

Research Article

Effect of crop establishment method on growth, survival, and productivity of rice under submergence condition

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ABSTRACT

An experiment was conducted to determine the effect of crop establishment method on survival, growth and yield performance of rice under submergence condition. The treatments of the trial comprised of three factors: i. two crop establishment methods (direct seeding, DS and transplanting, TP), ii. variety (AZ7006 and vs. BU dhan1), and iii. submergence (21-days of submergence and control). AZ7006 showed superior tolerance, with 98% survival via DS compared to 70% when transplanted. Conversely, BU dhan1 suffered 100% mortality across all methods. Results of morpho-physiological characteristics and yield attributes of AZ7006 were better under DS method as compared to TP. Under submergence, AZ7006 yielded 4.1 t ha⁻¹ with DS but only 2.9 t ha⁻¹ when transplanted, i.e., DS had a significant 1.2 t ha⁻¹ yield advantage over transplanting. AZ7006 had only a 15% yield loss with DS, compared to a 39% loss with transplanting. The results indicated that DS significantly enhanced the submergence tolerance of AZ7006.

Introduction

Rice (*Oryza sativa* L.), the staple food in Bangladesh, is a good source of calories, vitamins, minerals, and bioactive phytochemicals (Fukagawa and Ziska, 2019). More than 29.5% of the world's rice is produced in China, compared to 7.0% in Bangladesh, 5.4% in Vietnam, 6.9% in Indonesia, 23.8% in India, and 3.7% in Thailand (USDA, 2020). Bangladesh ranks third globally in rice production, trailing behind China and India, with 360 million tons grown across 11.55 million hectares of cultivated land. Approximately 80% of the net cropped area is dedicated for rice production to meeting the needs of its 169.04 million population (Salam et al., 2020; Nasim et al., 2021).

Rice growers face challenges posed by climate change, temperature fluctuations, limited water

availability, soil degradation, nutrient deficiencies, salinity and waterlogging, which significantly affect rice yield and quality (Zhang et al., 2020). Submerged conditions exert various external and internal pressures on rice plant impacting their growth, survival and yield (Pathak et al., 2021). Rice is cultivated in three growing seasons namely *aus*, *aman*, and *boro* (BRRI, 2022). Among the rice growing seasons, *aman* (July to November) is almost rainfed and suffers from partial to complete submergence for a day to as long as a few weeks every year in many parts of the country. Water stagnation is caused by heavy rainfall or flash flood in a short period. The most submergence-affected areas are in the Northern, as well as the Southeast of Bangladesh. Intense, localized rainfall particularly

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during peak flood months from April to July and September to October leads to water stagnation in rice field.

Gas diffusion is significantly slower under submerged conditions resulting in low oxygen (O_2) or complete absence of O_2 around plant tissues (Armstrong and Drew, 2002; Ito et al., 1999; Setter et al., 2009). Thus, flooding profoundly affects plant growth, and full submergence poses a grave threat to rice cultivation. Depending on the duration, depth and conditions of floodwaters, rice yield losses can vary from 10 to 100%. Rice plants employ various strategies to cope with flooding conditions (Mamun et al., 2021). Among these, the formation of aerenchyma in roots and leaves, along with their interconnections, facilitates efficient gas movement, particularly from the shoot to root, promoting root growth and plant survival under O_2 -deficient conditions (Vartapetian and Jackson, 1997). Additionally, plants exhibit slow stem elongation during flash flood conditions to conserve energy required for maintenance processes. They also synthesize proteins like cytosolic enzymes and increase the rate of alcoholic fermentation (Ito et al., 1999). Moreover, maintaining high levels of non-structural carbohydrates such as starch and soluble sugars aids in submergence tolerance (Das et al., 2005). The *SUB1* gene suppresses carbohydrate utilization, thereby, enhancing survivability after submergence removal (Xu et al., 2006).

As early as the 1950s, submergence-tolerant, low-yielding landraces like FR13A were identified (Bailey-Serres et al., 2010; Xu et al., 2006; Fukao et al., 2006; Schmitz et al., 2013). Bangladesh Rice Research Institute (BRRI) has developed submergence-tolerant varieties like BRRI dhan51, BRRI dhan52, and BRRI dhan79 (BRRI, 2022). Additionally, BRRI dhan33, BRRI dhan56, and BRRI dhan57 have shown improved performance under submerged conditions (Islam et al., 2019; Abedin et al., 2019).

Although many studies have been conducted on the morphological, physiological, biochemical and

anatomical basis of submergence tolerance, but little information is available regarding agronomic management of rice under flooding condition. Agronomic practices include appropriate methods of crop establishment, use of healthy seed or seedlings, adequate plant population and nitrogen fertilization. In general, crop established by direct seeding (DS) before the monsoon rains attains sufficient vigor to tolerate submergence better than a recently transplanted crop (Sharma, 1995). We hypothesized that rice plants in DS conditions accumulate higher dry matter, which is the key determinant of flooding tolerance in rice. Further it is essential to know the physiology of direct-seeded rice regarding survival, recovery and regrowth after flooding. Therefore, the experiment was conducted to assess the effect of crop establishment method on survival, growth, yield components and yield of rice under submergence conditions.

Materials and methods

Site

The experiment was conducted in the submergence tank of the Agronomy research field of Gazipur Agricultural University (GAU), Gazipur-1706 from June to October 2022. It is located in Madhupur Tract under Agro-Ecological Zone 28 at geographic coordinates 24° 09' North latitude and 90° 26' East longitude with an elevation of 8.4 m above the mean sea level. The experimental site's soil composition consists of silty clay on the surface and silty clay loam beneath it. The location is in a subtropical area with abundant rainfall during the monsoon season, which runs from May to September, and little precipitation during the other months of the year.

Experimental materials

AZ7006, a commercial submergence tolerant rice variety, used as planting material. BU dhan1 used as susceptible check variety. The seeds of AZ7006 were obtained from Bayer Crop Science in Dhaka, Bangladesh, and BU dhan1 from the Department of Agronomy of GAU, Gazipur.

Land preparation

The submergence tank's land was prepared with a spade. The stubble and weeds were gathered and taken out of the tank. The land was finally well leveled. To limit fertilizer loss from irrigation water lateral drainage, a ridge 8–10 cm high was created.

Experimental treatments and design

The treatments of the trial comprised of three factors, viz. factor A (crop establishment method): DS and transplanting; factor B (rice varieties): AZ7006 and BU dhan1; and factor C (submergence): 21-days of submergence (21-DS) and control. The experiment was laid out in a randomized complete block design with three replications.

Seedling transplanting

Rice seeds were soaked into water on June 30, 2022, and the sprouting seeds were sown in a field on July 7, 2022. In the submergence tank two seedlings per hill of 25-day-old were transplanted with a spacing of 25×15 cm. In the same tank direct seeding for other treatment were done on the same date. Table 1 displays the activities carried out chronologically during the experimentation.

Fertilizer application

A recommended dose of fertilizer was applied in the field (Mamun et al., 2025). Different fertilizers like urea, triple super phosphate (TSP), muriate of potash (MoP), and gypsum were applied as 165, 62, 107, and 62 kg ha⁻¹. The total amount of TSP, MoP, and gypsum

were applied at the time of final land preparation in both the direct and transplanting fields. Urea was applied into three splits in the direct sowing field and two splits in the transplanting field. The 1st split of urea was applied at 15 days after sowing (DAS) in a direct sowing field, and 7 days after transplanting (DAT) plot. The 2nd and 3rd splits of urea were applied at 7 and 27 days after de-submergence of water in both the plots. Hand weeding was done two times. When it was essential, irrigation and other cultural customs were carried out.

Imposition of submergence treatments

Submergence stress was given after 20 DAS (seedling age 20 days) and 10 DAT (seedling age 30 days) to the rice plants of DS and transplanting plots, respectively. The duration of submergence was 21-days. The depth of water was maintained 75 to 80 cm above the ground level during submergence. The tanks were de-submerged according to the treatments. The water quality data such as dissolved O₂, electrical conductivity, pH, turbidity, and temperature were measured.

