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Evaluation of morphologically important traits of deep water rice from advanced backcross families

Md. Mahmud Al Noor[1], Md. Shamiul Haque[1], Masud Perves[1], Md. Abul Kalam Azad[2] and Sakina Khanam[1]

[1]Plant Breeding Division, Bangladesh Institute of Nuclear Agriculture, Mymensingh-2202, Bangladesh
[2]Admin & Support Service, Bangladesh Institute of Nuclear Agriculture, Mymensingh-2202, Bangladesh

✉ For any information: sakina_khanam2003@yahoo.com (Khanam, S)
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ABSTRACT

Local germplasm of deep water rice has low yield productivity but posesses many attributes with floating capacity to survive in deep water environments. Our studies showed that grain yield in LaxmiDigha can be increased significantly through backcross program with the high yielding rice variety Binadhan-18. Advanced backcross progenies (LaxmiDigha x Binadhan-18) exhibited higher values for most of the yield and yield-related traits analyzed in comparison with the parent. Number of tillers plant^{-1} and filled grains panicles^{-1} are positively correlated to yield and those resulted in higher grain yield in backcross families. In S103, S104, S105, S106 and S111 families, yield increase ranges from 52.97 to 84.1% when compared to LaxmiDigha parent. Five families, viz., S103, S104, S105, S106 and S111, were identified through yield increase analysis as most promising genotypes for cultivar development and processes variation in special characteristics viz. aerial root number and Knee capacity. The backcross families will be used to develop a deep water rice variety and efficient source of genetic diversity for future breeding programs.

Key Words*: Deep water rice, Back cross families and Deep water rice screening tank.*

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I. Introduction

The world population is assumed to reach nine billion within the year 2050 and unavailability of staple food could become a major problem in the universe (Adjah, 2020). Meanwhile, it is emergence to enhance the yield potential of mostly cultivable cereal crops such as rice to fulfill the accelerating need of a population (Fitzgerald et al., 2009). Rice is grown predominately in tropical and subtropical countries over a wide range of soil and climatic conditions. It is estimated that for market year 2019/20, total rice area and production level are enhanced to 11.8 million hectares and 35.3 million metric tons to meet the demand of population (USDA, 2019). Deep water rice (DWR) represents the flood-prone rice where stagnant flood water occurs in a depth that usually exceeds 100 cm and

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continues for a longer period ranging from more than 10 days to five months (Karet al., 2010). Estimated deep water rice coverage enlisted approximately 0.54 million ha and 6 million tons rice have been devastated due to the deep flooded conditions in India and Bangladesh (IRRI, 2023). Usually, in deep water conditions, water level exceeds 4m, depending on the geographic location of the region, but in superficial stagnant areas, it lays between 1.5-2.0 m. Traditional tall with floating features is the special characteristic of deep-water rice (Ahmed et al., 2016). In most of the marshy land, water retains 2-3 months longer and average water depth ranges here between 200 and 250 cm. Many semi-deep water rice varieties cannot withstand flash floods where water levels rise and fluctuate from 30 to 50 cm per day (Lafitte et al., 2006). For this reason, it is time demanding to develop a variety which can adopt and sustain such specific conditions.

DWR is important for easily digestible protein with high biological value; provide shelter for fish and their food, refuge for wildlife and base of food chain. DWR cultivation in aquatic wetlands has excellent potential to mitigate the steady increasing need for food production, conserve plant diversity and stabilize traditional ecosystems in wetlands (Lafitte et al., 2006). In Bangladesh's low-lying regions, where water can stand for up to three months, the deep-water rice variety LaxmiDigha is specifically grown. It has large leaves that can elongate by more than 5 cm per day with knee capacity and floatability. However, because of its low yield (0.7–1.0 tons/ha), this cultivar is not widely used these days (BINA, 2020). Numerous experiments have shown that it is possible to introduce the traits of LaxmiDigha to the recipient parent and create a backcross family via which F_2 progenies can acquire desired traits (Hattori et al., 2007). The offspring of a single cross can differ in a number of morphological characteristics, including plant height, floatability and stem elongation (Ashikari et al., 2005; Ashikari and Matsuoka, 2006). Due to their lack of these unique characteristics, several traditional transplanting Aman rice types cannot thrive in this deep water table (BBS, 2009; Ahmed et al., 2016).

