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SURVIVAL, GROWTH AND YIELD OF AMAN RICE UNDER VARIED DURATION OF SUBMERGENCE

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Abstract

Sixteen *aman* rice varieties were screened against two and three weeks of submergence based on their survival, growth and yield performance following split-plot design with three replications. Rice varieties AZ7006, BRRI dhan49, BRRI dhan52 and BRRI dhan57 exhibited the highest survival rate and minimum lodging that were associated with greater dry matter production under two weeks of submergence. Submergence affected the production of tillers, panicle and spikelets resulting lower grain yield than control. All the rice varieties except AZ7006 and BRRI dhan52 died under three weeks of submergence, where a small shoot of these varieties lived. These two varieties took longer time for producing shoot dry matter, tiller, panicle and maturity. Though they produced spikelets, but these were sterile due to low air temperature at flowering stage. Moreover, rice varieties BRRI dhan52, BRRI dhan57, BRRI dhan90 and AZ7006 under two weeks; and BRRI dhan52 and AZ7006 under three weeks of submergence acquired a combination of morphological and yield contributing response that ultimately induced a higher level of submergence tolerance. As the study revealed that BRRI dhan52 and AZ7006 were submergence tolerant, they could be incorporated in breeding program to develop rice variety for submergence tolerant up to three weeks.

Keywords: Climate change, lodging, stagnation, survival, yield loss.

Introduction

Heavy rainfall during *aman* season creates complete or partial submergence, which causes severe damage to rice every year in many parts of Bangladesh. The submergence may occur for a day to few weeks. However, stagnation of flooding is often about 25 to 50 cm depth that only partially submerges the shoot (Kato *et al.,* 2014). Water stagnation is caused by heavy rainfall for a short period over a relatively small area. Flash floods are most common from April to July and from September to October. During flash flooding, water levels rise and fall rapidly. Typically, they occur in areas where the upstream basin topography is relatively steep and the time needed for the water to flow from the most remote point in a watershed to the watershed outlet is relatively short. The most affected areas are in the northern and southeastern part of Bangladesh.

Flooding seriously affects plant survival, while complete submergence is highly damaging to rice. Yield loss due to floods ranges from 10 to

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100% depending on flood duration, depth and floodwater conditions (Ismail *et al.,* 2013). A limited number of submergence tolerant high yielding rice varieties have been developed and commercialized. A few high yielding rice genotypes has also been identified, which is tolerant to submergence (Vergara *et al*., 2014).

Traditional rice varieties still predominate in flood-prone lowland farms and rice yield is low, ranging from 0.5 to 2.0 t ha^{-1}, less than half that of irrigated rice (Mackill *et al.*, 2012). Two submergence-tolerant varieties, such as BRRI dhan51 and BRRI dhan52, are popularly cultivated in Bangladesh which can tolerate submergence for two weeks. The BRRI dhan56 and BRRI dhan57 performed better under submerged condition as reported by Islam *et al.* (2019) and Abedin *et al.* (2019). These two verities produced higher number of tillers $hill^{-1}$ and grain $panicle^{-1}$ after 10 days of submergence. However, sometimes flash flood causes inundation of crops more than two weeks. Thus, a rice variety is needed that can tolerate more than two weeks of submergence. Therefore, the present study was conducted to investigate the effect of submergence on survival, growth and yield of *aman* rice, and to identify rice variety that can survive for three weeks of submergence.

Materials and Methods

Experimental site

An experiment was conducted in the submergence tank of Agronomy research field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur during *aman* season, 2020. It is located in Madhupur Tract under Agro Ecological Zone 28 at geographic coordinate 24° 09′ North latitude and 90° 26′ East longitude with an elevation of 8.4 m above the mean sea level. The soil of the experimental site is silty clay in surface and silty clay loam in sub-surface region. The site is situated in the sub-tropical region characterized by heavy rainfall during monsoon at the months from May to September and scanty rainfall in the rest of the months of the year.

Land preparation and planting materials

The land in the tank was prepared by spade. Sixteen *aman* rice varieties such as BRRI dhan87, BRRI dhan90, BRRI dhan93, BRRI dhan94, BRRI dhan95, AZ6007, BRRI dhan51, BRRI dhan52, BRRI dhan49, BU dhan1, BU dhan2, Kanihati1, Kanihati6, BINA dhan7 and Ganzia were tested against submergence. Among the tested materials, fourteen (except Kanihati1 and Kanihati6, they are local cultivars) are released rice varieties in Bangladesh. Seeds of BRRI dhan49, BRRI dhan51, BRRI dhan52, BRRI dhan87, BRRI dhan90, BRRI dhan93, BRRI dhan94, and BRRI dhan95 were collected from Bangladesh Rice Research Institute, Gazipur. However, BU dhan1, BU dhan2, Kanihati1, Kanihati6, and Ganzia were collected from the Department of Agronomy, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur. Moreover, BINA dhan7 was collected from Bangladesh Institute of Nuclear Agriculture, Mymensingh.

Experimental treatments and design

The selected sixteen *aman* rice varieties were tested against three treatments viz. i. no submergence (control), ii. two weeks of submergence, and iii. three weeks of submergence. The experiment was laid out

in a split-plot design with three replications. There are many rice varieties released for *aman* season. Including 23 *aman* rice varieties, Islam *et al*. (2019) conducted an experiment under two weeks of submergence. Based on the findings of Islam *et al*. (2019), other 16 varieties were included in this present experiment. Seeds are sown in seedbed on 10 August, 2020 and 33-day-old seedlings were transplanted in the main field on 13 September, 2020.

Crop culture

About 2-3 seedlings $hill^{-1}$ were transplanted maintaining 25 × 15 cm spacing. The experimental plots were fertilized with triple super phosphate, muriate of potash, gypsum, and zinc sulphate as the source of P, K, S and Zn at 10, 22.5, 2.5, and 0.14 kg ha^{-1}, respectively, during the final land preparation. Urea was applied at 150 kg ha^{-1} in three equal splits on 20 September, 05 and 20 October, 2020 in control; 20 September, 15 and 30 October, 2020 in two weeks of submergence; 20 September, 22 October and 07 November, 2020 in three weeks of submergence. Gap filling was done at 5 days after transplanting (DAT) with same aged seedling.

Imposition of submergence treatment

In the control plot, 2 to 3 cm water depth was maintained from transplanting until 15 days before harvest. For the submergence treatment, water depth was maintained at 2 to 3 cm up to 10 DAT. After that water depth of 75.0 ± 5 cm (BRRI, 2016), which was enough for complete submergence of the rice plant, was maintained from 11 to 25 DAT in case of two weeks of submergence, and 11 to 32 DAT in case three weeks of submergence. The water quality data was measured during submergence of the crop. Dissolved O_2 was 7.28 and 6.20 mg lit^{-1}, electrical conductivity 1.1 and 1.1 mS, pH 7.56 and 7.39, and turbidity 5.18 and 5.21 ntu (Nephelometric Turbidity unit) under three and two weeks of submergence, respectively. The crop was kept weed free throughout the growing period to reduce weed competition (Mamun *et al*., 2013). Irrigation and other cultural practices have been done whenever necessary. It was observed that all the rice varieties except AZ7006 and BRRI dhan52 died under three weeks of submergence.