Air temperature and rainfall of the growing period

The air temperature of the experimental site gradually increases from sowing time to maturity. The highest daily average temperature (33.5 °C) was recorded on 14th July 2022 and the lowest (14.5 °C) on 7th December 2022, and the highest rainfall was recorded on 25th August 2022 (81 mm) (Fig. 1).

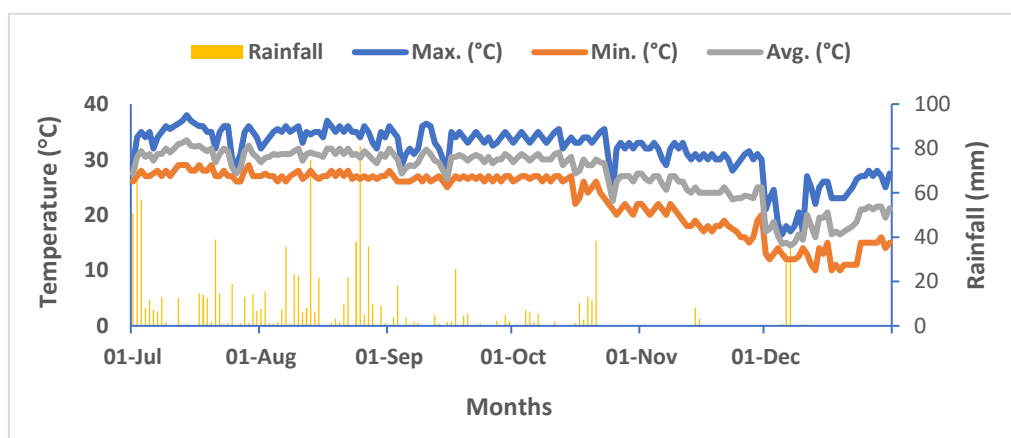


Fig. 1. Rainfall and daily maximum, minimum, and average temperature of site during crop growing period. Max. = Maximum, Min. = Minimum, Avg. = Average.

Collection of survival and lodging data

The survival of a variety means the ability to survive under flooding and renew its growth after the de-submergence of flood water (Bishas et al., 2022). Seedling survival rate was estimated after 14 and 21-DS treatment followed by de-submergence for 7 days. Plants survival was calculated as

$$\text{Survival (\%)} = \frac{\text{Number of plants survived of a variety}}{\text{Total number of plants transplanted of same the variety}} \times 100$$

The intensity of lodging of plants were recorded after recession of flood water based on visual observation according to Alam et al. (2025) and shown in Table 1.

Table 1. List of lodging score of plants after de-submergence.

Lodging score	Characteristics
0	No plant is lodged
1	Less than 20% of plants are lodged
3	20 - 40% of plants are lodged
5	41 - 60% of plants are lodged
7	61 - 80% of plants are lodged
9	More than 80% of plants are lodged

Collection of morphological parameters

Data on plant height was collected prior to submersion, 7 days after de-submergence (7 DADS) of flood water, and during harvesting of rice. Plant height of rice was measured with a meter scale, from the base of the plant to the top of the highest leaf or panicle in each variety. Height of three plants were measured and averaged the values.

Collection of physiological data

$$\text{Adjusted weight} = \frac{(100 - M_1)}{(100 - M_2)} \times W$$

Chlorophyll (Chl) content of rice was determined one day before submergence and 7 DADS of flood water. A Chl meter (SPAD-502, Minolta, Japan) was used to obtain SPAD value. Two plants from each treatment were selected randomly and SPAD values were recorded from the youngest fully expanded leaf from

the top of the plants. Three SPAD readings were taken plant⁻¹ and mean were calculated. Leaf chlorophyll (Chl) content was determined one day before submergence, 7 DADS and at flowering stage of the crop (Fatema et al., 2023). Total Chl content was measured for all the varieties.

$$\text{Total Chl (mg g}^{-1} \text{ FW)} = [20.2(D_{645}) + 8.02(D_{663})] \times [V/1000 \times W]$$

Where, D (663, 645) = Optical density of the Chl extract at a wavelength of 663 & 645 nm, respectively. V = Final volume (mL) of the 80% acetone with Chl extract and W = Weight of fresh leaf sample in g.

Dry matter partitioning and days to maturity

Root and shoot dry matter (DM) of rice plants was determined one day before submergence and 7 DADS of flood water. The plant parts were divided into root, stem and leaf components. Following a 72-hour drying period at 70° C in an oven, the divided plant parts were weighed. Days to grain maturity was counted when 80% plants had yellow grains.

Collection of yield data at harvest

Once the crop reached full maturity, it was harvested. The grain was threshed, cleaned, and dried separately. The yield and yield components data were recorded following standard procedure. Total number of panicles from selected hill were counted, recorded and averaged to find number of panicles hill⁻¹. Grains were separated from panicles and number of filled and unfilled grains per panicle were counted with a Multi Auto counter (Model DCI NO: 501102, ever well crop, Tokyo, Japan) an average was recorded. Thousand grains were randomly counted from the filled grain by Multi Auto counters and were weighed in an electronic balance (Model: FX-300). The rice hills from 1.8 m⁻² area was collected and threshed. After the grains were taken out of the straw, the weight of grains in each variety was measured using an electronic balance (Model: FX-300). The weight of grain was adjusted at a 14% content (Ahsan et al., 2023).

Where, W = fresh weight, M₁ and M₂ = fresh and adjusted moisture percent of the grain. After

separation of grain from the hills from 1.8 m⁻² area, the total weight of straw was taken and converted into t ha⁻¹. The harvest index (HI) was determined using the equation 9 (Mamun et al., 2022).

$$HI = \frac{\text{Grain yield}}{\text{Grain yield} + \text{straw yield}}$$

Statistical analysis

The collected data were analyzed using computer software CropStat (version 7.2). The treatment means were separated as Duncan's multiple range test at 5% level of significance (Gomez and Gomez, 1984). Graphs were prepared using excel software. The R version 4.2.2 software was used to carry out correlation and principal component analysis (PCA).

Results and discussion

Survival of rice plants under submergence conditions

The interaction of crop establishment method × rice variety × submergence exerted a significant effect on plant survival percent (Fig. 2a). Under 21- DS, the survival rate of AZ7006 was 98 and 70% in the case of DS and transplanting methods, respectively. This result indicated that the survival rate of AZ7006 was 28% higher in the case of DS than the transplanting method under 21-DS. AZ7006's survival rate under

21-DS was statistically identical to that of the control condition, according to the results. Under 21-DS, all of the BU dhan1 plants were damaged. The rice variety BU dhan1 was susceptible, meaning it couldn't withstand being submerged. Direct seeding increased the survival of the tolerant variety AZ7006, but it did not affect the submergence-susceptible BU dhan1. Direct seeding allowed for a good early-stage establishment, which enabled AZ7006 to tolerate 21-DS. When the crops were developed using the DS method, AZ7006 suffered less under submergence conditions. However, recently transplanted crops with poor establishment suffer more since their roots were damaged during the uprooting process from the seedbed (Sharma and Ghosh, 1999). Therefore, AZ7006's survival rate was lower in the transplanting than that of the DS approach. The two primary problems that limit rice plant's capacity to withstand prolonged submergence are low light intensity and oxygen (O₂) scarcity; these are brought on by the older leaves becoming seriously damaged and the plant's sensitivity not producing new leaves. Furthermore, reactive O₂ species (ROS) such as hydrogen peroxide, hydroxyl radicals, and superoxide anion are produced because submerged plants often lack oxygen and undergo intense light strain. These ROS have the potential to seriously impair cellular structure and eventually kill plants if they are not controlled (Oladosu et al., 2020).

