled grains panicle^{-1} (353.20) was found in the treatment combination of D_3S_2 and the minimum number (270.73) in D_1S_3. The maximum number of unfilled grains panicle^{-1} (52.33) was found in the treatment combination of D_1S_3 and the minimum number (6.80) in D_3S_1. The highest weight of 1000 grains (30.67 g) was found in the treatment combination of D_3S_2, and the lowest weight (27.79 g) in D_1S_2. The highest grain yield (5.56 t ha^{-1}) was found in the treatment combination of D_3S_2, and the lowest grain yield (2.87 t ha^{-1}) in D_1S_1. The highest straw yield (5.69 t ha^{-1}) was found in the treatment combination of D_3S_2, and the lowest straw yield (3.66 t ha^{-1}) in D_1S_1. The highest biological yield (11.25 t ha^{-1}) was found in the treatment combination of D_3S_2 and the lowest (6.53 t ha^{-1}) in D_1S_1. The highest harvest index (52.59%) was found in the treatment combination of D_2S_1 and the lowest (43.29%) in D_2S_3.

Considering the findings of the present experiment, the following conclusion may be drawn:

i. Thirty-five days old seedling age of black rice planted in 2 seedlings hill^{-1} revealed higher grain yield compared to other seedling ages and seedling rates.

ii. Before the recommendation of seedling age and seedling rate to optimize black rice production, further study is needed in different agroecological zones of Bangladesh for regional adaptability.

CHAPTER VI

REFERENCES

Adhikari, B., Mehera, B. and Haefele, S. (2013). Impact of rice nursery nutrient management, seeding density and seedling age on yield and yield attributes. *Am. J. Plant Sci*. **4**(12):146-155.

Ahmad, S. and Hasanuzzaman, M. (2012). Integrated effect of plant density, N rates and irrigation regimes on the biomass production, N content, PAR use efficiencies and water productivity of rice under irrigated semiarid environment. *Not. Bot. Horti. Agrobot.* **40**(1): 201-211.

Ahmed, Q.N., Biswas, P.K. and Ali, M.H. (2007). Influence of cultivation methods on the yield of inbred and hybrid rice. *Bangladesh J. Agri*. **32**(2): 65-70.

Amin, A.K.M.K. and Haque, M.A. (2009). Seedling age influence rice (*Oryza sativa* L.) performance. *Philippine J. Sci*. **138**(2): 219-226.

Aslam, M.M., Zeeshan, M., Irum, A., Hassan, M.U., Ali, S., Hussain, R. and Rashid, M.F. (2015). Influence of seedling age and nitrogen rates on productivity of rice (*Oryza sativa* L.). *Am. J. Plant Sci*. **6**(09): 1361.

Baloch, A.W. Soomro, A.M. Javed, M.A. and Ahmed, M. (2002). Optimum plant density for high yield in rice (*Oriza sativa* L.). *Asian J. Plant Sci*. **1**(1): 25-27.

Bhowmik, S.K., Sarkar, M.A.R. and Zaman, F. (2012). Effect of spacing and number of seedlings per hill on the performance of aus rice cv. NERICA 1 under dry direct seeded rice (DDSR) system of cultivation. *J. Bangladesh Agric. Uni.* **10**(2): 191-195. https://doi.org/10.3329/jbau.v10i2.14681

Biswas, P.K. and Salokhe V.M. (2001). Effect of planting date, intensity of tiller separation and plant density on the yield of transplanted rice. *J. Agric. Sci., Camb.* **137**: 279-287.

Bozorgi, H.R. Faraji, A. Danesh, R.K. Keshavarz, A. Azarpour, E. and Tarighi, F. (2011). Effect of plant density on yield and yield components of rice. *World App. Sci. J.* **12**(11): 2053-2057.

Cao, J., Li, X., Wang, F., Huang, J. and Peng, S. (2021). The Responses of Yield Performance to Seedling Ages with Varied Seeding or Transplanting Dates of Middle-Season Rice in Central China. *J. Plant Growth Reg*.1-16.

Chaudhary, R.C. (2003). Speciality rices of the world: Effect of WTO and IPR on its production trend and marketing. *J. Food Agric. Environ.* **1**(2): 34–41.

Chowdhury, M.T.U., Sanker, A.U., Saker, M.A.R. and Kashem, M.A. (1993). Effect of variety and number of seedling hill^{-1} on the yield and its components on late transplanted aman rice. *Bangladesh J. Agril. Sci.* **20**(2): 311-316.

