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BANGLADESH RICE RESEARCH INSTITUTE

Plant Breeding Division

2 Summary

confirmed during 2021-22. In pedigree nursery, 32,295 individual plants were selected from F_2 to F_6 generations based on phenotypic performances of segregating progenies of each cross and 37 fixed lines were bulked. A total of 5,64,725 individual plants were advanced from F_{2-6} generation following single seed decent (SSD) method under rapid generation advanced (RGA) condition. From line-stage testing (LST), 19,024 genotypes were selected based on yield and other agronomic performances. A total of 1,229 genotypes from observational yield trial (OYT) and 593 advanced breeding lines were selected from yield trials (PYT, SYT, AYT, RYT and PVT). A total of 33 germplasm from different biotic and abiotic screening nurseries were selected to use as parents in the breeding programme.

National Seed Board (NSB) of Bangladesh has released two promising genotypes *viz* BR8938-19-4-3-1-1-P2-HR3 and IR99285-1-1-1-P2 as BRRI dhan101 and BRRI dhan102, respectively for cultivation throughout the country in Boro season on 18 January 2022. BRRI dhan101 produced 0.33 t/ha higher yield than the popular check variety BRRI dhan58 (7.39 t/ha) with 142 days growth duration. The variety BRRI dhan101 showed strong resistance to BB (BB score-1) under artificial inoculation with virulent BB pathogens. QTL fingerprinting with functional SNP markers for the BB resistance detected three dominant BB resistant genes *Xa4*, *Xa7* and *Xa21* in this variety. The average yield of zinc enriched variety BRRI dhan102 was 8.11 t/ha with 150 days growth duration and zinc content of the milled rice was 25.5 mg/kg which was higher than that of BRRI dhan29 (18.2 mg/kg).

Development of upland rice (B. Aus). Efforts were made to develop upland rice varieties with multiple traits viz quick seedling emergence, vigorous growth, short growth duration (90-100 days); tolerance to lodging and drought and pre-harvest sprouting tolerance; medium bold to medium slender grains and good eating quality. In 2021-22, seven crosses were made using 11 parents. Out of 20, eight crosses were confirmed as true F_1. A total of 9,360 progenies obtained from 14 crosses of F_5 generation were advanced through field RGA (Rapid generation advance). Out of 2,830 lines, a total of 207 breeding lines comprising 21 crosses were selected from LST lines based on identical flowering, grain type traits and phenotypic acceptability under field condition. Twenty nine entries were selected considering growth duration, yield, uniformity of morpho-agronomic traits and superiority in one or more traits over the standard checks from 176 advanced breeding lines in OYT. Three genotypes such as BR11274-B-35-1-36, BR11274-B-11-1-16 and BR11262-B-109-3-47 were selected from five tested entries on the basis of yield and short growth duration in PYT. Five genotypes viz BR10756-2B-8-72, BR10759-2B-11-3, BR10418-32-1-58, BR10417-15-2-11 and BR10409-15-2-8 were selected from eight tested entries in SYT.

Improvement of jhum rice under upland rice programme was implemented to develop high yielding rice variety with low (10-19%) to high (>25%) grain amylose content and drought tolerance along with good eating quality for jhum cultivation acceptable to tribal population of Chattogram hill districts. Seven crosses were made involving10 parents including four local Jhum cultivars, two exotic varieties, single BRRI variety and three advanced breeding lines having low to intermediate level amylose content. Six crosses out of 15 were confirmed as true F_1. Seventeen F_2 population were grown for generation advance through field RGA (Rapid generation advance). A total of 18,970 progenies obtained from 17 crosses of F_3 generation were advanced through field RGA. Fourteen, eight and eight entries from 31 entries in OYT#1, 18 entries in OYT#2 and nine entries in OYT#3 were selected, respectively. Six out of 15 entries and four out of nine entries were selected in preliminary yield trial (PYT#1 and PYT#2), respectively. Five out of eight entries were selected in SYT. Farmers chose chinese rice variety (Luyin 46) AYT (Advanced yield trial) in hills of three upazilas of two hill districts i.e. Khagrachari and Bandarban having about half t/ha yield advantage over the local cultivar Mongthongno (**Table 1**) along with medium slender grain, dense panicle, lodging and drought tolerance, high amylose content with light aroma.

Table 1. Yield, agronomic performance and physico-chemical properties of the genotypes in AYT, development of Jhum rice, B. Aus 2021-22.