BINA emphasized developing tall deep water rice varieties having deep water tolerance and high level of stem elongation suitable for shallow, deep flooded areas. In this regard, through mutation breeding, we are trying to develop deep water tolerant rice mutants. But desired lines not been developed yet which will survive after sudden surge with high water depth. Thus, the present study was undertaken to develop and evaluate the morpho-physiological, agronomic and yield performances of backcross families that will accelerate the chance of obtaining desirable lines.

II. Materials and Methods

A local DWR LaxmiDigha (donar) was crossed with BINA developed high yielding rice variety Binadhan-18 (recipient), to develop deep water submergence tolerant rice variety at Bangladesh Institute of Nuclear Agriculture. Twenty viable seeds were collected from First-filial generation (F_1). The F_1 (recipient) plants were backcrossed with Binadhan-18 to transfer its high yield contributing trait to receipient parent for producing BC_1F_1 generation. From BC_1F_1 lines, BC_1F_2 families were developed. Plots in a randomized complete block design with two replications were assigned to the BC_1F_2 families, which were considered as treatments. 26 plots made up a single replication. Different backcross families were sown at Deep water rice screening tank (DWRST) at BINA Headquarter, Mymensingh (AEZ-9) on 25th April, 2022. The experiment was conducted at two tanks separated by a permanent wall. The depth of each deep water tank was 3.0 m having silt loam soil with 6.85 PH. Prior to planting, the soil was pelverized. The values of total N (%), exchangeable K (cmolkg-1) and accessible P (mgKg-1 soil) were 0.1, 15 and 0.151 respectively. Each plot had eighteen plants (3 m length by 1.5 m width) with three rows in each plot. Plants were positioned 15 cm apart inside rows with a 20 cm gap between rows. The required rates of fertilization (170: 80: 150 N: P: K, kg ha^{-1}) were applied to the both tanks. Plant protection agents were used as required; cartap (insecticide) was applied @ 5g/L every 40 days after transplanting. Weeding was done after 14 and 28 days of sowing, respectively. Water was inundated by the pipe after 45 Days of Sowing (DAS) and before that plant height was measured. It was done after 10 days interval by this way elongation rate was calculated. Aerial root can emerge from any part of the plant and total number was calculated. When the seeds of all progenies were matured, harvesting was done on 18th November, 2022. Before that, water was removed very slowly from the tank to observe the knee capacity of selected progeny population. The duration of backcross families ranges from 203-209 days. Ten plants in each plot at near-maturity were seen to have significant reproductive features. Panicle length was measured from the base to the

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tip of the panicle (excluding the awn) using the same tiller used to record culm length. The total number of tillers-both grain-bearing and non-grain-bearing- per plant was counted. To record the number of filled and unfilled grains per panicle, 30 panicles (three panicles from each of the ten plants planted) were used for each plot. The mean weight of three separate samples of 1000 fully filled grains was used to estimate the weight of 1000 grains in grams. The grains were dried in a hot-air oven at 40°C for two hours to ascertain the moisture content (MC). They were then stored in a desiccator for 20 minutes before the weight was recorded. The dry grain weight was then multiplied by an adjustment coefficient to get the grain weight adjusted to 14% MC (Gomez and Gomez, 1984). The weight of bulked grain taken from ten plants in each plot was used to compute the yield per plant and expressed in grams.

Morphological traits like awn and grain type were evaluated in both replications for the BC_1F_2 families and the parents. Awn-free samples were designated as Binadhan-18 types, while samples with long awns were classed as LaxmiDigha types and awns of the intermediate form, they were considered as tiny. There were two groups for grain color: Binadhan-18 (white pericarp) and LaxmiDigha (raddish pericarp). Families with varying varieties of grains or awns were classified as mixed types.

Utilizing type III sum of squares and the General Linear Model (GLM) approach, an analysis of variance was conducted on yield and yield-related features, assuming a random effects model (SAS Institute Inc., 2006; SAS version 9.1 was utilized for the data analysis utilizing individual plant data).

III. Results and Discussion

Plants (Family) analysis was performed by collecting 30 panicles from a family and grain yield per plant was calculated from the weight of bulked grain harvested from 10 plants in each family (Table 01). Significant variations were found in grain yield between parental or progeny types (Table 01). Balakrishnan et al. (2016) proposed that segregation in backcrossing populations resulting from interspecific hybridization brings about yield variation among progenies. Martinez et al. (1998) discovered no discernible variation in grain yield between backcross population progeny in a related investigation. Furthermore, Table 01 displays highly significant differences ($P < 0.001$) between the mean values of the BC_1F_2 population.