Data collection

The air temperature of the experimental site gradually was decreased from October, 2020 to January, 2021. The highest daily average temperature (31°C) was recorded on 09 October, 2020 and the lowest (13.0 °C) on 21st December, 2020 and 07 January, 2021 (Fig. 1).

Seedling survival rate was estimated after two and three weeks of submergence treatment followed by 7 days after de-submergence (DADS). Plants survival rate were calculated as calculated as

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

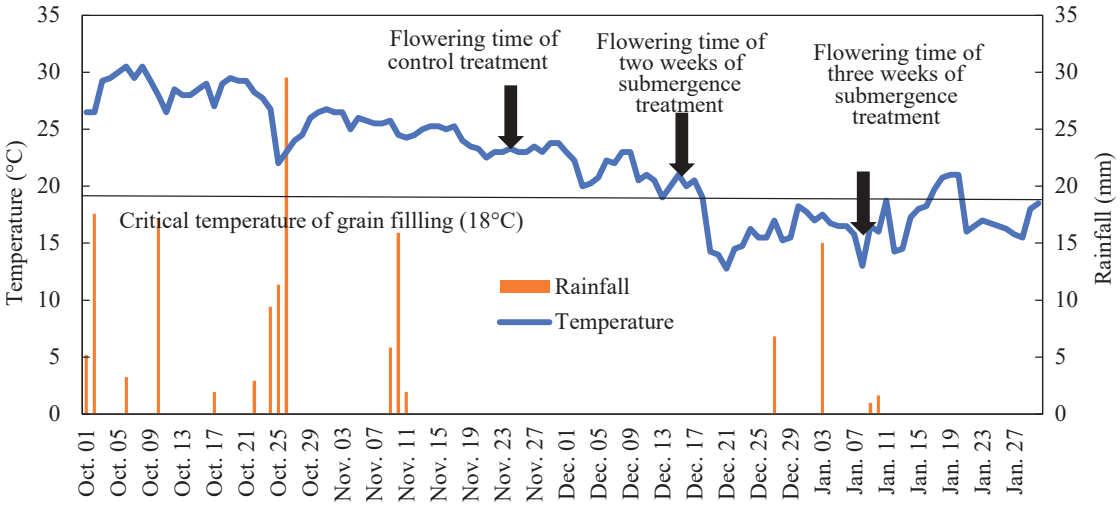

Fig. 1. Daily mean air temperature and rainfall of the field area during the experiment. Seedling survival rate was estimated after 7 days after de-submergence (DADS) of flood water.

The survival of a variety means that the ability of that to survive under flooding and renew its growth after de-submergence of flood water (Catling, 1992). The intensity of lodging of plants were recorded only once i.e., 7days after recession of flood water based on visual observation according to IRRI (1988). Lodging score 0 indicates no plant is lodged. However, score 1, 3, 5, 7 and 9 directs 1-20, 21-40, 41-60, 61-80 and more than 80% of plants are lodged.

Data on plant height, SPAD value, shoot and root dry matter (DM) were collected two times after 7 DADS and 21 DADS of flood water. During sample collection the border-line was avoided to maintain data accuracy. To record shoot DM, plant shoots were dried in an oven at 70 °C for 72 h and weighed. The SPAD value was taken by SPAD meter (model: SPAD-502, Minolta, Japan) at 7 and 21 DADS. Days to flowering and growth duration were recorded. The crop was harvested at full maturity. Threshing, cleaning, and drying of grain were done separately variety by variety. Panicles number m^{-2}, filled grains and unfilled grains $panicle^{-1}$, 1000-grain weight, grain yield and straw yield were determined at harvest. The grain was cleaned and sun dried to a moisture content of 14%.

Calculation of stress tolerance index (STI)

The stress tolerance index (STI) for each morpho-physiological and yield-related trait at two and three weeks of submergence were computed individually using the following formula: $STI = [(X_c \times X_s)/(\bar{X}_c)^2]$ (Fernandez, 1992), where X_c and X_s represent the measured values of a trait in a given genotype under the control and submergence stress, respectively, while $\bar{X}_c$ is the average value of a specific trait estimated in both genotypes under control condition.

Data analysis

The data were statistically analyzed by 'CropStat 7.2' software and treatment means

were separated following DMRT at the 5% level of significance (Gomez and Gomez, 1984). The data obtained from control and two weeks of submergence were considered for statistical analysis. Relative values (RV) of each parameter of rice variety were determined as

$$RV = \frac{\text{Performance of a variety under submergence}}{\text{Performance of a variety under control condition}}$$

Results and Discussion

Plant height

Plant height was increased by 22, 73, 55 and 37% under two weeks of submergence in case of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively (Table 1). However, the shoot length of AZ7006, BU dhan51 and BU dhan52 did not increased significantly under two weeks of submergence. Most of the rice cultivars elongated their shoot during submergence

Table 1. Effect of submergence on plant height of 16 rice varieties at 7 and 21 days of de-submergence (DADS)

Varieties	Plant height (cm)					
	At 7 DADS			At 21 DADS		
	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
BRRI dhan87	54.00 i	77.75 def	1.44	75.33 cde	49.05 h	0.65
BRRI dhan90	61.33 gh	74.75 ef	1.22	84.16 bc	61.25 fg	0.73
BRRI dhan93	52.00 i	90.00 ab	1.73	83.00 bcd	55.00 gh	0.66
BRRI dhan94	56.30 hi	87.25 abc	1.55	81.83 bcd	57.25 fgh	0.70
BRRI dhan95	56.83 hi	78.00 cdef	1.37	87.50 b	56.00 gh	0.64
AZ7006	54.50 hi	57.50 hi	1.06	78.66 bcd	57.50 fgh	0.73
BRRI dhan51	57.16 hi	62.50 gh	1.09	78.00 bcd	62.00 fg	0.79
BRRI dhan52	57.66 hi	63.00 gh	1.09	67.33 e	54.75 gh	0.81
BRRI dhan57	52.00 i	83.50 bcde	1.61	79.00 bcd	58.50 fgh	0.74
BRRI dhan49	54.16 hi	84.00 bcd	1.55	78.16 bcd	62.25 fg	0.80
BU dhan1	60.50 hi	86.75 abc	1.43	82.00 bcd	56.50 gh	0.69
BU dhan2	56.50 hi	80.00 cde	1.42	76.66 cde	53.25 gh	0.69
Kanihati1	63.66 gh	70.33 fg	1.10	73.50 de	66.50 ef	0.90
BINA dhan7	53.33 i	70.00 fg	1.31	76.66 cde	56.50 gh	0.74
Ganzia	61.50 gh	95.00 a	1.54	101.50 a	48.25 h	0.48
Kanihati6	49.66 i	75.00 ef	1.51	79.50 bcd	55.25 gh	0.69
CV (%)	11.5			13.8		