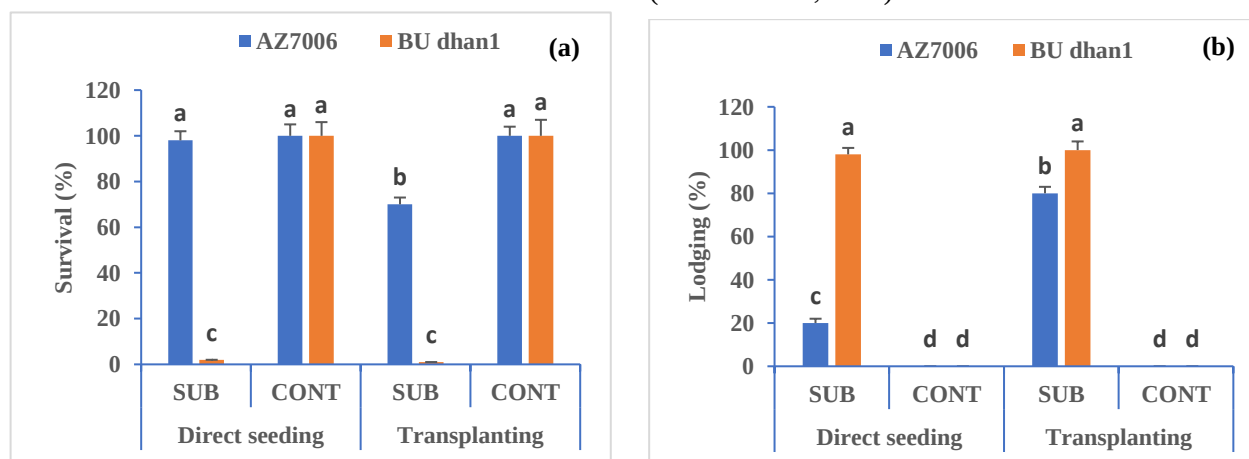


Fig. 2. Effect of crop establishment method on survival (a) and lodging (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Plant lodging of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exhibited a significant effect on plant lodging (Fig. 2b). Under 21-DS, the lodging rate of AZ7006 80% in the case of transplanting, which decreased to 20% in the case of the DS method. This result indicated that the lodging rate of AZ7006 was 60% lower in the case of DS than the transplanting method under 21-DS. The lodging rate of BU dhan1 under 21-DS was statistically identical under DS and transplanting methods, according to the results. Under 21-DS, all of the BU dhan1 plants perished. Because it was vulnerable, the rice variety BU dhan1 was unable to tolerate submersion. The tolerant variety AZ7006 saw less lodging when direct sowing was used, while the submersion-susceptible BU dhan1 died under 21-DS. Because DS produced a good early-stage establishment, AZ7006 was able to withstand 21-DS. When the direct sowing method was used to mature the crops, AZ7006 experienced reduced submersion damage and a lower lodging rate. As a result, the transplanting strategy had a greater lodging rate for AZ7006 than the direct sowing method. Rice stems have nodes because of lodging, and these nodes break under extreme pressure from wind or rain. The process of photosynthesis, which produces food, is slowed down by submersion, and rice plants get weaker and die when exposed to less sunlight (Nishiuchi et al., 2012).

Plant height of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence had a significant effect on plant height under submergence condition (Figs. 3a and b). Before submergence, both rice varieties produced taller plants in case of DS compared to transplanting method (Fig. 3). AZ7006 produced plants of 52.00 cm and 52.33 cm in DS, while 39.33 and 39.33 cm in transplanting method before submergence. Similarly, BU dhan1 produced plants of 61.33 cm and 51.33 cm in DS, while 40.33 and 44.33 cm in transplanting under submergence and control condition, respectively (Fig. 3a). This result indicated that height of AZ7006 gave 12.67 cm and 13 cm taller plants in the case of DS than transplanting method, and BU dhan1 had 21 cm and 7 cm taller plants in the case of DS than transplanting method before

submergence. Direct seeding method increased the height of the tolerant variety AZ7006 and also susceptible variety BU dhan1 compared with transplanting method. Direct seeding approach allowed for a good early-stage establishment.

At 7 days after de-submergence (DADS), it was observed that AZ7006 produced plants of 70 cm in case of DS, while 62 cm in transplanting methods under 21-DS. AZ7006 and BU dhan1 produced plants of 79 cm and 79.66 cm in case of DS, while 78.66 cm and 77.33 cm in transplanting, respectively under control condition (Fig. 3b). This result indicated that height of AZ7006 was 8 cm higher in the case of DS than transplanting method under after 21-DS, and all the plants of BU dhan1 died under 21-DS. Submergence stress significantly affects all growth parameters of rice plant. During 14 DS, plant height of rice significantly reduced during the vegetative stage (Khanal et al., 2024).

Root dry matter production of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence showed a significant effect on root DM production under submergence conditions (Figs. 4a and b). Before submergence, AZ7006 and BU dhan1 showed significantly higher root DM production in the DS method compared to transplanting. The rice variety AZ7006 produced root DM of 5.4 and 1.5 g plant⁻¹ in DS, while 0.33 and 0.43 g plant⁻¹ in transplanting method under submergence and control, respectively (Fig. 4a). Similarly, BU dhan1 produced root DM of 5.24 and 3.31 g plant⁻¹ in DS, while 0.28 and 0.38 g plant⁻¹ in transplanting under submergence and control, respectively (Fig. 4a). This result indicated that root DM production of AZ7006 was 5.07 g and 1.07 g higher in the case of DS than transplanting, and BU dhan1 had 4.96 g and 2.93 g higher root DM in the case of DS than transplanting before submergence. Given that the seeds were sown directly into the field and germinated there, this suggests that both types tend to invest more in root growth when DS is used. The competitive character of DS, in which the seedlings lack the benefit of early establishment offered by transplanting, may be the cause of this increased root DM (Negi et al., 2024).

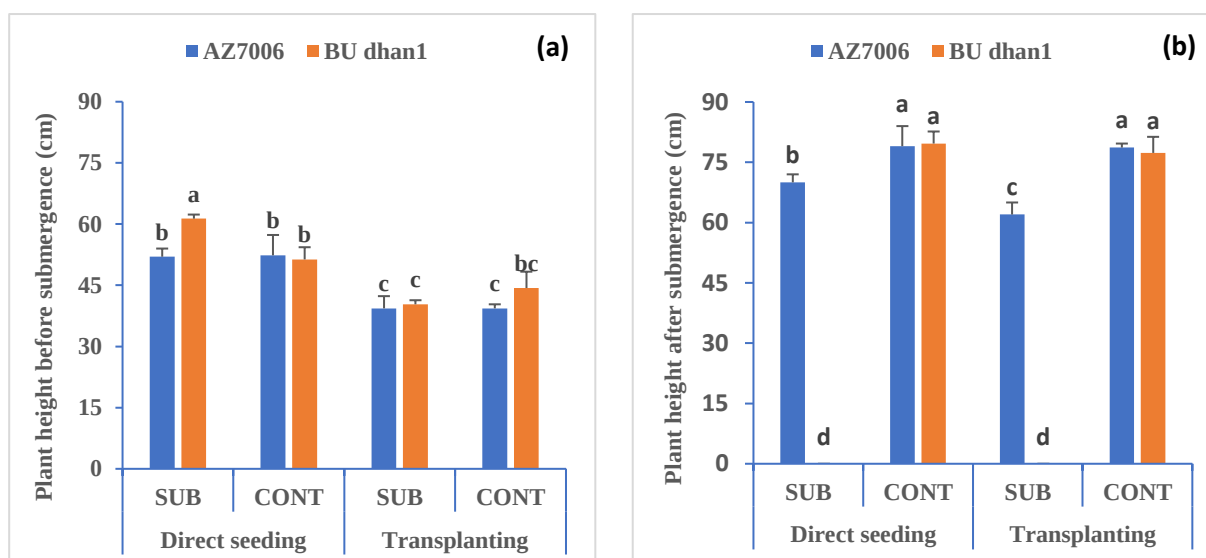


Fig. 3. Effect of crop establishment method on plant height before submergence (a) and after submergence (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

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character of DS, in which the seedlings lack the benefit of early establishment offered by transplanting, may be the cause of this increased root DM (Negi et al., 2024).

At 7 DADS, it was observed that AZ7006 produced root DM of 6.9 g plant⁻¹ in the case of DS, while 2.0 g plant⁻¹ in transplanting condition under 21-DS. All the plants of BU dhan1 died under 21-DS. Moreover, root DM production of AZ7006 was 35.2 and 12.7 g plant⁻¹, while 37.88 and 12.93 g plant⁻¹ in the case of BU dhan1 in DS and transplanting, respectively under control (Fig. 4b). This result indicated that root DM of AZ7006 was 4.9 g higher in the case of DS than transplanting method under submergence conditions. The situation of submersion significantly affects the growth of the root biomass, which in turn affects the overall development of the plant (Manik et al., 2019). Direct seeding ensures better growth, which allows better nitrogen intake, however, flooded situations reduce nitrogen intake primarily because of the lower roots in flooded soil. Decreased plant nitrogen uptake reduces plant growth, as evidenced by the low biomass generated (Ahadiyat et al., 2023).