Dhillon, B.S., Kaur, G. and Mangat, G.S. (2021). Influence of seedling age on growth, productivity and heat use efficiency of rice genotypes in North West India. *J. Agrometeorol.* **23(**1): 30-37.

Dhungana, R., Bhandari, R., Rasmi Paude, P., Paudel, M.B., Bohora, S.L. and Bista, B. (2021). Effect of age and number of seedlings in productivity of Tilki rice in Dang, Nepal. *Nepalese J. Agric. Sci*. **5.**

Donald, C.M. and Hamblin, J. (1976). The biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Adv. Agron.* **28**: 361-405.

Dongarwar, U.R., Patankar, M.N. and Pawer, W.S. (2002). Response of hybrid rice to spacing and number of seedlings hill^{-1}. *J. Soils Crops*. **12**(2): 248-249.

Ehsanullah, K.J., Asghar, G., Hussain, M. and Rafiq, M. (2012). Effect of nitrogen fertilization and seedling density on fine rice yield in Faisalabad, Pakistan. *Soil Environ*. **31**(2): 152-156.

El-Rahem, A. and Abo-Marzoka, E.E. (2020). Differantral response of some rice cultibars to seedling age and plant spacing and their effect on growth traits and yield. *Egyptian J. Plant Breed*. **24**(3): 599-616.

FAO (Food and Agriculture Organization) (2009). FAO Production Yearbook, Food and Agriculture Organization, Rome, Italy. pp. 63-78.

Gurjar, G. N., Swami, S. and Meena, N. K. (2018). Effect of age of seedling and number of seedlings per hill on growth and yield of low land rice cultivation in Asia. *Int. J. Curr. Microbiol. Appl. Sci.* **7**(06): 3751-3760.

Haque, M.A. and Haque, M.M. (2016). Growth, yield and nitrogen use efficiency of new rice variety under variable nitrogen rates. *American J. Plant Sci.* **7**: 612-622.

Herliana, O., Widiyawati, I. and Hadi, S.N. (2019). The effect of stable manure and seedling number on growth and yield of black rice (*Oryza sativa* L. *Indica*). *Caraka Tani: J. Sust. Agric*. **34**(1): 13-21.

Hossain, M., and Deb, U.K. (2003). Trade liberalisation and the crop sector in Bangladesh (No. 23). Centre for Policy Dialogue (CPD).

Hushine, M. A. (2004). Effect of methods of transplanting and seedlings per hill on the growth and yield of transplant aman rice. M. S. Thesis, Department of Agronomy, BAU, Mymensingh, Bangladesh.

IRRI (International Rice Research Institute) (2014). World rice statistics. http://ricestat.irri.org:8080/wrsv3/entrypoint.htm.

IRRI (International Rice Research Institute) (2021). Rice Straw Energy. http://ricestraw.irri.org/rice-straw-energy. (2021).

Islam, M.R., Salam, M.A., Hannan, M.A. and Sarker, M.A.R. (2002). Effect of hill density and number of seedlings hill^{-1} on the yield and yield components of fine rice cv. Kalizira. *Bangladesh J. Agril. Sci*. **29**(2): 325-328.

Itani, T., and Ogawa, M. (2004). History and recent trends of red rice in Japan. *Japanese J. Crop Sci*. **73**(2): 137–147.

Ito, V.C. and Lacerda, L.G. (2019). Black rice (*Oryza sativa* L.): A review of its historical aspects, chemical composition, nutritional and functional properties, and applications and processing technologies. *Food Chem*. 301:125304. doi:10.1016/j.foodchem.2019.125304.

Joshi, P., Shrivastav, A., Dangal, N.K. and Paneru, P. (2021). Effect of different seed rates on yield and growth of short duration rice varieties under direct seeded condition. *Nepalese J. Agric. Sci*. **20**: 19-27.

Kabir, M.H. (2002). Growth and yield of hybrid and inbred varieties of boro rice as affected by number of seedlings per hill. M.S. thesis, BAU, Mymensingh, Bangladesh.

Karmakar, B., Sarkar, M.A.R., Uddin, M.R. and Biswas, M. (2002). Effect of row arrangements, number of seedlings hill^{-1} and nitrogen rates on yield and yield components of late transplanted aman rice. *Bangladesh J. Agril. Sci*. **29**(2): 275-281.

Kaur, M. and Dhillon, B.S. (2020). Effect of age of seedling on the performance of rice (*Oryza sativa* L.) cultibars. *J. Pharma. Phytochem*. **9**(6): 1275-1279.