Similar letters in a column did not vary significantly. Under three weeks of submergence, the plant height of AZ7006 and BRRI dhan52 was 29.50 and 19.08 cm at 7 DADS, while 29.50 and 20.50 cm at 21 DADS, respectively. RV = Relative value.

at two weeks of submergence and this is one of the escape strategies for adaptation to submergence (Oladosu *et al.,* 2020). The level of shoot elongation during submergence depends on the genetic character of the cultivar and is affected by the submergence environment or state of seedling growth before submergence. In submerged conditions, Afrin *et al*. (2018) and Asante *et al*. (2019) found that plant height varied significantly between genotypes. Energy shortage caused by anoxia may lead to reduced nutrient uptake by plants, resulting in the cessation of root elongation, leading to pronounced root injury and death of the tips (Bui *et al.,* 2019).

All the rice varieties except AZ7006 and BRRI dhan52 died due to three weeks of submergence. At three weeks of submergence, the plant height of AZ7006 and BRRI dhan52 was decreased by 45.87 and 66.90% at 7 DADS, while 45.87 and 64.45% at 21 DADS, respectively.

Dry matter production

Submerged rice plants showed significant reduction of DM during submergence. At 7 DADS, shoot DM of all genotypes decreased significantly under two weeks of submergence (Table 2). Shoot DM of BRRI dhan87 was

Table 2. Effect of submergence on shoot dry matter production of 16 rice varieties at 7 and 21 days of de-submergence (DADS)

Varieties	Shoot dry matter (g hill^{-1})					
	At 7 DADS			At 21 DADS		
	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
BRRI dhan87	2.54 de	0.70 h	0.28	14.79 cd	0.96 fg	0.06
BRRI dhan90	3.43 bcd	0.86 gh	0.25	16.58 bcd	3.20 fg	0.19
BRRI dhan93	3.16 bcd	0.70 h	0.22	19.36 b	1.15 fg	0.06
BRRI dhan94	4.21 ab	0.76 gh	0.18	14.44 cde	1.71 fg	0.12
BRRI dhan95	2.99 bcde	0.68 h	0.23	15.70 cd	1.61 fg	0.10
AZ7006	3.73 abc	0.81 gh	0.22	19.40 b	3.42 fg	0.18
BRRI dhan51	2.96 cde	0.69 h	0.23	16.19 bcd	1.40 fg	0.09
BRRI dhan52	2.85 cde	0.68 h	0.24	11.24 e	4.29 f	0.38
BRRI dhan57	2.61 de	1.15 fgh	0.44	14.69 cde	4.37 f	0.30
BRRI dhan49	2.88 cde	0.75 gh	0.26	13.88 de	2.22 fg	0.16
BU dhan1	4.87 a	0.97 gh	0.20	18.00 bc	1.72 fg	0.10
BU dhan2	2.25 def	0.62 h	0.28	14.93 cd	1.11 fg	0.07
Kanihati1	4.03 abc	0.81 gh	0.20	14.79 cd	2.78 fg	0.19
BINA dhan7	3.08 bcd	0.88 gh	0.29	16.78 bc	2.33 fg	0.14
Ganzia	4.52 a	0.60 h	0.13	23.44 a	0.62 g	0.03
Kanihati6	1.98 efg	0.81 gh	0.41	16.90 bc	2.61 fg	0.15
CV (%)	14.4			16.3		

Similar letters in a column did not vary significantly. Under three weeks of submergence, the shoot DM of AZ7006 and BRRI dhan52 was 0.15 and 0.12 g hill^{-1} at 7 DADS, while 0.20 and 0.16 g hill^{-1} at 21 DADS, respectively. RV = Relative value.

2.54 g hill^{-1} in control, which decreased to 0.7 g hill^{-1} under two weeks of submergence. Similarly, shoot DM was decreased by 74, 77, 81 and 77% under two weeks of submergence in case of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. Under three weeks of submergence, the shoot DM of AZ7006 and BRRI dhan52 was 0.15 and 0.12 g hill^{-1} at 7 DADS, while 0.20 and 0.16 g hill^{-1} at 21 DADS, respectively (data not shown).

At 7 DADS, root DM of all genotypes decreased significantly due to two weeks of submergence (Table 3). Root DM of BRRI dhan87 was 1.73 g hill^{-1} in control, which was decreased to 0.17 g hill^{-1} under two weeks of submergence. Similarly, root DM was decreased by 85, 92, 90 and 80% under two weeks of submergence in case of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. The root DM of AZ7006 and BRRI dhan52 were 0.08 and 0.04 g hill^{-1}, respectively under three weeks of submergence when measurement was taken at 7 DADS. At 21 DADS, lower root DM of rice was recorded at 21 DADS. Submergence

Table 3. Effect of submergence on root dry mater production of 16 rice varieties at 7 and 21 days of de-submergence (DADS)

Varieties	Root dry mater (g hill^{-1})					
	At 7 DADS			At 21 DADS		
	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
BRRI dhan87	1.73 bcd	0.17 g	0.10	9.15 a	0.48 e	0.05
BRRI dhan90	1.44 cd	0.21 g	0.15	5.92 bcd	1.09 e	0.18
BRRI dhan93	1.90 abc	0.15 g	0.08	7.18 abc	0.51 e	0.07
BRRI dhan94	2.56 ab	0.25 g	0.10	7.61 abc	0.62 e	0.08
BRRI dhan95	1.26 cde	0.24 g	0.19	4.12 d	0.54 e	0.13
AZ7006	2.57 ab	0.29 fg	0.11	8.17 ab	0.83 e	0.10
BRRI dhan51	1.16 cdef	0.16 g	0.14	7.10 abc	0.52 e	0.07
BRRI dhan52	1.69 bcd	0.17 g	0.10	5.85 bcd	1.09 e	0.19
BRRI dhan57	1.35 cd	0.26 g	0.19	6.89 bc	1.24 e	0.18
BRRI dhan49	1.83 abc	0.24 g	0.13	7.53 abc	1.30 e	0.17
BU dhan1	2.63 a	0.40 efg	0.15	7.93 ab	0.64 e	0.08
BU dhan2	1.27 cde	0.29 f	0.23	7.93 ab	0.56 e	0.07
Kanihati1	1.46 cd	0.24 g	0.16	5.23 cd	0.78 e	0.15
BINA dhan7	2.05 abc	0.25 g	0.12	7.79 ab	0.69 e	0.09
Ganzia	2.34 ab	0.21 g	0.09	6.97 abc	0.31 e	0.04
Kanihati6	0.87 defg	0.22 g	0.25	6.72 bc	0.60 e	0.09
CV (%)	15.8			11.6		

Similar letters in a column did not vary significantly. Under three weeks of submergence, the root DM of AZ7006 and BRRI dhan52 was 0.08 and 0.04g at 7 DADS, while 0.10 and 0.09g at 21 DADS, respectively. RV = Relative value.

dramatically reduces the amount of oxygen that limits root development. Flooding inhibits respiration in the root due to insufficient supply of oxygen (Visser and Pierik, 2007).