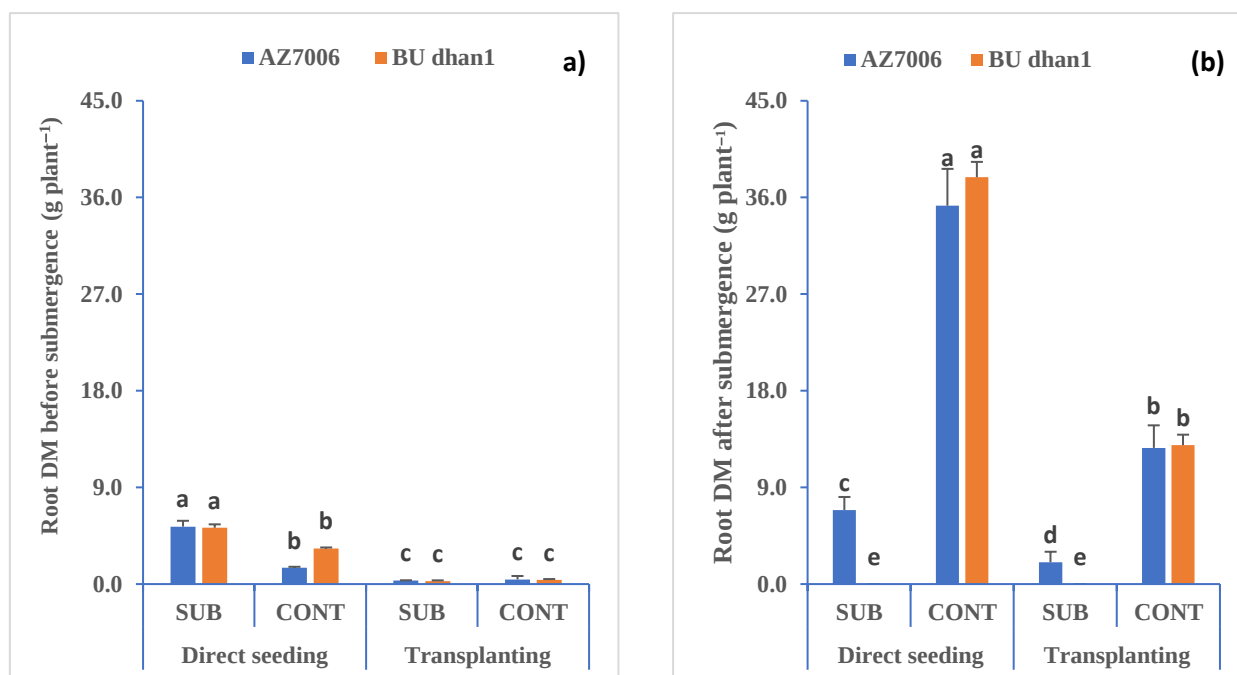


Fig. 4. Effect of crop establishment method on root dry matter (DM) before submergence (a) and after submergence (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Shoot dry matter production of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exerted a significant effect on shoot DM production under submergence conditions (Fig. 5). Before submergence, both rice varieties produced a higher amount of shoot DM in the case of DS compared to the transplanting method. The rice variety AZ7006 produced shoot DM of 4.8 and 4.4 g plant⁻¹ in DS, while 1.9 and 2.2 g plant⁻¹ in the transplanting method respectively. Similarly, BU dhan1 produced shoot DM of 6.07 and 6.98 g plant⁻¹ in DS, while 1.0 and 1.51 g plant⁻¹ in transplanting method before submergence, respectively (Fig. 5a). This result indicated that shoot DM production of AZ7006 was 2.9 g and 2.2 g higher in the case of DS than the transplanting method and BU dhan1 was 5.07 g and 5.47 g higher in the case of DS than the transplanting method before submergence.

At 7 DADS, it was observed that AZ7006 produced shoot DM of 5.6 g plant⁻¹ in the case of DS, while 3.0 g plant⁻¹ in TP condition under 21-DS. All the plants of BU dhan1 died under 21-DS. Moreover, shoot DM production of rice variety AZ7006 was 36.2 and 26.0 g plant⁻¹ in the case of DS, while BU dhan1 was 45.09 and 27.13 g plant⁻¹ in the case of transplanting method, respectively under control condition (Fig. 5b). This result indicated that shoot DM production of AZ7006 was 2.6 g higher in the case of DS than transplanting method under submergence conditions. Similarly, shoot DM production of AZ7006 and BU dhan1 was 10.2 g and 17.96 g higher in the case of DS than the transplanting method under control conditions. Several studies have found a negative relationship between the survival rate and the shoot elongation rate. Both sensitive and tolerant genotypes showed signs of shoot elongation under submersion conditions, but shoot DM did not rise. In terms of DM buildup, this process is not true growth, and the DM loss was brought on by tissue deterioration and cellular leakage (Bui et al., 2019).

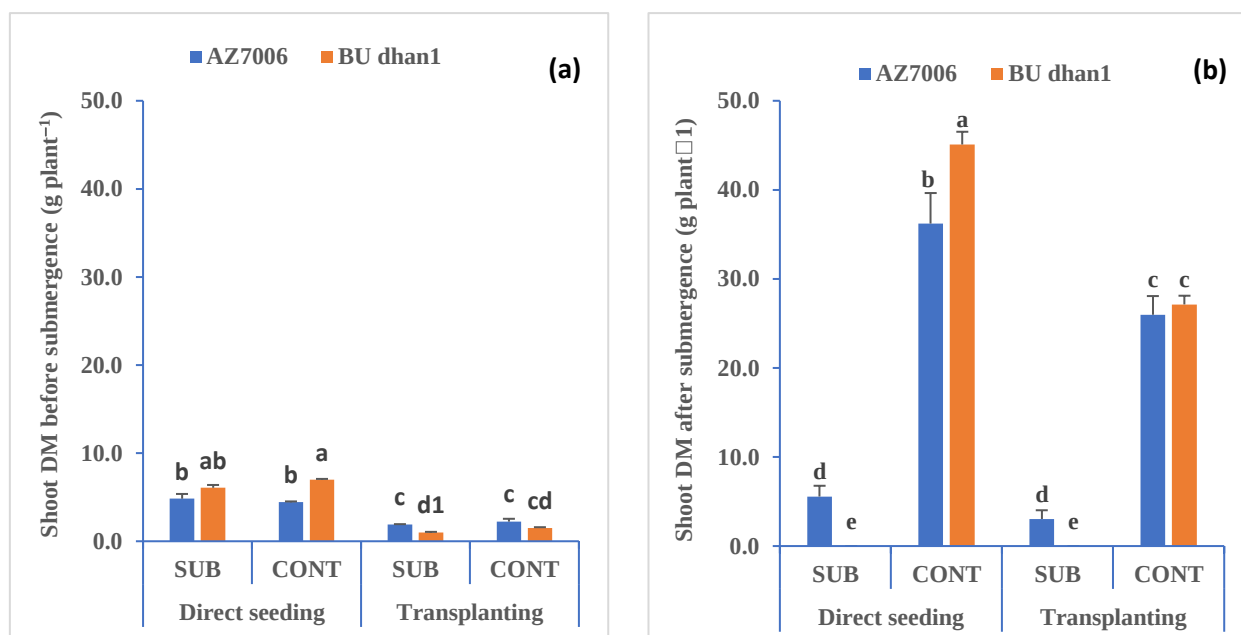


Fig. 5. Effect of crop establishment method on shoot dry matter (DM) before submergence (a) and after submergence (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Chlorophyll content of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exerted a significant effect on chlorophyll (Chl) content under submergence conditions (Fig. 6). Before submergence, the Chl content of both rice varieties was higher in the case of DS compared to the transplanting method. The rice variety AZ7006 contained Chl of 4.1 and 3.7 mg g⁻¹ FW in DS, while 4.2 and 3.8 mg g⁻¹ FW in the transplanting method under submergence and control conditions, respectively (Fig. 6a). Similarly, BU dhan1 contained Chl of 3.4 and 3.3 mg g⁻¹ FW in DS, while 2.4 and 3.3 mg g⁻¹ FW in the transplanting method under submergence and control conditions, respectively. At 7 DADS, it was observed that AZ7006 contained Chl of 3.8 mg g⁻¹ FW in the case of DS, while 3.5 mg g⁻¹ FW in transplanting methods under 21-DS. All the plants of BU dhan1 died under 21-DS