Genotype	GD (day)	Yield (t/ha)	Amylose content (%)	Protein content (%)	Head rice recovery (%)	Size & Shape	ER	IR
Chinese rice	114	2.2	26.0	7.0	23	MS	1.5	3.7
Koshihikari	106	0.9	17.8	8.2	28	SR	1.8	3.1
Japanese black rice	126	1.7	10.9	10.3	50	LB	1.2	4.2
Mongthongno	107	1.6	22.8	8.1	51	LB	1.2	4.3
BRRI dhan83 (ck)	111	2.6	26.6	7.7	46	MB	1.4	4.5
Gunda (Local check)	119	1.9	23.1	7.1	58	MB	1.4	3.6
LSD	2.8	0.5						
Heritability	0.94	0.9						

ER-Elongation ratio IR-Imbibition ratio

Investigators: M A Hossain and N Jahan

Development of transplanted Aus rice (T. Aus). The project was aimed to develop short duration (105-110 days), high yield potential genotypes having tolerance to lodging and heat (high temperature) at the reproductive phase, pre-harvest sprouting and good grain quality. In total, 20 crosses were made using 35 parents and 5,348 F_1 seeds were obtained; 29 crosses were confirmed as true F_1; 18270 progenies of 37 crosses in T. Aus season were advanced through modified field rapid generation advance (FRGA) technique. Out of 12,491 lines of 39 crosses, 792 uniform lines were identified from LST based on uniformity in heading, plant height, and acceptable grain type in the field condition. Finally, 713 fixed lines were selected from 792 lines on the basis of trait genotyping with 12-SNP indica panel. Ninety-three genotypes were selected from 384 entries from observational yield trial (OYT), ten advanced lines out of 37 from PYT were selected for T. Aus growing areas of Bangladesh on the basis of homogeneity with respect to plant height, phenotypic acceptability at vegetative and maturity stages and physicochemical properties. With respect to performance in ALART, one genotype BR8781-16-1-3-P2 was recommended for PVT for non-saline tidal condition of Bangladesh (**Table 2**). The promising genotype BR9006-40-2-3-1 was evaluated along with the check variety BRRI dhan48 under PVT in ten locations of T. Aus growing areas of Bangladesh.

Table 2. Agronomic performance of the advanced lines under advanced line adaptive research trial (ALART), T. Aus 2021-22.

Designation	GD	PH	Yield (t/ha)							
			L1	L2	L3	L4	L5	L6	L7	Avg.
BR8784-4-1-2-P2	123	119	3.03	4.58	4.23	5.46	4.47	4.65	4.02	4.35
BR8781-16-1-3-P2	121	114	3.84	**5.53**	5.00	5.43	4.72	5.51	3.94	**4.85**
BRRI dhan27 (Ck)	118	137	3.21	4.02	3.88	4.79	3.77	4.12	4.09	3.98
BRRI dhan48 (Ck)	114	108	3.09	5.47	4.86	5.36	4.86	5.49	4.49	4.80
LSD(0.05)	**0.46**									**0.18**

*Mean of seven locations GD-Growth duration PH-Plant height

Locations : L1=Barguna (Nilganj, Amtali), L2= Barguna (Nilganj, Amtali), L3=Patuakhali (Kalapara), L4= Barguna (Taltoli),L5=Pirojpur (Kuakhali), L6= Mirsori (Chattogram), L7= BRRI Gazipur

Investigators: M Khatun, S K Debsharma and J Ferdousy

Improvement of rice for shallow flooded and deep water environment. The major objectives of the this project were to develop high yielding (4.0-5.0 t/ha) rice varieties for deep (>1.0 m), shallow flooded area (up to 1.0 m depth), shallow deep area (30 cm water) and medium deep area (50-60 cm water) along with submergence, facultative elongation and hypoxia tolerance. Seventeen crosses were made by using 20 parents and produced 1,413 F_1 seeds. In total 25 F_1 crosses were confirmed through QC SNP panel analysis. A total of 3,748 progenies of 19 F_2 crosses, 3,541 progenies of 20 F_3 crosses, 2001 progenies of 18 F_4 crosses were advanced through RGA. In yield trials, 15 genotypes were selected out of 30 genotypes. In OYT the genotype BR10211-22-9-2_PS4 produced the highest yield (2.6 t/ha) which is significantly higher than the check variety BRRI dhan91 (1.4 t/ha) whereas in PYT the genotype BR10260-7-19-2B (3.8 t/h) produced highest yield which was significantly higher than the check variety BRRI dhan91 (1.7 t/ha). In SYT, two tall advanced breeding lines (stagnant water, 50-90 cm) were evaluated. The breeding lines BR9377-21-3B (5.9 t/ha) and BR9396-6-2-2B (5.4 t/ha) with BRRI dhan91 (4.7 t/ha) performed better than Fulkori (2.6 t/ha) as checks. Six RYT breeding materials under direct seeded deep flooded (100-150 cm water depth) condition was evaluated. The genotypes BR10230-7-19-2B (2.5 t/ha), BR9892-6-2-2B (2.8 t/ha), BR9376-6-2-2B (2.9 t/ha), BR9392-6-2-1B (3.0 t/ha), BR-KM (Mun)-PL-5-7-3-B (2.9 t ha), BR-DL(Hbj)-PL-12-4-7-B (3.2 t/ha) performed better than the local check Fulkori (2.4 t/ha). ALART for shallow deep (50-100 cm) flooded areas were conducted in five locations, two advanced genotypes BRBR9390-6-2-1B (3.4 t/ha) and BR10260-5-15-21-6B (4.5 t/ha) produced better yield than the standard check BRRI dhan91 (2.35 t/ha). The genotypes were characterized with moderate elongation and better yield than the check variety. Notably, BR9390-6-2-1B was found as strongly photoperiod sensitive, BR10260-5-15-21-6B and BRRI dhan91 were moderately photoperiod sensitive.