Chlorophyll content

Submergence exerted a significant effect on SPAD value of rice (Table 4). At 7 DADS, SPAD value was decreased significantly in all genotypes except BRRI dhan51, BRRI dhan52 and BRRI dhan94 due to two weeks of submergence. BRRI dhan51, BRRI dhan52 and BRRI dhan94 was recovered earlier than others. The SPAD value of BRRI dhan87 was 40.03 in control, which was decreased to 30 under two weeks of submergence. Similarly, SPAD value was decreased by 14, 21, 16 and 20% under two weeks of submergence in case of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. At 21 DADS, the SPAD value of BRRI dhan87 was increased from 37.8 to 41.95 under control and two weeks of submergence, respectively (Table 4). Under three weeks of submergence, the SPAD value of AZ7006 and BRRI dhan52 were 20.3 and 18.5 at 7 DADS, which were 22.2 and 19.3 at 21 DADS, respectively (data not shown). The reduction (not all cases) in Chl under hypoxic condition was probably due to the slow synthesis and fast degradation

Table 4. Effect of submergence on chlorophyll content (SPAD value) of 16 rice varieties at 7 and 21 days of de-submergence (DADS)

Varieties	SPAD value					
	At 7 DADS			At 21 DADS		
	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
BRRI dhan87	40.03 bcd	30.00 ij	0.75	37.80 ef	41.95 cd	1.11
BRRI dhan90	41.63 bcd	35.40 efg	0.85	44.73 abc	42.55 bcd	0.95
BRRI dhan93	43.63 ab	34.25 fgh	0.79	40.26 def	45.10 abc	1.12
BRRI dhan94	29.33 ij	34.05 gh	1.16	41.10 de	40.40 def	0.98
BRRI dhan95	43.23 ab	34.30 fgh	0.79	45.36 abc	46.25 ab	1.02
AZ7006	45.03 a	39.20 cde	0.87	43.66 abcd	47.25 a	1.08
BRRI dhan51	39.10 cde	39.40 cde	1.01	38.30 ef	42.15 bcd	1.10
BRRI dhan52	37.33 def	37.75 def	1.01	36.20 f	42.30 bcd	1.17
BRRI dhan57	42.46 abc	34.70 fgh	0.82	40.46 de	40.00 def	0.99
BRRI dhan49	41.10 bcd	31.90 hi	0.78	38.80 ef	36.85 f	0.95
BU dhan1	39.03 cde	23.60 j	0.60	36.13 f	39.35 ef	1.09
BU dhan2	38.90 cde	31.75 hi	0.82	41.93 cde	39.40 ef	0.94
Kanihati1	46.60 a	33.35 ghi	0.72	44.86 abc	41.00 de	0.91
BINA dhan7	38.06 def	21.50 j	0.56	38.00 ef	39.60 def	1.04
Ganzia	38.80 cde	24.75 j	0.64	43.76 abcd	44.65 abc	1.02
Kanihati6	38.20 de	36.50 efg	0.96	42.56 bcd	40.90 de	0.96
CV (%)	12.5			8.5		

Similar letters in a column did not vary significantly. Under three weeks of submergence, the SPAD value of AZ7006 and BRRI dhan52 was 20.3 and 18.5 at 7 DADS, while 22.2 and 19.3 at 21 DADS, respectively. RV = Relative value.

of Chl pigment (Ashraf, 2003). This might reduce the SPAD value due to submergence. The results of this experiment of decreasing SPAD value under submergence condition is in agreement with the findings of other studies (Sarkar and Ray, 2016).

Plant lodging and survival

After recession of flood water, all the varieties lodged due to submergence. At two weeks of submergence, plant lodging varied from 20 to 60%, where AZ7007 and BRRI dhan52 lodged minimum (Fig. 2). At three weeks of submergence, AZ7007 and BRRI dhan52 lodged by 36 and 86%, respectively. On the other hand, 100% lodging were obtained from other varieties at three weeks of submergence (Fig. 2). At two weeks of submergence, plant survival varied from 40 to 100% (Fig. 2). The survival percentage were the highest in case of AZ7007, BRRI dhan52 and BRRI dhan57 (100%). At three weeks of submergence, all the plants died except AZ7007 and BRRI dhan52. The survival percentage of AZ7007 and BRRI dhan52 were 60 and 19%, respectively under three weeks of submergence. Vergara *et al.* (2014) reported that elongation rate that maintains about 50% of the shoot height above the water surface is likely to be optimum for higher yields under submergence. The extent of damage to rice crops caused by complete submergence during their vegetative stage depends on environmental conditions (Ye *et al.,* 2018).

Days to flowering and maturity

Flowering and maturity were delayed in all genotypes exposed to submergence (Table 5). Flowering was delayed by 18 to 52 days, and maturity by 21 to 52 days under two weeks