Introgression of yield contributing and required traits in the local germplasm is not a recent approach through backcross breeding. In former study, Gaikwad et al. (2021) revealed that genome from yield contributing genotype can accelerate potentiality of yield and solely wild relatives of local germplasm contribute 20% in that aspect. Our study showed that, in BC_1F_2 backcross families, yield increased up to 84.1 g/plant (S-105) (Table 02). In spite of influencing in yield increment, traits detrimentally influencing another desired plant type may exhibit connection with yield-increasing determiners. Backcross family lies in D category showed higher yield, erect flag leaf but contained awn in plant population and that is not desired (Table 02). The tillers of a slandered plant type must be of the closed variety, with flag leaves pointing upward. It is highly anticipated that this unique plant architecture will prevent lodging, evenly position the plants in the field and maximize solar absorption, all of which will boost the plant's potential production in C type plant progenies (Table 02). In this experiment, about 23% of the BC_1F_2 families are A type (both awn and LaxmiDigha type), 19% B type (awnless but grain Binadhan-18 type), 27% C type (awn intermediate type but grain LaxmiDigha type), 15.38% D type (awn and grain mix type) and 19% E (awn mix type but grain Binadhan-18 type) (Table 02).

In general, 5% but in some cases >27% higher yield per plant increase was suggested by Sabu et al. (2006). Morphological and yield contributing characters were examined in previous studies; Bai et al. (2010) found it for plant height in a backcross population, while Faruq et al. (2004) found it for kernel elongation ratio in F_2 offspring. High phenotypic variation was found for plant height in our study (Table 02). According to Moncada et al. (2001) and Septiningsih et al. (2003), the QTL for plant height showed the highest % phenotypic variance or significance. This runs counter to the general nature of quantitative traits, which are characterized by a variety of specific genes having minute effects. Numerous genome studies of rice have revealed that one major gene plus a few modifier genes influence a trait (Thomson et al., 2003; Uga et al., 2003; Faruq et al., 2004; Bai et al., 2010; Birchler et al., 2010).

Table 01. Analysis of variance for yield and yield related traits for BC_1F_2 families

Trait	Source	df	Mean Square
Plant height, cm	Replication	1	352**
Family	26		231**
Plants (Family)	936		5.76
Error	442		67.29
Panicle length, cm	Replication	1	256.66**
Family	26		150**
Plants (Family)	936		3.44
Error	442		1.23
Tillers per plant	Replication	1	115.36**
Family	26		121.70**
Plants (Family)	936		2.89
Error	442		36.98
Filled grains/panicle	Replication	1	103**
Family	26		86**
Plants (Family)	936		1.89
Error	442		0.98
Unfilled grains/panicle	Replication	1	55**
Family	26		13**
Plants (Family)	936		0.46
Error	442		0.10
Yield (g/plant)	Replication	1	21.3**
Family	26		4.2**
Plants (Family)	936		0.6
Error	442		0.01