Kawatra, A., Ghai, N. and Dhillon, B. S. (2021). Growth and reproductive efficiency of transplanted rice (*Oryza sativa*) in relation to seedling age and growth regulators. *Agric. Res*. **10**(4): 582-591.

Koudjega, K., Ablede, K.A., Lawson, I.Y.D., Abekoe, M.K. and Owusu-Bennoah, E. (2019). Assessing the effect of seedling age and time of urea supergranule application on rice growth, yield and nitrogen use efficiency. *West African J. Appl. Ecol*. **27**(1): 78-94.

Krishna, A. (2008). Influence of system of rice intensification (SRI) cultivation on seed yield and quality. *Karnataka J Agric Sci*. **21**(3): 369-372.

Kumar, G., Acharya, S., Pathak, S.K., Kumar, S., Homa, F. and Kumar, A. (2019). Studies on effect of age of seedling and levels of nitrogen on performance of hybrid rice (*Oryza sativa* L.). *Int. J. Biores. Stress Manag*. **10**(4): 382-388.

Lampayan, R., Xangsayasane, P. and Bueno, C. (2019). Crop performance and water productivity of transplanted rice as affected by seedling age and seedling density under alternate wetting and drying conditions in Lao PDR. *Water*. **11**(9): 1816.

Lile, N.S. (2021). Seedling age, nitrogen fertilizer, and seed storage time affect the seed germination of rice varieties in Nigeria. *J. Current Opinion Crop Sci*. **2**(2): 233-237.

Liu, Q., Zhou, X., Li, J. and Xin, C. (2017). Effects of seedling age and cultivation density on agronomic characteristics and grain yield of mechanically transplanted rice. *Sci. Rep*. **7**(1): 1-10.

Miah, M.N.H. Talukder, S. Sarkar, M.A.R. and Ansari, T.H. (2004). Effect of number of seedling per hill and urea supergranules on growth and yield of the rice cv. BINA Dhan4. *J. Biol.-Sci*. **4**(2): 122-129.

Mishra, A. and Salokhe, V.M. (2008). Seedling characteristics and the early growth of transplanted rice under different water regimes. *Exp. Agric*. **44**(3): 365-383.

Nisa, R.I., Wulandari, R.A. and Kurniasih, B. (2022). Effect of Salinity During Seedling Stage on the Growth and Yield of Black Rice (*Oryza sativa* L.'Jeliteng'). In IOP Conference Series: Earth and Environmental Science. pp. 012011.

Obulamma, U., Reddeppa, R. and Reddy, R. (2002). Effect of spacing and seedling number on growth and yield of hybrid rice. *J. Res. Angrau*. **30**(1): 75-78.

Patel, A.R., Patel, M.L., Patel, R.K. and Mote, B.M. (2019). Effect of different sowing date on phenology, growth and yield of rice–a review. *Plant Arc*. **19**(1): 12-16.

Paul, S.K.K., Akter, M., Sarkar, S.K. and Sarkar, M.A.R. (2018). Effect of nursery seeding density, age of seedling and number of seedlings hill^{-1} on the performance of short duration transplanted Aus rice (cv. Parija). *J. Bangladesh Agric.Univ.* **16**(2): 215-220.

Raut, S.D., Mahadkar, U.V., Varnekar, K.D., Chavan, L.S., Dodke, S.B., Burondkar, M.M. and Dhekale, J.S. (2019). Effect of age of seedling, levels and methods of fertilizer application on growth, yield attributes and yield of rice (*Oryza sativa* L.). *Int. J. Conserv. Sci.* **7**(5): 1641-1647.

Roberts, S.R., Hill, J.E., Brandon, D.M., Miller, B.C., Scardaci, S.C., Wick, C.M., and Williams, J. F. (1993). Biological yield and harvest index in rice: nitrogen response of tall and semidwarf cultivars. *J. Prod. Agric*. **6**(4): 585-588.

Shrestha, G., Chaudhary, R.D. and Shrestha, S. (2019). Rice Seedling Age Influences Yield Attributes in Rainfed Condition. *J. Agric. Environ. Int. Dev.* **20:** 205-216.

Shrirame, M.D., Rajgire, H.J. and Rajgire, A.H. (2000). Effect of spacing and seedlings number per hill on growth attributes and yield of rice under lowland condition. *Indian J. Soils Crops.* **10(**1): 109-113.