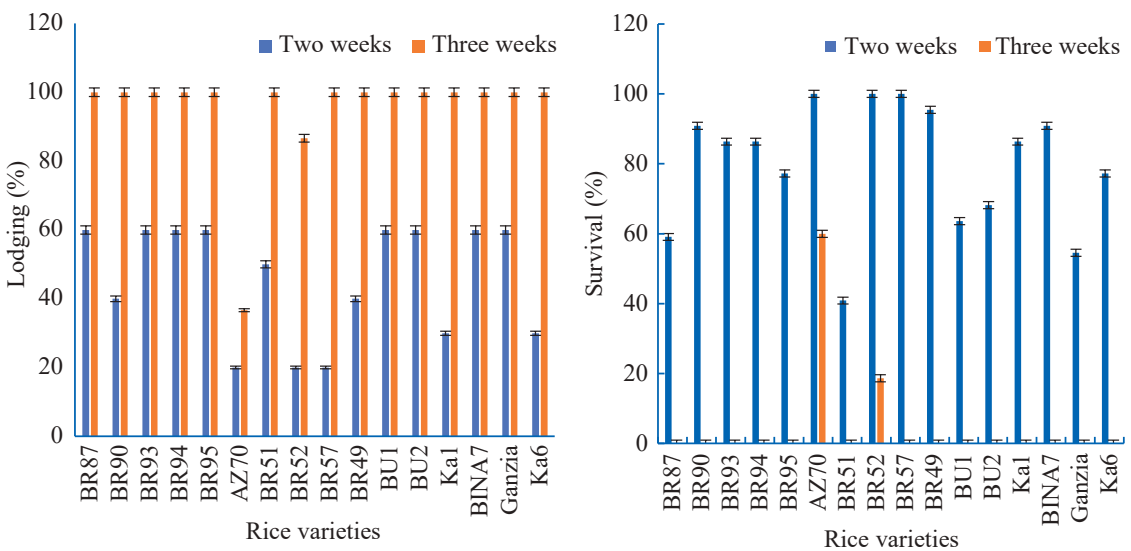

Fig. 2. Effect of submergence on plant lodging and survival after de-submergence. BR87 = BRRI dhan87, BR90 = BRRI dhan90, BR93 = BRRI dhan93, BR94 = BRRI dhan94, BR95 = BRRI dhan95, AZ70 = AZ7006, BR51 = BRRI dhan51, BR52 = BRRI dhan52, BR53 = BRRI dhan57, BR49 = BRRI dhan49, BU1 = BU dhan1, BU2 = BU dhan2, Ka 1 = Kanihati1, BINA 7 = BINA dhan7 and Ka6 = Kanihati6.

of submergence across the genotypes. Due to three weeks of submergence, flowering was delayed by about 55 to 66 days, and maturity delayed by about 59 to 67 days in the case of AZ7006 and BRRI dhan52, respectively (data not shown). Delay in flowering and maturity occurred after de-submergence as surviving plants took time to recover the damage due to flooding. The plants needed time to resume normal vegetative growth and overcome oxidative damage during and after de-submergence (Dwivedi *et al.,* 2018). However, the apparent delay in maturity was mostly because of the delay of flowering (Table 5). Flood destroyed crop establishment and new shoots emerged from the stem base of damaged plants during the post-emergence period. Real recovery growth during this time could be considered as re-establishment of the crop after flood damage (Ram *et al.*, 2009).

Plant height and straw yield at harvest

Submergence showed a significant effect on plant height of rice at maturity (Table 6). Plant height of BRRI dhan87 was 91 cm in control, while it was reduced to 82.25 cm under two weeks of submergence. Similarly, plant height was decreased by 9, 17, 13 and 43% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. However, AZ7006 produced plant of 91.66, 84.50 and 77.67 cm; and BRRI dhan52 gave plant of 96.66, 94.75 and 75.33 cm under control, two

Table 5. Effect of submergence on days to flowering and maturity of 16 rice varieties

Varieties	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
	Days to flowering			Days to maturity		
BRRI dhan87	102 efgh	136 abc	1.33	135 cdef	172 ab	1.27
BRRI dhan90	91 h	109 defg	1.20	122 f	157 bcd	1.29
BRRI dhan93	98 fgh	128 bcd	1.31	131 ef	159 bc	1.21
BRRI dhan94	106 defg	145 ab	1.37	130 ef	173 ab	1.33
BRRI dhan95	87 h	118 def	1.36	122 f	159 bc	1.30
AZ7006	85 h	123 bcde	1.45	128 ef	161 bc	1.26
BRRI dhan51	95 gh	119 cdef	1.25	136 cdef	157 bcd	1.15
BRRI dhan52	99 fgh	142 ab	1.43	136 cdef	167 ab	1.23
BRRI dhan57	95 gh	113 defg	1.19	127 f	157 bcd	1.24
BRRI dhan49	103 efgh	140 abc	1.36	135 cdef	173 ab	1.28
BU dhan1	101 efgh	153 a	1.51	136 cdef	187 a	1.38
BU dhan2	102 efgh	151 a	1.48	138 cdef	190 a	1.38
Kanihati1	94 gh	119 cdef	1.27	135 cdef	159 bc	1.18
BINA dhan7	95 gh	118 def	1.24	128 ef	154 bcde	1.20
Ganzia	89 h	115 def	1.29	121 f	169 ab	1.40
Kanihati6	92 h	123 bcde	1.34	133 def	158 bcd	1.19
CV (%)	15.6			13.5		

Similar letters in a column did not vary significantly. Under three weeks of submergence, AZ7006 and BRRI dhan52 needed 151 and 154 days for flowering, while 195 and 195 for maturity, respectively. RV = Relative value.

and three weeks of submergence, respectively. Generally, taller plants were found under submergence. Submergence promotes to release different hormones, including abscisic acid, gibberellins and auxin (Jackson, 2008). These hormones are responsible for elongation of rice plant under submerged condition. In this study, the height of rice plant decreased due to submergence. After recession of flood water, the plants lodged and died. After death of primary shoot of rice due to submergence, a new shoot developed from the base of the rice plants. Thus, the height of regenerated tillers at maturity were shorter than that of control one.

On the other hand, two weeks submergence showed a significant effect on straw weight of rice at maturity. Similarly, the straw weight of rice also varied significantly among the varieties. Straw weight of rice increased due to submergence in all varieties except BRRI dhan95, BRRI dhan51 and Ganzia (Table 6). Straw weight of BRRI dhan87 was 18.52 g plant^{-1} in control, while it was reduced to 30.72 g plant^{-1} under two weeks of submergence. Similarly, straw weight was increased by 45, 75, 2 and 9% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan57, respectively. Similar trend in case straw weight was also recorded for BRRI dhan49, BU dhan1, BU dhan 2, Kanihati1, Kanihati6 and BINA dhan7. However, AZ7006 produced plant of 17.34, 67.00 and 276.71 g plant^{-1}; and BRRI dhan52 gave plant of 20.07, 68.00 and

Table 6. Effect of submergence on height and straw yield of 16 rice varieties at harvest