** 1% level of significance.

Table 02. Performance of agronomic traits of 26 outperforming BC_1F_2 families

Family	Type	PH (cm)	ET	PL(cm)	FGP	UGP	GY (g/p)	YI (%)
S101	C	163.6	6.5	22.8	40.8	25.1	21.4	32.9
S102	A	149.4	5.5	21.9	122.4	60.9	24.3	48.1
S103	D	153.5	8.4	22.7	141.6	35.3	26.1	59.4
S104	B	144.1	6.3	22.3	160.5	30.2	28.5	73.7
S105	A	146.4	7.2	22.7	155.3	5.5	30.2	84.1
S106	E	144	6.4	22.80	141.9	6.8	26.7	62.8
S107	B	149.6	6	22.6	135.5	9.2	21.3	29.8
S108	A	147.9	7.3	23.6	140.4	22.2	23.4	42.6
S109	E	141.5	9.4	23.2	125.6	11.1	22.6	37.8
S110	C	143.5	10	23.1	127.5	10.4	19.3	17.6
S111	B	146.3	6.5	23.2	129.6	6.7	26.2	52.97
S112	C	156.7	5.3	21.4	111.4	21.3	17.7	7.90
S113	E	134.6	6.4	19.6	123.1	18.5	13.2	1.95
S114	C	151.2	4.2	15.3	133.6	15.6	15.7	0.31
S115	D	146.7	5.3	18.3	145.3	17.8	18.3	11.5
S116	B	138.6	6.4	19.3	148.4	15.8	16.8	2.43
S117	C	162.4	5.7	17.5	136.4	14.9	15.1	0.79
S118	D	149.6	6.3	19.8	97.4	12.8	9.8	0.40
S119	A	173.2	7.3	23.1	65.4	34.2	14.6	1.09
S120	C	145.3	5.8	24.6	45.7	22.8	11.7	2.80
S121	D	152.6	4.7	23.9	34.7	24.6	16.8	2.00
S122	A	184.6	6.4	18.5	121.7	21.3	9.45	0.42
S123	A	183.5	5.3	21.4	141.3	18.2	13.6	7.00
S124	E	134.8	6.3	25.7	135.7	20.6	11.8	2.80
S125	B	148.6	9	19.3	124.4	12.1	13.5	1.70
S126	C	155.4	8.7	14.5	111.4	8.9	14.1	1.40
Selected BC_1F_2		167.8ab	6.8a	24.3a	121.8a	10.5a	21.3a	22.54
Luxmidigha		176a	5.6a	22.7b	178.6a	27.0a	16.4b	
Binadhan-18		105.4a	7.3a	23.1c	59.0a	13.1a	25.3b	

Mean values followed by the same letter are not significantly different in Duncan's Multiple Range Test; Abbreviations: Parental or progeny types (TYPE), Plant height cm (PH), panicle length, cm (PL), effective tillers per plant (ET), filled grains per panicle (FGP), unfilled grains per panicle (UGP) and grain yield per plant (GY); A-both awn and grain LaxmiDigha type; B-awnless but grain Binadhan-18 type; C-awn intermediate type but grain LaxmiDigha type; D-awn and grain mix types; E—awn mix type but grain Binadhan-18 type. YI-Indicates Yield Increase

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On average, the 26 families exhibited 23% greater yield than the parent LaxmiDigha and highest yield increase was recorded as 84.1% (Table 02 and Table 03). Highest tiller plant-1 was found in family S109 (9.4) compared to LaxmiDigha (5.6) and Binadhan-18 (7.3), respectively. Increased tillers per plant among the BC_1F_2 families may have inherited from the positive gene frequencies of LaxmiDigha and Binadhan-18. In deep water rice, more tiller production and elongation are the causes of the yield enhancement (Oad et al., 2006; Kar et al., 2010). Local germplasm has been shown to favorably contribute to yield enhancement in several crop species while being inferior in most agronomic attributes (Moncada et al., 2001; Thomson et al., 2003; McCarty et al., 2004a).

The strongest correlation (r = 0.648) was found by correlation analysis between panicle length and filled grain/panicle. This indicates that among BC_1F_2 progenies, a longer panicle length results in the maximum number of filled grains/panicle (Table 04). There was a negative correlation (r = -0.381) between unfilled grain per plant and yield/plant. Similar other result (r = –0.18) was found by other researchers between the same traits (Spinningsih et al., 2003). Our investigation also revealed a positive association between filed grains per panicle and effective tillers.

Yield per plant hasrobust, positive and statistically significant correlation with effective tillers/plant and filled grains per panicle, respectively. Selection will be emphasized on these two components due to their strong influence on grain yield increase, which was also observed by Oladosu et al. (2018).

Backcross families viz. S1013, S104, S105, S106 and S111 have knee capacity, aerial root, stem elongation capacity in our study. Higher stem elongation rate was observed in S104 backcross families in contrast lowest was found in S105 family (Figure 01). Similar number of aerial roots (4.2) was found in S103 and the parent LaxmiDigha (Figure 02). Aerial roots can emerge from any part of the stem in deep water rice. Coleoptiles are formed due to cell enlargement and proliferation (Narsai et al., 2015). Some backcross families does not exhibit aerial roots merely survive in deep water conditions because it is one of the common phenomena in submerged conditions (Septiningsih et al., 2013). Most of the backcross families have red pericarp and stem elongation abilities those are inherited by LaxmiDigha (Figure 03). Knee capacity was found in all the backcross families in our study; medium slender and slender grains with separate awn characters were also observed (Table 05). Stem elongation and knee capacity are controlled by co-dominant gene and can be transferred through backcross breeding approach (McCarty et al., 2004). Gibberellic Acid (GA) is the main hormone that triggers stem elongation in deep-water rice and ethylene accelerates the responsiveness for GA between the internodes (Nagai et al., 2020). The amount of ethylene and GA production among the backcross families will be evaluated in further study.