Sompong, R. Siebenhand, E.S. Linsberger, M.G. and Berghofer, E. (2011). Physicochemical and antioxidative properties of red and black rice varieties Thailand, China Sri Lanka. *Food Chem.* **124**(1): 132–140.

Srivasta, G.K. and Tripathi, R.S. (2000). Response of hybrid and composite rice to number of seedling and planting geometry. *Annual Agril. Res*. **19**(2): 235-236.

Sultan, T., Rashed, R.U., Shawan, S.I., Swapan, K.P. and Sarkar, A.R. (2018). Effect of age of Seedlings at Staggered Planting and Spacing on Growth and Yield of Transplant Aman Rice (cv. BRRI dhan 46). *Agric. Res.Tech*. **17**: 1-5.

Sultana, N., Hossain, M., Salam, M. and Rasul, S. (2020). Effect of age of seedling and level of nitrogen on the growth and yield of transplant aman rice CV. Binadhan-15. *Asian Plant Res. J*. **6**(4): 75-85.

Tadesse, Z. (2021). Effect of Seedling Age at Trans Planting on Yield and Yield Components of Low Land Rice in Fogera Plain. *Glob. j. biol. agric.* **11**(8): 2224-3208.

Thapa, S., Thapa, K., Shrestha, J. and Chaudhary, A. (2019). Effect of seedling age, seeding density and nitrogen fertilizer on growth and grain yield of rice (*Oryza sativa* L.). *Int. J. Applied Biol*. **3**(1): 81-87.

Thawait, D., Patel, A.K., Kar, S.A.M.A.P.T.I.K.A., Sharma, M.K. and Meshram, M.R. (2014). Performance of transplanted scented rice (*Oryza sativa* L.) under SRI based cultivation practices; a sustainable method for crop production. *The Bioscan*. **9**(2): 539-542.

Tian, Y., Zhao, X., Yin, B., Zeng, K. and Yan, X. (2022). Direct Canopy Uptake of Atmospheric Reactive Nitrogen: A Significant Pathway for Airborne Nitrogen Input into Rice Paddy Ecosystems. *J. Agric. Food Chem.* https://doi.org./10.1021/acs.jafc.2c04467

USDA. (2022). World agricultural supply and demand estimates; department of agriculture: Washington, DC, USA.

Widian, J., Nurhidayah, S., Rahayu, S., Firmansyah, E. and Yunita, R. (2021). Morphology Performance On Six Black Rice Accessions (*Oryza sativa* L.) In M1 Generation Irradiated By Gamma Rays. *JERAMI Indonesian J. Crop Sci.* **3**(2): 62-67.