Varieties	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
	Plant height (cm)			Straw weight (g plant^{-1})		
BRRI dhan87	91.00 cdef	82.25 fg	0.90	18.52 efg	30.72 de	1.66
BRRI dhan90	82.50 fg	74.75 g	0.91	13.19 fg	19.24 efg	1.46
BRRI dhan93	103.83 ab	86.00 efg	0.83	22.30 ef	39.06 c	1.75
BRRI dhan94	98.16 abcd	84.50 efg	0.86	17.71 fg	54.38 ab	3.07
BRRI dhan95	87.33 def	49.50 h	0.57	15.76 fg	14.22 fg	0.90
AZ7006	91.66 cdef	84.50 efg	0.92	17.34 fg	67.00 ab	3.86
BRRI dhan51	94.33 bcde	54.75 h	0.58	14.29 fg	7.45 g	0.52
BRRI dhan52	96.66 bcd	94.75 bcde	0.98	20.07 ef	68.00 a	3.39
BRRI dhan57	82.83 fg	81.50 fg	0.98	12.26 fg	24.00 ef	1.96
BRRI dhan49	89.50 def	85.75 efg	0.96	21.05 ef	37.17 c	1.77
BU dhan1	99.00 abc	85.00 efg	0.86	19.30 efg	37.60 c	1.95
BU dhan2	100.66 abc	101.70 abc	1.01	17.94 fg	43.89 bc	2.45
Kanihati1	87.00 def	75.75 g	0.87	15.70 fg	30.82 de	1.96
BINA dhan7	82.00 fg	75.00 g	0.91	13.28 fg	38.28 c	2.88
Ganzia	109.50 a	80.50 fg	0.74	24.31 e	9.70 g	0.40
Kanihati6	86.83 def	76.25 g	0.88	15.90 fg	35.94 cd	2.26
CV (%)	7.8			14.3		

Similar letters in a column did not vary significantly. At maturity, the plant height of AZ7006 and BRRI dhan52 was 77.67 and 75.33 cm, while straw weight 276.71 and 207.83 g plant^{-1} under three weeks of submergence, respectively. RV = Relative value.

207.83 g plant^{-1} under control, two weeks (Table 6) and three weeks (data not shown) of submergence, respectively.

Das *et al.* (2005) reported that straw biomass was comparatively decreased in submergence than control. In submergence, less amount of photosynthetically active radiation reached at canopy level was supposed to be the main reason for tiller mortality and reduced growth. In this present experiment, rice plants produced significantly higher amount of shoot DM because submerged plant got longer time to produce more tillers resulting higher straw production (Table 6). Sarker and Das (2003) and Yin *et al.* (2010) suggested that the increase in dry weight each day was mainly due to the increase in culm DM content rather than leaf area or total leaf dry weight.

Tillers and panicle production

The tiller of rice was increased due to submergence in all varieties except BRRI dhan51 and Ganzia (Table 7). The tiller of BRRI dhan87 was 10.83 in control, while it was increased to 17.75 under two weeks of submergence. Similarly, the tiller was increased by 6, 37, 87 and 20% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. In general, the submergence is an acute problem at the early growth stages which causes serious damages of plants (Ismail *et al.,* 2009). In this experiment, submergence

Table 7. Effect of submergence on tillers and panicle production of 16 rice varieties

Varieties	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
	Tillers (no. hill^{-1})			Panicles (no. hill^{-1})		
BRRI dhan87	10.83 e	17.75 a-f	1.64	10.16 bcd	13.75 abcd	1.35
BRRI dhan90	15.33 cde	24.75 abc	1.61	13.50 abcd	20.00 ab	1.48
BRRI dhan93	14.33 de	19.75 abcd	1.38	12.66 abcd	16.50 abcd	1.30
BRRI dhan94	11.33 e	21.25 abcd	1.88	10.16 bcd	18.00 abcd	1.77
BRRI dhan95	10.83 e	13.00 e	1.20	8.50 cd	11.50 bcd	1.35
AZ7006	13.83 e	26.50 a	1.92	12.50 abcd	22.75 a	1.82
BRRI dhan51	12.16 e	10.50 e	0.86	12.00 abcd	8.00 d	0.67
BRRI dhan52	10.66 e	17.75 a-f	1.67	10.33 bcd	15.00 abcd	1.45
BRRI dhan57	12.16 e	16.50 bcde	1.36	11.00 bcd	12.75 abcd	1.16
BRRI dhan49	16.00 bcde	20.50 abcd	1.28	14.16 abcd	18.00 abcd	1.27
BU dhan1	16.16 bcde	24.75 abc	1.53	14.66 abcd	18.25 abcd	1.24
BU dhan2	13.83 e	21.50 abcd	1.55	12.66 abcd	19.75 abc	1.56
Kanihati1	15.00 de	20.25 abcd	1.35	13.33 abcd	15.75 abcd	1.18
BINA dhan7	12.16 e	22.25 abcd	1.83	10.50 bcd	18.50 abcd	1.76
Ganzia	25.50 ab	13.00 e	0.51	23.00 a	8.50 cd	0.37
Kanihati6	15.00 de	24.00 abcd	1.60	14.33 abcd	18.75 abc	1.31
CV (%)	14.4			14.6		

Similar letters in a column did not vary significantly. At maturity, the tillers of AZ7006 and BRRI dhan52 was 79.5 and 74.5 hill^{-1}, while panicles 66.67 and 61.83 hill^{-1} under three weeks of submergence, respectively. RV = Relative value.

stress enhanced the growth duration of rice varieties (Table 6). After regeneration of new shoots, plants got longer time for harvesting more light energy and produced higher amount of photo assimilates that stored in their body. Tillers are the branches of rice plants and more panicles production are the result of more tillers. The panicle of rice increased due to submergence in all varieties except BRRI dhan51 and Ganzia (Table 7). The panicle of BRRI dhan87 was 10.16 in control, while it was increased to 13.75 under two weeks of submergence. Similarly, the panicle was increased by 48, 30, 77 and 35% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. Gautam *et al.* (2015) reported that submergence reduced the tillers production of rice due to reduced photosynthesis. Excess water deprives the plant from their basic resources such as oxygen, carbon dioxide and light for photosynthesis. For this reason, tiller production drastically reduces during submergence.

In rice, the number of panicles and the size of panicles are consistently regarded as selection criteria for realizing adequate productivity or grain yield. However, Kato *et al.* (2014) stated that panicle number decreases due to the suppression of tiller growth or mortality of tiller either due to prevalence of lessen light below 50 cm water depth or lack of sufficient supply of oxygen.

Spikelet production

The filled grain of BRRI dhan87 was 96.82 in control, while it was decreased to 16.89 under two weeks of submergence. Similarly, the filled grain was decreased by 8, 91, 88 and 71% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively (Table 8). Similar trend in case the filled grain was also recorded for AZ7006, BRRI dhan51, BRRI dhan52, BRRI dhan57, BRRI dhan49, BU dhan1, BU dhan2, Kanihati1, Kanihati6, BINA dhan7 and Ganzia. On the other hand, submergence showed a significant effect on the unfilled grain of rice at maturity. Similarly, the unfilled grain of rice also varied significantly in the varieties. the unfilled grain of rice increased due to submergence in all varieties except BRRI dhan49 (Table 8). The panicle of BRRI dhan87 was 42.15 in control, while it was increased to 55.3 under two weeks of submergence. Similarly, the unfilled grain was increased by 2, 8, 1 and 2% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. Similar trend in case the unfilled grain was also recorded for AZ7006, BRRI dhan51, BRRI dhan52, BRRI dhan57, BU dhan1, BU dhan2, Kanihati1, Kanihati6, BINA dhan7 and Ganzia. Poor grain filling of the rice varieties under submergence could pose a serious problem and frequently limits the yield potential (Duan and Sun, 2005). Prolonged duration of monsoon or elevated water level due to flash flood is the major concern to rice plants for poor development of spikelet, infertile grain, reduced grain weight and finally substantial curtail of yield (Perata and Voesenek, 2007). Fukao *et al.* (2006) and Barding *et al.* (2012) described that number of grains panicle^{-1} drastically reduces under submergence compared to control. Low light under water and low photosynthetically active