Table 03. Mean values of agronomic traits for parents and BC_1F_2 families

Type	PH	PL	ET	FGP	UGP	GW
Luxmidigha	155*aa	25.3b	5.7a	62.5a	8.4c	14.1a
Binadhan-18	102**c	23.5b	12.7c	145.7c	95.3a	25.0b
BC_1F_2families	88.5**b	24.6**a	11.9**b	103.9**b	88**b	20.7**ab
SD	8.9	1.1	3.7	13.7	2.0	1.7
Min	97.0	20.6	2.0	23.0	0.0	6.87
Max	211.0	28.0	17.0	152.0	54.0	27.5

Mean values followed by the same letter are not significantly different at 0.05 probability level of Duncan's Multiple Range Test. Means followed by * and ** indicate significant differences at 5% and 1% level of significance, respectively. Significance within parental or progeny types are based on TYPE III Sum of Squires (PROC GLM).

Table 04. Pearson correlation coefficients among various traits in BC_1F_2 population (Luxmidigha/Binadhan-18)

PH	ET	PL	FGP	UGP	GY
Plant height (PH)	-0.103 ^{ns}	0.191 ^{ns}	0.186 ^{ns}	0.028 ^{ns}	0.017^{ns}
Effective tillers (ET)		0.287^{ns}	0.328*	0.209*	0.140**
Panicle length (PL)			0.648**	0.007 ^{ns}	0.105**
FGP (Filled Grain per panicle)				-0.273*	0.346**
UGP (Unfilled grain per panicle)					-0.381**

**, *, ^{ns} denotes significant at 1% level of significance, significant at 5% level of significance and non-significant respectively

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Table 05. Grain and other special attribute of 5 BC_1F_2 families in deep water rice screening tank

Backcross families with LaxmiDigha parent	Type	Awn	Grain type	Knee capacity
S103	D	Present	Bold	Present
S104	B	Present	Medium Slender	Present
S105	A	Absent	Bold	Present
S106	E	Mix type	Medium slender	Present
S111	B	Present	Medium slender	Present
Luxmidigha		Present	Bold	Present

A-both awn and grain LaxmiDigha type; B-awnless but grain Binadhan-18 type; C-awn intermediate type but grain LaxmiDigha type; D-awn and grain mix types; E—awn mix type but grain Binadhan-18 type. YI-Indicates Yield Increase.

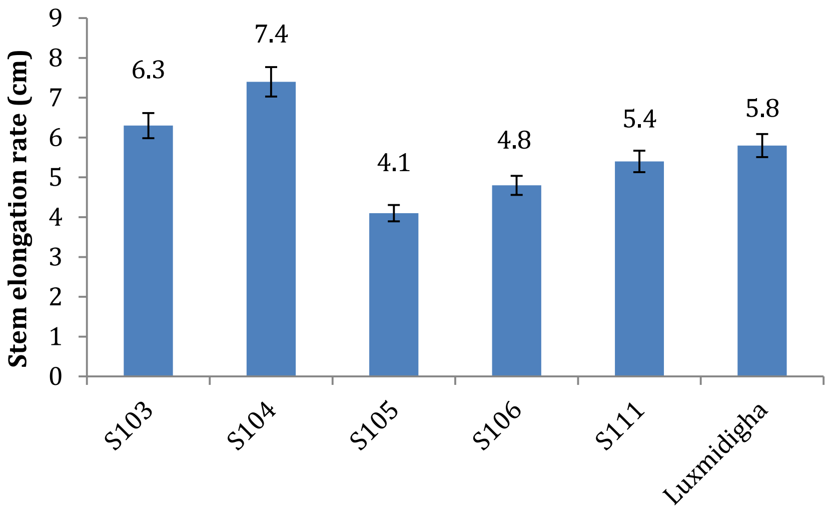

Figure 01: Stem elongation rate of 5 BC_1F_2 families in deep water rice screening tank