(Fig. 6b). Moreover, Chl content of rice variety AZ7006 was 3.9 and 3.8 mg g⁻¹ FW, while 3.2 and 3.4 mg g⁻¹ FW in the case of BU dhan1 in DS and transplanting method, respectively under control conditions. Chl concentration decreases significantly for all genotypes under submergence, with sensitive cultivars experiencing severe damage, indicating faster leaf senescence (Khanal et al., 2024). Chl content is a vital indicator of photosynthetic activity and plant health. Flooding typically reduces Chl content due to limited gas exchange and increased chlorophyll degradation. This significant reduction indicates that while the cultivar can maintain some level of Chl during stress, its ability to recover post-stress is limited. Chl degradation under submergence is a common response due to oxidative stress and reduced photosynthetic efficiency (Umar et al., 2024).

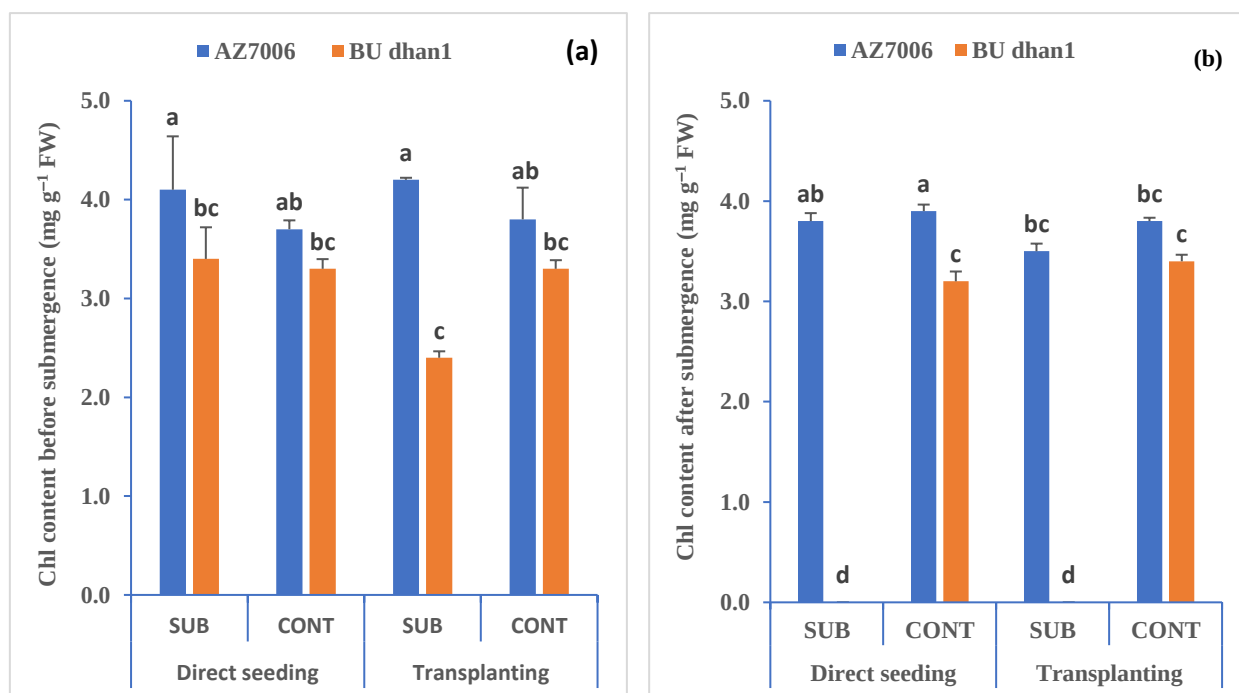


Fig. 6. Effect of crop establishment method on chlorophyll (Chl) content before submergence (a) and after submergence (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Plant height and panicle production of rice under submergence at harvest

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exerted a significant effect on plant height and panicle production of rice under submergence condition (Fig. 7). Rice variety AZ7006 produced a plants height of 110 cm in case of DS, while 100 cm in transplanting methods under 21-DS. Plant height of AZ7006 and BU dhan1 rice varieties were identical under control conditions which ranged from 121.0 and 128.88 cm in case of DS, 128.0 cm and 127.88 cm in the case of transplanting methods, respectively (Fig. 7a). This result indicated that plant height at harvest of AZ7006 rice variety was 10 cm higher in the case of DS than the transplanting method after submergence under submergence conditions. But plant height at harvest of BU dhan1 rice variety was 7 cm lower in the case of DS than transplanting method under control conditions.

Under submergence condition, the panicle of AZ7006 was 10 and 13 plant⁻¹ in case of DS and transplanting condition, respectively (Fig. 7b). In control condition, the panicle of AZ7006 was 12 and 9 plant⁻¹ in case of DS and transplanting, respectively, while 11 and 9 plant⁻¹ in BU dhan1 under DS and transplanting method, respectively. This result indicated that the panicle of AZ7006 rice variety was 3 plant⁻¹ lower in the case of DS than transplanting method under submergence condition. AZ7006 and BU dhan1 rice variety was 3 and 2 plant⁻¹ higher in the case of DS than transplanting method under control condition. The number of tillers effect during the tillering stage influences the quantity of panicles produced. Many earlier research has shown that tiller number declines dramatically during submergence, and we discovered that tiller number reduced significantly in the submergence treatment compared to the control. As a result, the lower effective tiller numbers led to a decreased panicle number at the maturity stage (Chen et al., 2021).

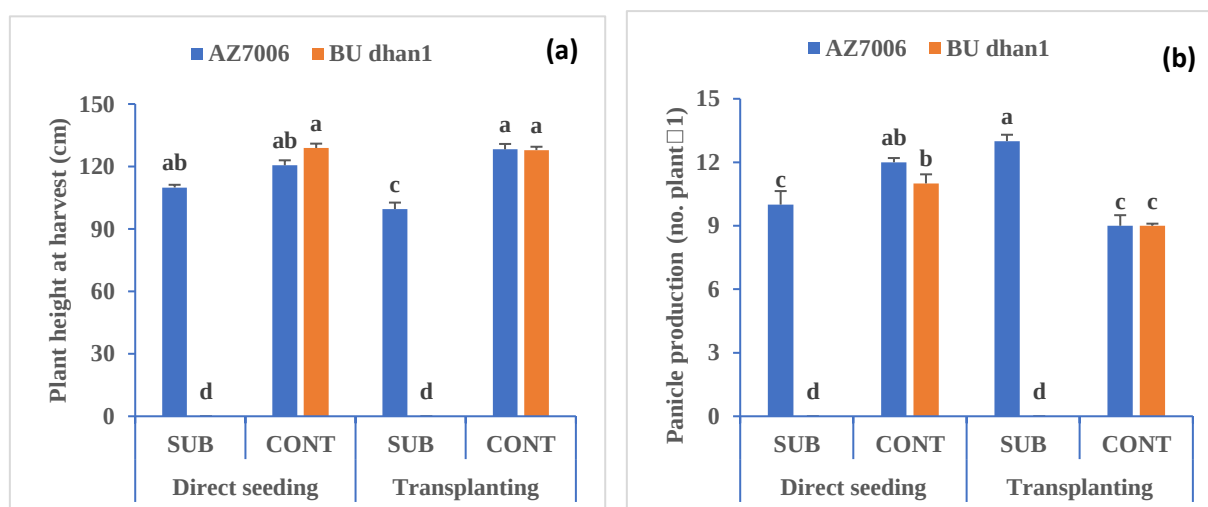


Fig. 7. Effect of crop establishment method on plant height at harvest (a) and panicle production (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters are vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Filled and unfilled grain production of rice under submergence at harvest

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exerted a significant effect on filled and unfilled grain production of rice under submergence condition (Fig. 8). Rice variety AZ7006 produced filled grains of 161 panicle⁻¹ in case of DS, while 158 in transplanting methods under 21-DS (Fig. 8a). In control condition, production of filled grains of AZ7006 was 96 and 134 panicle⁻¹, while it was 90 and 94 in case of BU dhan1 under DS and transplanting method, respectively. This result indicated that filled grain of AZ7006 rice variety was insignificant in the case of DS and transplanting method after submergence under submergence condition and filled grain of AZ7006 rice variety was significant that filled grains of 38 panicle⁻¹ lower in the case of DS than transplanting method after submergence under submergence condition in control methods. BU dhan1 rice variety was insignificant in the case of DS and transplanting method after submergence under submergence condition in control methods. The genetic makeup of the cultivar has a substantial impact on the quantity of filled grains panicle⁻¹. Khatun et al. (2020) discovered that variations in grain filling might be attributed to genetic, environmental, or cultural management approaches.