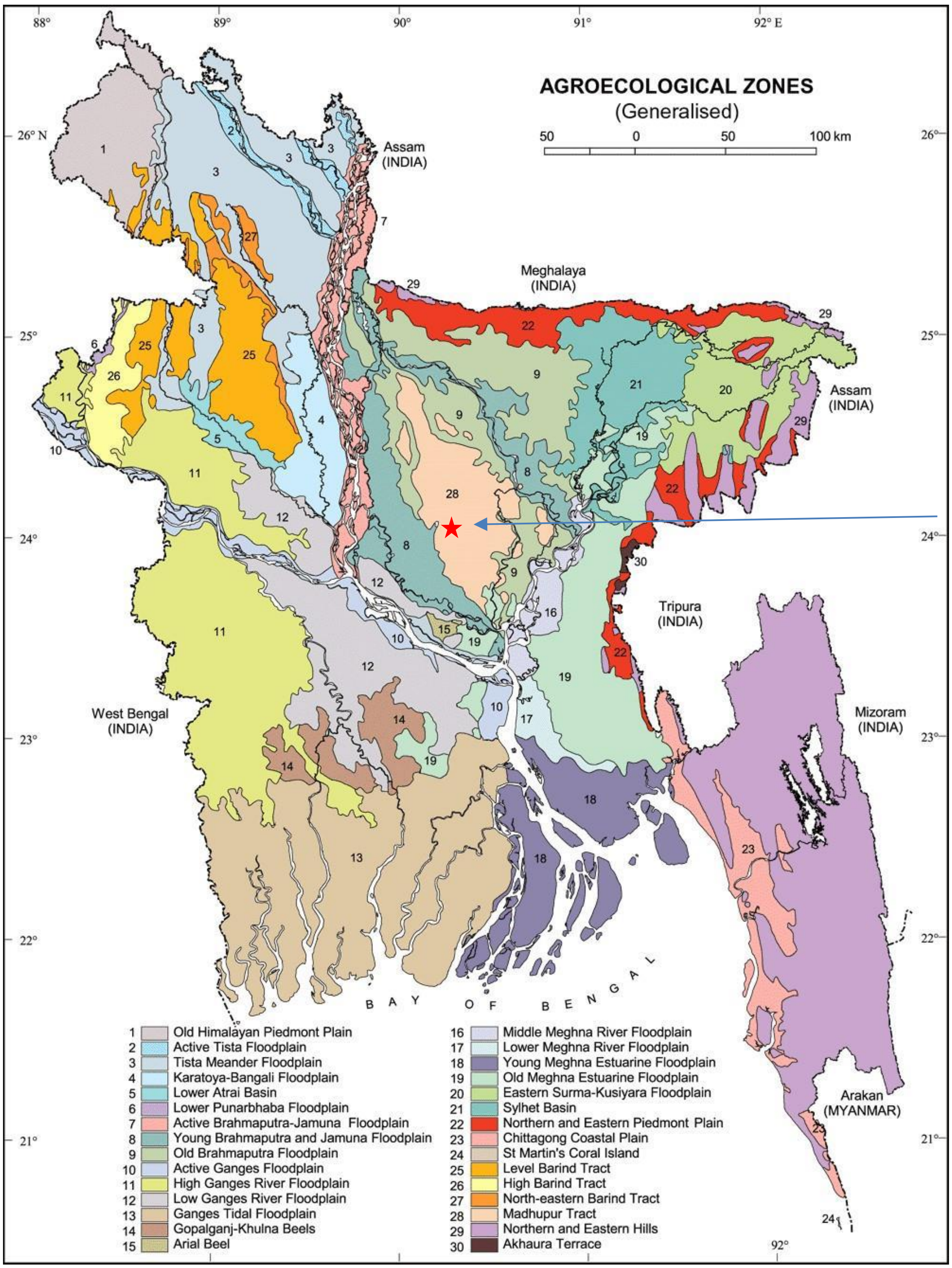
Yawadio, R., Tanimori, S. and Morita, N. (2007). Identification of phenolic compounds isolated from pigmented rices and their aldose reductase inhibitory activities. *Food Chem.* **101**(4): 1616–1625.

Zhimomi, T., Tzudir, L., Reddy, P.R.K. and Kumari, S. (2021). Effect of spacing and age of seedling on yield of rice under system of rice intensification. *Int. J. Curr. Microbiol. App. Sci*. **10**(02): 763-769.

CHAPTER VII

APPENDICES

Appendix I Map showing the experimental site under study



Appendix II Physical characteristics of field soil analyzed in Soil Resources Development Institute (SRDI) laboratory, Khamarbari, Farmgate, Dhaka

A. Morphological characteristics of the experimental field

Morphological features	Characteristics
Location	Agronomy field, SAU, Dhaka
AEZ	Madhupur Tract (28)
General Soil Type	Shallow red brown terrace soil
Land type	High land
Soil series	Tejgaon
Topography	Fairly leveled
Flood level	Above flood level
Drainage	Well drained

B. Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% clay	30
Textural class	Silty-clay
pH	5.6
Organic carbon (%)	0.45
Organic matter (%)	0.78
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100 g soil)	0.10
Available S (ppm)	45

Source: Soil Resources Development Institute (SRDI)

Appendix III Monthly record of air temperature, relative humidity, rainfall, and sunshine of the experimental site during the period

Month	*Air temperature (ºc)		*Relative humidity (%)	Total Rainfall (mm)	*Sunshine (hr)
	Maximum	Minimum			
June 2021	22.4	13.5	74	00	6.3
July 2021	24.5	12.4	68	00	5.7
August 2021	27.1	16.7	67	30	6.7
September 2021	31.4	19.6	54	11	8.2
Oct - November 2021	34.2	23.4	61	112	8.1
December 2021	34.7	25.9	70	185	7.8

* Monthly average, Source: Bangladesh Meteorological Department (Climate & weather division) Agargoan, Dhaka – 1212.