radiation at canopy level are supposed to be the main reason for reduced grain number per panicle. After recession of flood water, plant used most of their photosynthates for maintaining vegetative growth. According to BRRI (2020), the night temperature 13 °C and day temperature 24 °C during panicle initiation stage is the critical temperature for rice. Air temperature below the critical level enhances spikelet sterility of rice. The seedlings were trans planted on 13th September, 2020. In this experiment, the rice plants treated under three weeks of submergence were forced to flower late during the month of January, 2021. Low air temperature of 13 to 19 °C was prevailed in the present experimental site during the month of mid-December of 2020 to mid-January of 2021 (Fig. 1). During flowering the three weeks submergence treated plants experienced air temperature varied from 13 to 19 °C (Fig. 1). A night temperature 12 to 13 °C and day temperature 23 to 24 °C during panicle initiation to booting causes sterility to rice (BRRI, 2022). Therefore, the prevailing low temperature presumably caused increased sterility in this experiment due to three weeks of submergence (Table 8). However, the air temperature of rice plants that's were treated with two weeks of submergence flowered before mid-December

Table 8. Effect of submergence on grain production per panicle in 16 rice varieties at harvest

Varieties	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
	Filled grains (no. panicle^{-1})			Unfilled grains (no. panicle^{-1})		
BRRI dhan87	96.82 cd	16.89 lmn	0.17	42.15 fgh	55.30 def	1.31
BRRI dhan90	115.08 ab	105.56 bc	0.92	31.10 hij	121.21 b	3.90
BRRI dhan93	124.36 a	10.58 n	0.09	37.59 ghi	68.36 de	1.82
BRRI dhan94	97.10 cd	11.12 n	0.11	32.74 hij	73.62 cd	2.25
BRRI dhan95	82.47 ef	23.63 lmn	0.29	16.15 jk	52.58 efg	3.26
AZ7006	77.65 efg	12.01 n	0.15	27.57 hijk	90.49 c	3.28
BRRI dhan51	78.09 efg	26.71 klm	0.34	18.01 ijk	30.64 hij	1.70
BRRI dhan52	85.12 de	12.59 n	0.15	55.52 def	166.13 a	2.99
BRRI dhan57	71.23 fg	66.69 g	0.94	17.04 ijk	52.78 efg	3.10
BRRI dhan49	82.80 ef	13.74 n	0.17	47.02 efg	34.15 ghij	0.73
BU dhan1	52.90 hi	0.00	0.00	32.86 hij	40.92 fgh	1.25
BU dhan2	79.02 efg	0.00	0.00	40.15 fgh	61.35 def	1.53
Kanihati1	38.28 jk	15.35 mn	0.40	16.63 jk	59.35 def	3.57
BINA dhan7	75.45 efg	21.47 lmn	0.28	19.65 ijk	54.58 def	2.78
Ganzia	61.44 h	29.44 jkl	0.48	9.20 k	34.00 ghij	3.70
Kanihati6	41.67 ij	13.03 n	0.31	33.24 ghij	54.38 defg	1.64
CV (%)	42.4			14.4		

Similar letters in a column did not vary significantly. At maturity, the unfilled grains of AZ7006 and BRRI dhan52 were 130.0 and 62.26 panicle^{-1} under three weeks of submergence, respectively. RV = Relative value.

of 2020. At this period air temperature was more than 20 °C. Thus, sterility of rice at two weeks of submergence was less than that of three weeks of submergence. However, the sterility of rice was significantly higher due to two weeks of submergence as compared to control (Table 8).

Grain yield

The 1000-grain weight of rice was reduced due to 2-weeek submergence in all varieties except AZ7006 and BRRI dhan49 (Table 9). Similarly, 1000-grain weight was reduced by 23, 5, 2 and 17% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. Similar trend in case 1000-grain weight was also recorded for BRRI dhan52, BU dhan1, Kanihati1, BINA dhan7 and Ganzia. Moreover, the plant of BRRI dhan87, BRRI dhan51 and Kanihati6 did not reduce mentionable grain weight due to submergence of two weeks of submergence. Since current photosynthesis is readily depleted under inundated condition of submergence, plants use its alternative source of respiratory substrate from storage carbohydrates, and this also sets a bottleneck for adequate accumulation of starch in the panicles for grain filling (Kawano *et al*., 2009).

Grain yield of rice reduced significantly due to submergence in all varieties except BRRI dhan57 (Table 9). The grain yield of

Table 9. Effect of submergence on 1000-grain weight and yield of 16 rice varieties

Varieties	Control	Two weeks of submergence	RV	Control	Two weeks of submergence	RV
	1000-grain weight (g)			Grain yield (g plant^{-1})		
BRRI dhan87	20.52 abc	20.65 abc	1.01	16.26 abc	2.2 gh	0.14
BRRI dhan90	8.79 e	6.76 e	0.77	11.62 cdef	8.1 defg	0.70
BRRI dhan93	16.07 cd	15.23 cd	0.95	19.71 a	3.94 gh	0.20
BRRI dhan94	16.09 cd	15.73 cd	0.98	14.52 abcd	5.61 efgh	0.39
BRRI dhan95	17.81 bcd	14.61 d	0.82	11.67 cde	3.12 gh	0.27
AZ7006	18.91 abcd	20.07 abcd	1.06	14.46 abcd	5.12 fgh	0.35
BRRI dhan51	16.38 cd	16.28 cd	0.99	14.6 abcd	1.21 h	0.08
BRRI dhan52	16.83 cd	14.6 d	0.87	13.29 abcd	3.93 gh	0.30
BRRI dhan57	19.44 abcd	17.13 cd	0.88	12.04 bcde	13.53 abcd	1.12
BRRI dhan49	16.14 cd	19.02 abcd	1.18	13.93 abcd	5.93 efgh	0.43
BU dhan1	23.28 a	0.00	0.00	18.79 ab	0.00	0.00
BU dhan2	23.22 ab	0.00	0.00	12.66 bcd	0.00	0.00
Kanihati1	23.76 a	20.22 abc	0.85	11.78 cde	5.44 efgh	0.46
BINA dhan7	18.88 abcd	17.66 bcd	0.94	14.48 abcd	4.67 gh	0.32
Ganzia	15.83 cd	18.91 abcd	1.19	17.29 abc	5.79 efgh	0.33
Kanihati6	20.83 abc	19.90 abcd	0.96	11.10 cdef	4.62 gh	0.42
CV (%)	13.4			43.2		

Similar letters in a column did not vary significantly. At maturity, AZ7006 and BRRI dhan52 produced no grains under three weeks of submergence. RV = Relative value.