Under submergence condition, the number of unfilled grains of AZ7006 was 47 and 42 panicle⁻¹ in case of DS and TP condition, respectively (Fig. 8b). In control condition, number of unfilled grains of AZ7006 was 21 and 30 panicle⁻¹ in case of DS and TP, respectively, while 38 and 40 panicle⁻¹ in BU dhan1 under DS and TP method, respectively. This result indicated that unfilled grain of AZ7006 rice variety was 5 panicle⁻¹ higher in the case of DS than transplanting method under submergence condition and unfilled grain of AZ7006 rice variety was significant that unfilled grains of 9 panicle⁻¹ lower in the case of DS than transplanting method under submergence condition in control methods. BU dhan1 rice variety was insignificant in the case of DS and transplanting method under submergence condition in control methods. Prolonged flood duration is a key concern for rice plants, resulting in poor spikelet development, sterile grain, reduced grain weight, and, ultimately, a significant reduction in yield (Perata and Voesenek, 2007). Fukao et al. (2006) and Barding et al. (2012) found that the number of grains per panicle decreases dramatically when submerged compared to the control. Low light and low photosynthetically active radiation at canopy level are thought to be the primary causes of decreased grain number panicle⁻¹. After the floodwaters receded, plants used the majority of their photosynthates for vegetative growth rather than reproduction.

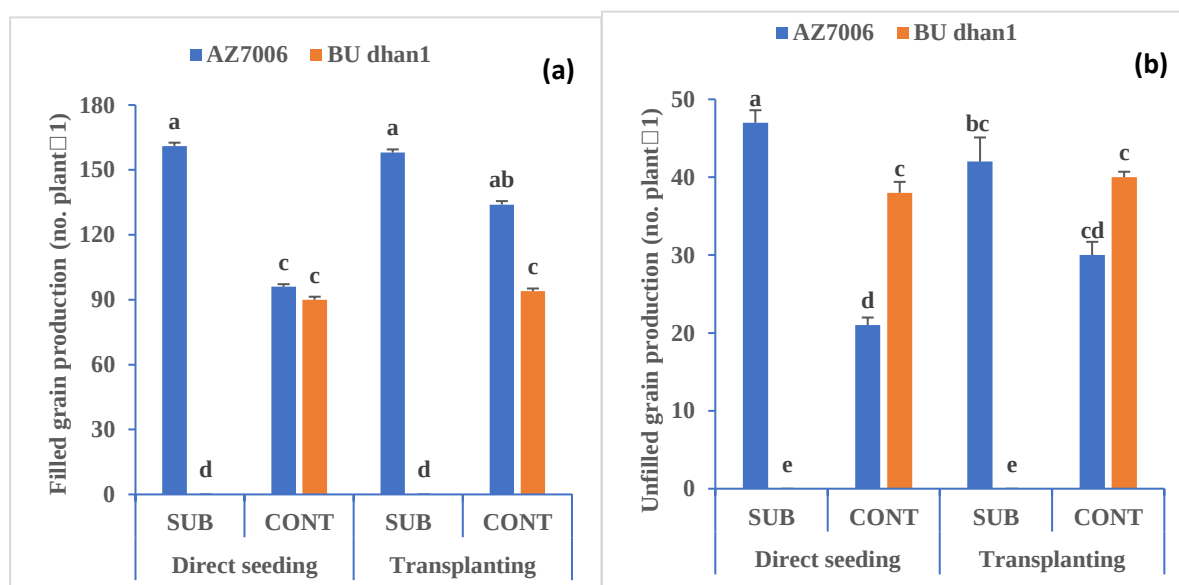


Fig. 8. Effect of crop establishment method on filled grain production (a) and unfilled grain production at harvest (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters are vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

The 1000-grain weight and harvest index of rice under submergence at harvest

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exerted a significant effect on 1000-grain weight and harvest index of rice under submergence condition (Fig. 9). The 1000-grain weight of AZ7006 was 22 and 23 g in case of DS and transplanting method under 21-days submergence (Fig. 9a). In control condition, 1000-grain weight of AZ7006 was 21 and 20 g, while it was 21.03 and 20.39 in case of BU dhan1 under DS and transplanting method, respectively. This result indicated that 1000-grain weight of AZ7006 rice variety was insignificant in the case of DS and transplanting method under submergence condition. Under submergence condition, the grain harvest index (GHI) of AZ7006 was 49 and 43% in case of DS and transplanting method, respectively. In control condition, GHI of AZ7006 was 51 and 50% in case of DS and transplanting method,

respectively, while 50 and 53% in BU dhan1 under DS and transplanting method, respectively (Fig. 9b). This result indicated that harvest index of AZ7006 rice variety was 6% higher in the case of DS than transplanting method under submergence condition. AZ7006 and BU dhan1 rice variety was insignificant in the case of DS and transplanting method under control condition. The reduction in 1000 seed weight after submergence was because submergence reduced the weight of the grain. Submergence stress reduced the yield of all genotypes. However, the tolerant check and *SUB1* introgressed lines showed less reduction under submerged treatment. The reduction in yield contributing components like tiller number, effective tiller, panicle length in submerged condition finally reduced the yield of the submergence-affected plant. Reduction in yield leads to a reduction in the GHI of the submerged plant (Afrin et al., 2018).