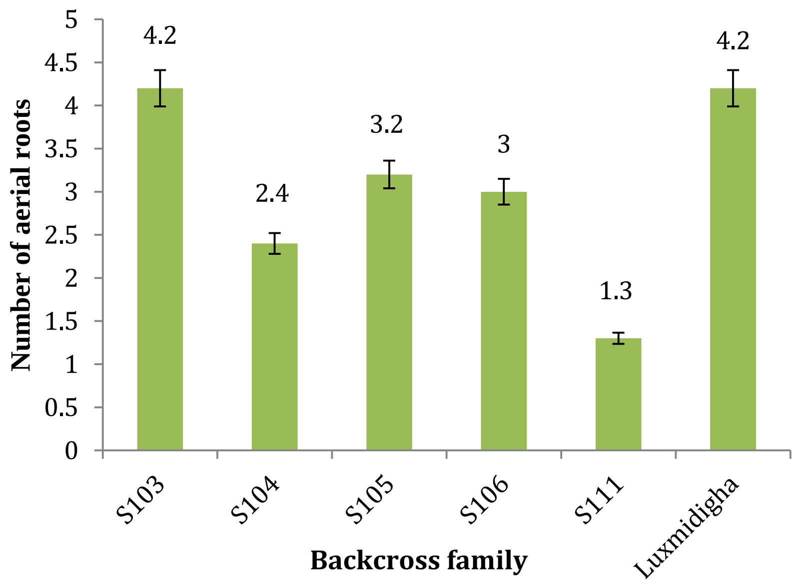

Figure 02. Aerial root number of 5 BC_1F_2 families in deep water rice screening tank

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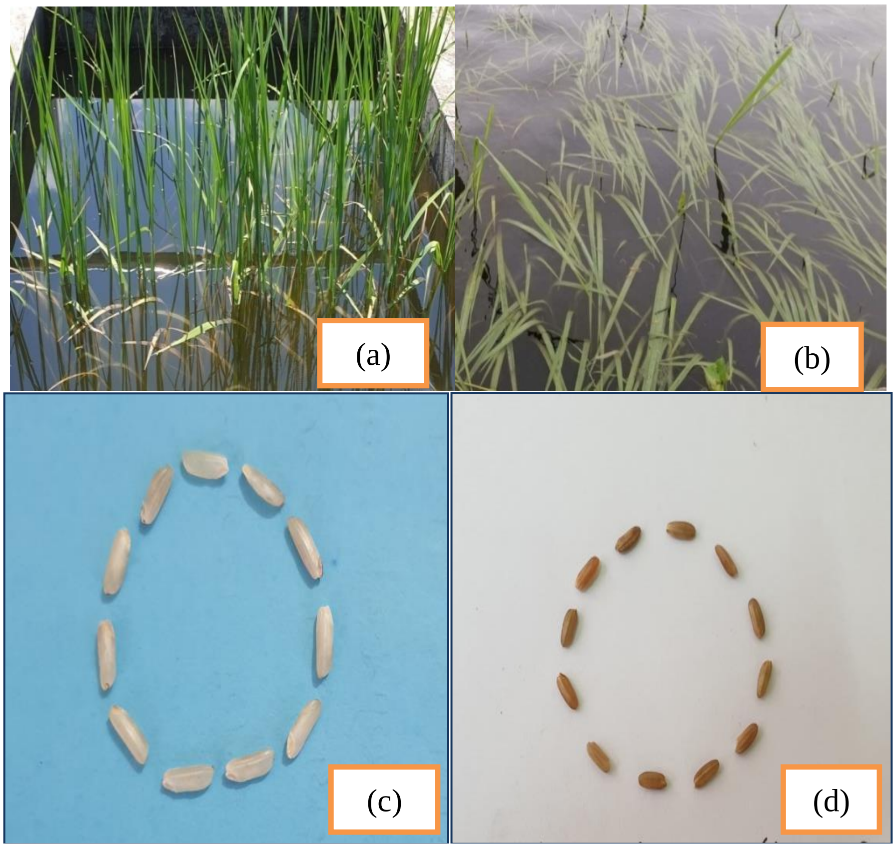

Figure 03. Plate (a)- stem elongation; plate (b)- floatability; plate (c)- white pericarp; plate (d)- red pericarp of backcross families

IV. Conclusion

Yield and yield contributing characters were presented for all 26 backcross families. Effective tillers and filled grain/panicles are positively associated with the yield. The present study also revealed that S103, S104, S105, S106, S111 backcross families have higher yield increases although segregating but showed deep water characteristics such as higher elongation rate, aerial root number and knee capacity. Further study is needed to develop a deep water rice tolerant variety from these populations.

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