Appendix IV Means square values for plant height of black rice at different growth duration

Sources of variation	Degrees of freedom	Mean square				
		30 DAT	45 DAT	60 DAT	75 DAT	Harvest
Replication	2	0.4804	1.657	4.352	1	5.785
Seedling age (D)	3	25.1959*	103.693	212.16	255.432	370.289
Seedling rate (S)	2	14.5300^{NS}	59.889	81.726	126.464	166.439
D × S	6	1.5678*	5.289	4.063	5.364	12.728
Error (b)	22	0.3094	1.073	2.046	2.452	3.206

* Significant at 5% level;   NS = Non significant

Appendix V Means square values for the number of tillers hill^{-1} of black rice at different growth duration

Sources of variation	Degrees of freedom	Mean square				
		30 DAT	45 DAT	60 DAT	75 DAT	Harvest
Replication	2	0.0864	0.1759	0.2438	0.4815	0.0178
Seedling age (D)	3	4.5792	7.749	9.963	15.0072	15.2367
Seedling rate (S)	2	13.6512	18.787	22.2994	25.8611	35.4478
D × S	6	0.7212	1.178	1.5093	1.8158	2.2211
Error (b)	22	0.3389	0.5497	0.6411	0.734	0.2626

* Significant at 5% level;   NS = Non significant

Appendix VI Means square values for dry matter hill^{-1} of black rice at different growth duration

Sources of variation	Degrees of freedom	Mean square			
		45 DAT	60 DAT	75 DAT	Harvest
Replication	2	1.154	1.57	1.976	0.628
Seedling age (D)	3	50.0357	98.842	131.953	324.308
Seedling rate (S)	2	33.1349	66.5518	89.088	206.772
D × S	6	2.3617	4.3494	6.478	19.683
Error (b)	22	0.2752	0.4974	0.632	0.926

* Significant at 5% level;   NS = Non significant

Appendix VII Means square values for yield contributing characters of black rice at different growth duration

Sources of variation	Degrees of freedom	Mean square				
		Effective tillers hill^{-1} (No.)	Ineffective tillers hill^{-1} (No.)	Filled grains panicle^{-1} (No.)	Unfilled grains panicle^{-1} (No.)	Total grains hill^{-1} (No.)
Replication	2	0.3333	0.1944	11.77	9.83	20.99
Seedling age (D)	3	78.2593	29.287	7967.04	1968.73	2201.31
Seedling rate (S)	2	39.25	1.3611	465.36	263.22	182.32
D × S	6	5.287	0.8426	115.42	61.94	125.57
Error (b)	22	0.5152	0.5278	45.85	12.4	55.44

* Significant at 5% level;   NS = Non significant

Appendix VIII Means square values for yield of black rice at different growth duration

Sources of variation	Degrees of freedom	Mean square				
		Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Replication	2	3.13792	0.05701	0.013	0.1199	0.9861
Seedling age (D)	3	0.62297	6.17505	4.00372	19.8795	29.094
Seedling rate (S)	4	0.63232	1.28606	0.57485	3.5754	8.0165
D × S	12	3.48907	0.68815	0.06757	0.7976	25.9483
Error (b)	32	2.06699	0.06585	0.04012	0.1093	4.0817

* Significant at 5% level; NS = Non significant

Appendix VII: Some photos document during experiment

Plate 3. Black rice seed collection

Plate 2. Black rice seed soaking

Plate 4. Seed sprouting

Plate 1. Seedbed preparation

Plate 7. Seed sowing

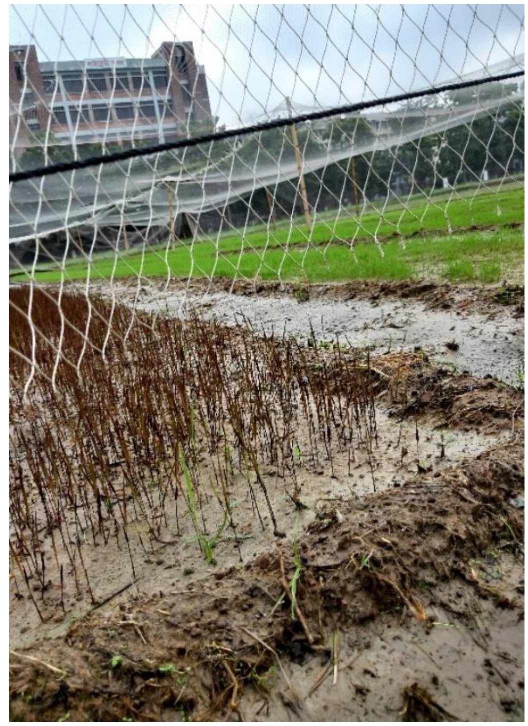


Plate 8. Young seedling after sowing

Plate 6. Seed sowing

Plate 5. Seed sowing

Plate 12. Seedling after sowing

Plate 11. Field view

Plate 10. Seedling transplanting

Plate 9. Tagging

Plate 14. Data collection

Plate 13. Dry weight