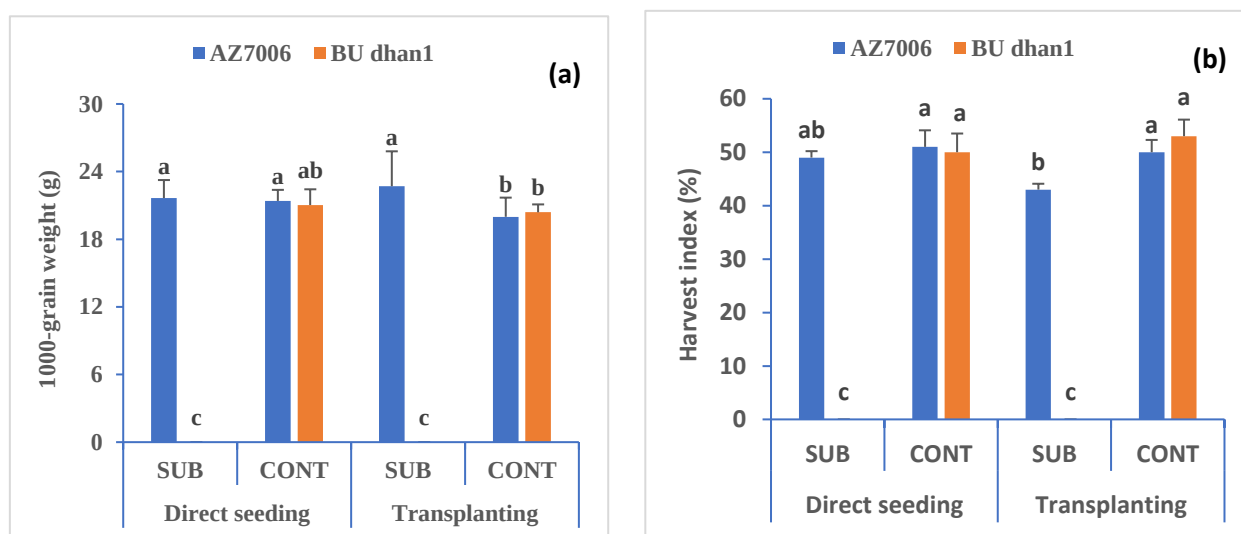


Fig. 9. Effect of crop establishment method on 1000-grain weight and harvest index at harvest of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Grain and straw yield of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exhibited a significant effect on grain and straw yield of rice under submergence condition (Fig. 10). The rice variety AZ7006 yielded 4.8 t ha^{-1} grain under control, while it was 4.1 t ha^{-1} under submergence condition in case of DS method (Fig. 10a). Similarly, the grain yield of AZ7006 was 4.8 t ha^{-1} grain under control, while it was 2.9 t ha^{-1} under submergence condition in the case of transplanting method. BU dhan1 gave 4.67 and 4.71 t ha^{-1} grain yield under control condition in case of DS and transplanting method, respectively. However, all the plants of BU dhan1 were damaged under 21 days of submergence. This result indicated that under submergence conditions, AZ7006 produced 1.2 t ha^{-1} higher yield in case of DS than transplanting method. Flooding is a persistent threat to grain productivity in rainfed lowland rice because it causes significant damage and plant mortality if it lasts more than a week. Because current photosynthesis is quickly depleted under inundated conditions of submergence, plants use storage carbohydrates as an alternative

for 49 adequate accumulations of starch in the panicles for grain filling (Kawano et al., 2009). Regardless of sink capacity, the panicle number in the current experiment was dramatically reduced under submergence when compared to normal as recorded.

In case of straw yield, AZ7006 produced 4.2 and 3.8 t ha^{-1} under submergence, while 4.6 and 4.9 t ha^{-1} under control in the case of DS and transplanting method, respectively (Fig. 10b). Similarly, straw yield of BU dhan1 was 4.71 and 4.33 t ha^{-1} in DS and transplanting method, respectively under control conditions. This result indicated that under submergence condition, AZ7006 produced 0.4 t ha^{-1} higher straw yield in the case of DS than transplanting method. AZ7006 produced 0.3 t ha^{-1} lower and BU dhan1 produced 0.38 t ha^{-1} higher straw yield in the case of DS than transplanting method under control condition. According to Das et al. (2005), straw biomass fell more in submergence than in control. Tiller mortality and reduced growth were thought to be caused by a lack of photosynthetically active radiation reaching the canopy level during submergence.

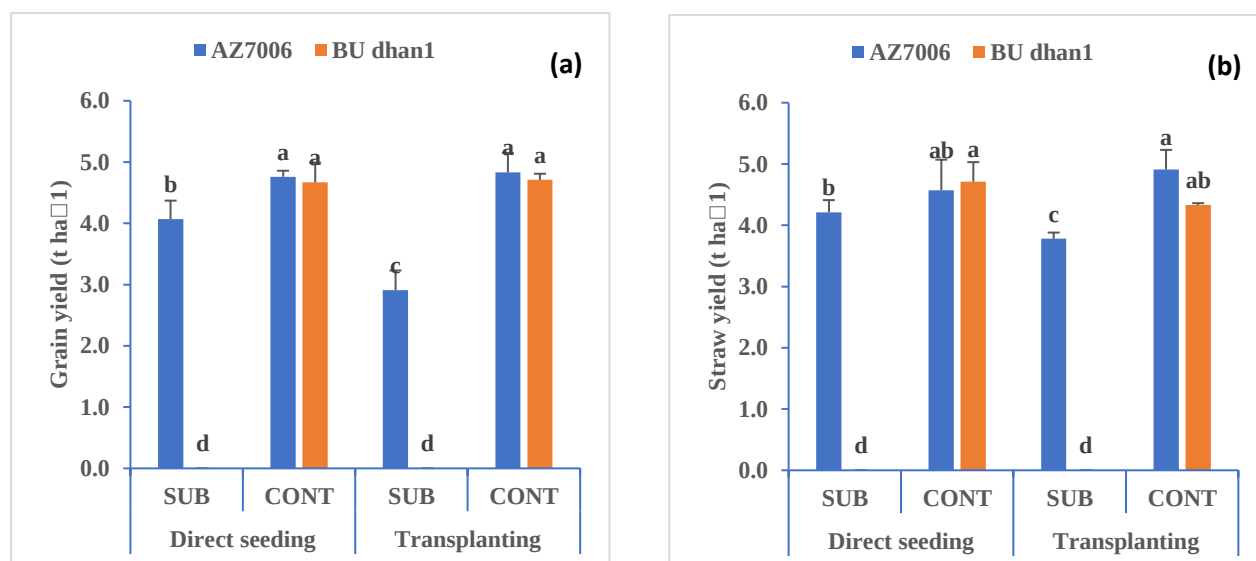


Fig. 10. Effect of crop establishment method on grain (a) and straw yield (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters are vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

Yield loss and growth duration of rice under submergence condition

The interaction of crop establishment method $\times$ rice variety $\times$ submergence exerted a significant effect on yield loss and growth duration of rice under submergence condition (Fig. 11). The yield loss of AZ7006 was 15 and 39% under DS and transplanting methods, respectively due to submergence stress (Fig. 11a). All the plants of BU dhan1 died under 21-DS and the 100% yield loss occurred due to submergence under both crop establishment methods. This result indicated that yield loss of AZ7006 rice variety was 24% lower in the case of DS than transplanting method after submergence under submergence condition. Submergence reduces leaf chlorophyll concentration (Li et al., 2018). This decrease in chlorophyll has an effect on plant photosynthetic capability, either directly or indirectly (Yu et al., 2019). This decrease in transpiration and photosynthesis is due to stomatal closure (Tian et al., 2018), which limits CO₂ transport (Chu et al., 2018). To summarize, submergence reduces total plant growth, resulting in a significant yield loss (Wollmer et al., 2018).

Growth duration of the rice variety AZ7006 took 118 and 117 days for maturity under control condition in case of DS and transplanting method, respectively. On the other hand, this variety needed 131 and 149 days to complete its life cycle under submergence conditions in the case of DS and transplanting method, respectively (Fig. 11b). This result indicated that growth duration or maturity of AZ7006 and BU dhan1 rice variety was insignificant in the case of DS and transplanting method under control condition and AZ7006 rice variety was significant in the case of DS than transplanting method under submergence condition. Growth duration or maturity of AZ7006 was 18 days later in the case of DS than transplanting method under submergence condition. The days to maturity for submergence vary significantly. The days to maturity differed significantly amongst types. Maturity was determined to be delayed by 134.00 days and to arrive at the earliest by 120.00 days (Sultana et al. 2018). Sultana et al. (2018) also reported that varietal differences cause differences in Days to Maturity. The combination of submergence time and variety had a substantial effect on days of maturity.

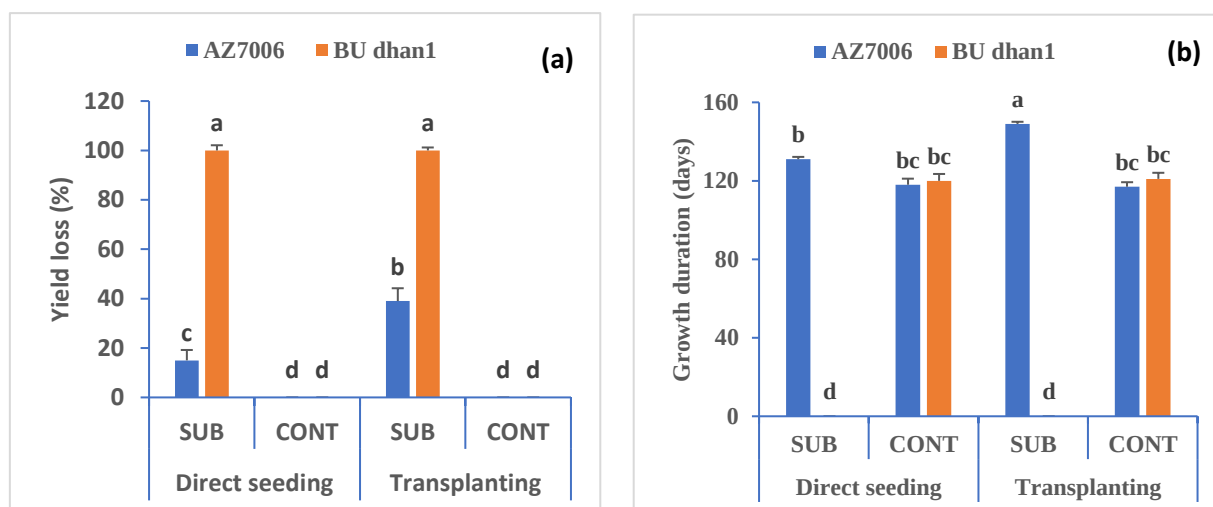


Fig. 11. Effect of crop establishment method on yield loss (a) and growth duration (b) of rice under submergence condition, SUB = Submergence, CONT = Control, Bars with different letters are vary significantly, as determined by ANOVA followed by Duncan's multiple range test ($P < 0.05$). Small bars on bar graphs indicate mean $\pm$ standard error.