BRRI dhan87 was 16.26 g plant^{-1} in control, while it was reduced to 2.2 g plant^{-1} under two weeks of submergence. Similarly, grain yield was reduced by 30, 80, 61 and 73% in case of two weeks of submergence of BRRI dhan90, BRRI dhan93, BRRI dhan94 and BRRI dhan95, respectively. Similar trend in case grain yield was also recorded for BRRI dhan51, BRRI dhan52, BRRI dhan49, BU dhan1, BU dhan2, Kanihati1, Kanihati6, BINA dhan7 and Ganzia.

The sink capacity otherwise, the panicle number in the present experiment was significantly reduced under submergence compared to normal as recorded. In general, if submergence prevails vegetative growth during early phases and extends thereafter, plants in general fail to develop adequate number of panicles as compared to those under non-submerged condition. In this experiment, BU dhan1 and BU dhan2 produced empty grain due to two weeks of submergence because they flowered when the air temperature was less than 20° C (Fig. 1 and Table 5). However, other rice varieties except AZ7006 and BRRI dhan52 did not produced spikelets under three weeks of submergence (Table 8). Though AZ7006 and BRRI dhan52 rice varieties produced spikelets under three weeks of submergence, but all the spikelts were sterile. The sterility of the grain was presumably due to low temperature (13 to 19° C) during flowering (Fig. 1 and Table 8). Grain yield in rainfed lowland rice is constantly challenged by this type of flooding (Iftekharuddaula *et al.,* 2016) and can result in severe damage and plant mortality if sustained for more than a week.

Inter-trait association in response to submergence

To evaluate the relationship among observed trait variations contributed by the rice varieties, with regard to morphologic and agronomic traits related to grain yield at two and three weeks of submergence, pairwise correlations were calculated based on STI values (Fig. 3). The dark blue color with straight shape of ellipses indicates strong positive correlation, whereas reddish color with straight shape represents highly negative association. At two weeks of submergence, grain yield showed positive association with shoot and root DM at 21 DADS, plant surviality, number of filled grains and 100-grain weight (Fig. 3). Mamun *et al*. (2021) reported that shoot DM and plant elongation were the key determinants of plant survival under prolong water stagnation in rice. However, days to flowering and maturity showed a negative correlation with grain yield. Moreover, plant height and SPAD value exhibited moderate positive relation and shoot and root DM at 7 DADS did not show correlation with grain yield at two weeks of submergence. On the other hand, rice plants produced empty grains under three weeks of submergence. However, the traits other than grain yield showed strong positive correlations among themselves (Fig. 3).

Conclusion

Submergence for two weeks significantly reduced tiller number, shoot and root dry matter, enhanced lodging and decreased survival resulting lower yield of *aman* rice. However, BRRI dhan57, BRRI dhan90, BRRI dhan94 and AZ7006 gave considerable yield

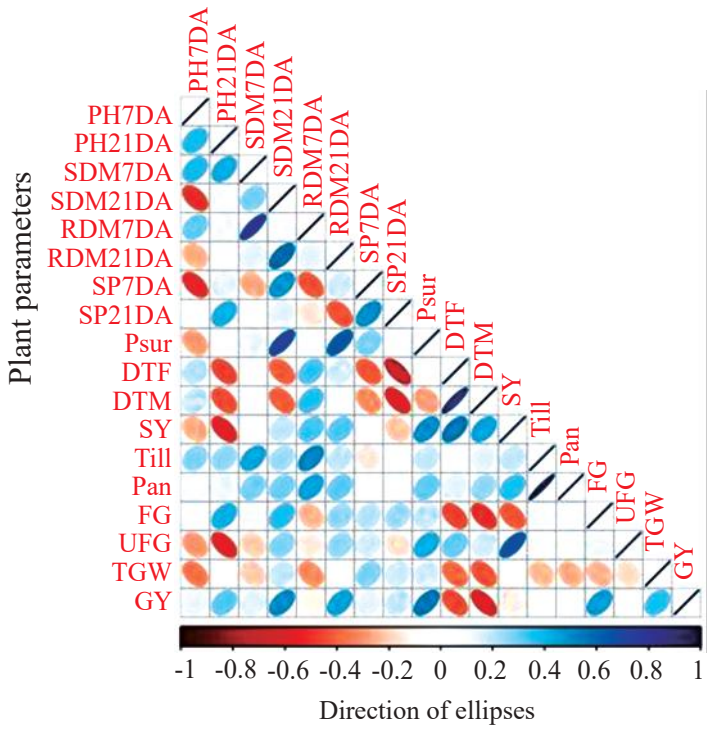

Fig. 3. Inter-trait association among the associated traits based on submergence tolerance at two weeks of submergence. Direction and closeness of Pearson's coefficient of correlation are represented by the size, shape and depth of shading of the ellipses. Non-significant associations are displayed by white boxes. PH7DA = Plant height at 7 DADS, PH21DA = Plant height at 21 DADS, SDM7DA = Shoot dry matter at 7 DADS, SDM21DA = Shoot dry matter at 21 DADS, RDM7DA = Root dry matter at 7 DADS, RDM21DA = Root dry matter at 21 DADS, SP7DA = SPAD at 7 DADS, SP21DA = SPAD at 21 DADS, PSur = Plant survival, DTM = Days to maturity, DTF = Days to flowering, Till. = Tillers, SY = Straw yield, FG = Filled grains, Pan = Panicles, TGW = Thousand grain weight, UFG = Unfilled grains, GY = Grain yield.

under two weeks of submergence. All the rice varieties except BRRI dhan52 and AZ7006 died under three weeks of submergence. A small shoot of BRRI dhan52 and AZ7006 lived under two weeks of submergence. However, these two varieties took longer time for producing shoot dry matter, tiller, panicle and maturity under three weeks of submergence. Though these two rice varieties produced spiklets, but they were sterile probably due to low temperature during flowering. Therefore, the transplanting of *aman* rice should be completed within August in submergence prone area to avoid low temperature effect during flowering. However, cultivation of submergence tolerant, photoperiod sensitive and cold tolerant rice variety may be another option to avoid grain sterility due to low temperature after submergence during *aman* season. Rice varieties AZ7006 and BRRI dhan52 could be exploited as valuable genetic materials and might be used in breeding program to develop new rice varieties tolerant for three weeks of submergence.

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