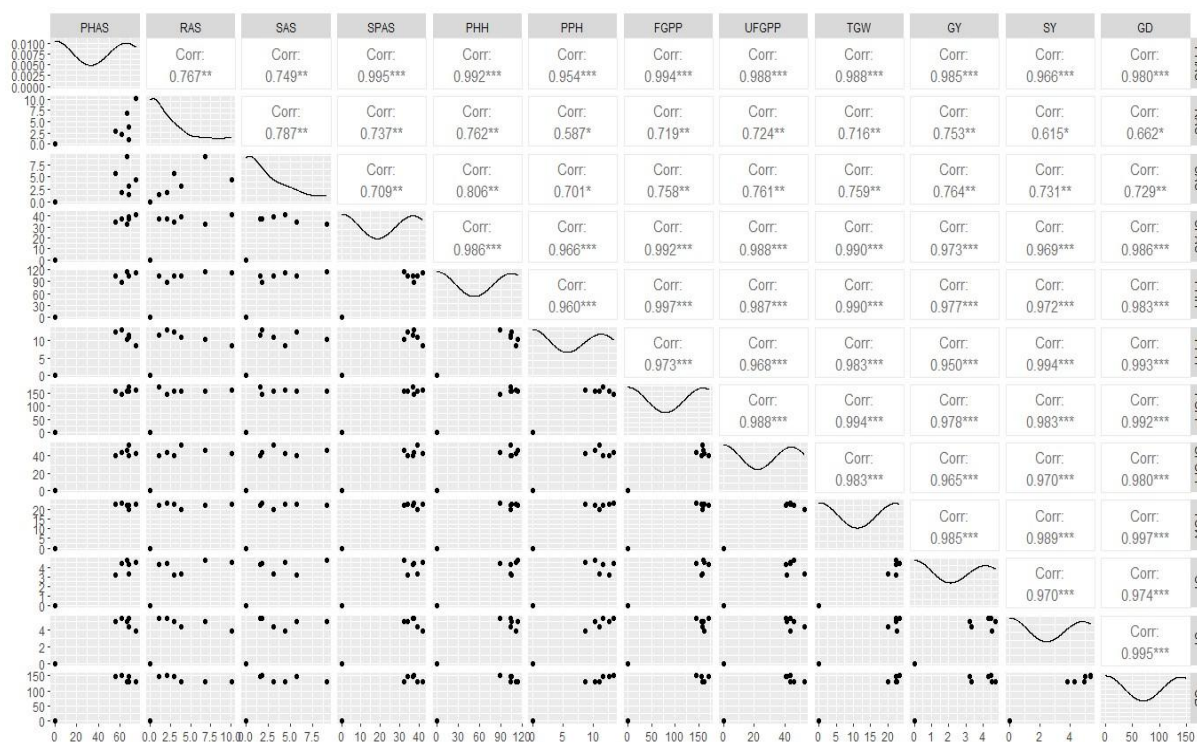


Fig. 12. Correlation coefficient for the association among different parameters of rice growing under 21-DS. Pearson's coefficient of correlation is represented by the size, shape and depth of shading of the circles. Non-significant associations are displayed by white boxes. *, **, *** represent significance at 5, 1 and 0.1% level. PHAS = Plant height after de-submergence, RAS = Root dry matter after de-submergence, SAS = Shoot dry matter after de-submergence, SPAS = SPAD value after de-submergence, PHH = Plant height at harvest, PPH = Panicle hill⁻¹, FGPP = Filled grains panicle⁻¹, UFGPP = Unfilled grains panicle⁻¹, TGW = 1000-grain weight, GY = Grain yield, SY = Straw yield, GD = Growth duration.

Correlation analysis

Pair wise correlation was calculated to evaluate the relationship among different traits of rice, with regards to morphological parameters and attributes related to grain yield under 21-DS (Fig. 12). All the parameters showed positive association with each other. Grain yield of rice had a strong relation with plant height at before submergence ($r = 0.985^{**}$), shoot weight after submergence ($r = 0.973^{**}$), plant height at harvest ($r = 0.977^{**}$), panicle hill^{-1} ($r = 950^{***}$), filled grains panicle $^{-1}$ ($r = 978^{***}$), 1000-grain weight ($r = 0.985^{***}$), and straw yield ($r = 0.970^{***}$).

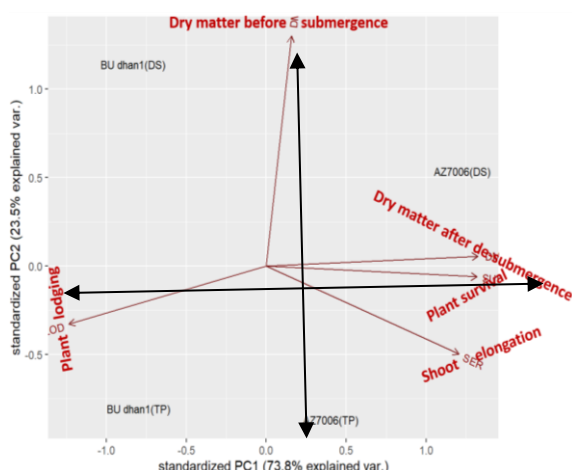


Fig. 13. Principal component analysis of rice growing under 21-DS based on plant lodging after de-submergence, shoot elongation, plant survival, shoot DM before and after de-submergence.

Principal component analysis

Principal component analysis (PCA) was performed in respect of different growth parameters of rice varieties (Fig. 13). The two components PC1 and PC2 explained 73.8 and 23.5% for 21- days of submergence, respectively. The PCA outputs under submergence condition exhibited that traits like plant survival, shoot elongation, DM production after de-submergence of flood water form cluster with AZ7006 while it was cultivated following DS. On the other hand, plant lodging form cluster with BU dhan1 when it was cultivated following transplanting method.

Conclusion

Based on the findings of this study it was concluded that about 98% plants of rice variety AZ7006 survived with minimum lodging under 21-day of submergence when this variety cultivated following direct seeding method. Under direct seeding method, the morpho-physiological attributes and yield contributing parameters of AZ7006 were minimally affected due to submergence stress. Under 21-days of submergence, AZ7006 produced 4.1 and 2.9 t ha^{-1} in case of direct seeding and transplanting method, respectively. This finding revealed that AZ7006 produced 41% higher yield under direct seeding than transplanting method. Though, this variety took 13 days more for maturation under submergence as compared to control, the yield loss of AZ7006 was 15%, when it was cultivated through direct seeding method. As this study disclosed that AZ7006 can tolerate 21-days of submergence when it is grown following direct seeding method, the variety may be tested in the flood affected field conditions to ascertain the obtained findings.

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Authors contribution

Md. Abdullah Al Mamun: Conceptualization, supervision, data analysis and manuscript drafting, Mahmudun-Nabi-Sobuj: Field experiment and collect data, Mohammed Zia Uddin Kamal and M. Moynul Haque: Editing.

Conflict of interest

The authors have no potential conflicts of interest regarding the publication of this article.

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