Performance of main and ratoon crops of F_1 and their parents in respect to perennial growth habit in rice was evaluated in B. Aman 2021-22. Development of a robust tall rice variety BRRI dhan91 having perennial growth has opened the door of breeding for better ratooning ability in inbred and hybrid rice. A basic study was conducted to evaluate the perennial growth habit or superior vegetative ratooning performance in modern rice. The objectives of the studies were to evaluate ratooning performance under standard ratoon system (10 cm stubbles remain after harvest) compared to main crops of perennial BRRI dhan91, non-perennial BRH11-9-11-4-5B (CN6) and their hybrid. Bio-chemical analysis showed that stem of BRRI dhan91 contained three times more starch than BRH11-9-11-4-5B indicating its more energy storage capacity for better ratooning ability. In this study, main crop did not die after harvest, new tillers originated from dormant buds of stubbles provided a second crop as taller as like main crop, yield was same as main crop with almost same growth duration.

Investigators: Sharmistha Ghosal, A S M Masuduzzaman, Z A Riyadh, N Jahan and K M Iftekharuddaula

Development of rainfed lowland rice (RLR). The project aims to develop genotypes superior to standard varieties and adaptable to rainfed lowland environment in T. Aman season. In T. Aman, 7,442 F_1 seeds were obtained from 37 single crosses and 23 crosses were confirmed as true hybrid using 10-SNP *indica* QC panel. A total of 7,506 individual progenies of 32 crosses from F_3-F_5 generations were harvested through RGA method in T. Aman season. In Boro 2021-22, 8,666 progenies were harvested from 27 crosses from F_2 and F_4 generations through RGA method. A total 507 genotypes were selected from 10,333 progenies of line stage testing (LST) trial. Figure 1 and 2 present the selection intensity and trait marker profile of the genotypes of LST. A total of 699 genotypes were evaluated in four observation yield trials (OYTs) in Gazipur, Cumilla and Rangpur. Among the tested genotypes 60 genotypes were selected for Advanced Yield Trial (AYT). Out of the preliminary yield trials (PYT) consisting seven tested genotypes, three were advanced for secondary yield trial (SYT) based on grain yield. Only one genotype was selected from five genotypes of regional yield trial (RYT). Three genotypes were selected for retrial in RYT.

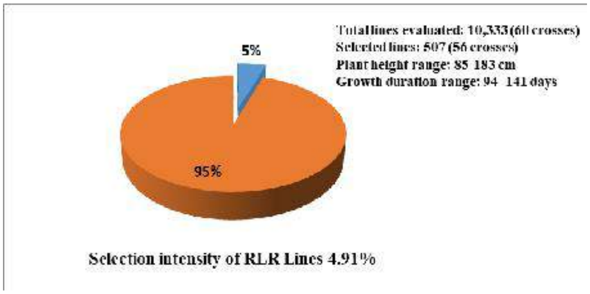


Fig. 1. Selection intensity in the genotypes of LST, RLR, T. Aman 2021-22.

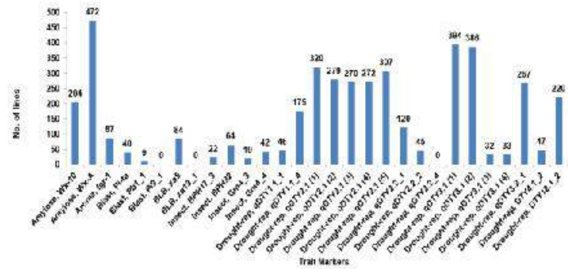


Fig. 2. Trait marker profile of the genotypes of LST, RLR, TA 2021-22.

Investigators: M A Kader, R R Majumder, U R Shaha and K Fatema

Development of high yielding superior variety (SHR). Three SYT trials were performed during T. Aman 2021-22. Secondary yield trial (SYT-Short Slender) under recommended management practices was performed to evaluate the yield potential of short slender grain type materials in comparison with BRRI dhan49. Three materials viz, BRH13-2-14-2-1B (5.5 t/ha), BRH17-23-8-2-7B (5.0 t/ha) and BRH13-7-9-3-2B (5.2 t/ha) were selected compared to BRRI dhan49 (4.9 t/ha). Secondary yield trial (SYT-Swarna and long slender type) under recommended management practices was performed to evaluate the yield potential of Swarna and long slender grain type materials. The breeding materials BRH9392-6-2-1-3-4 (5.7 /tha), BR9396-6-2-2B (5.4 t/ha), BR9392-10-20-1B (5.6 t/ha), BRH11-2-4-7B (5.5 t/ha) were selected for their better yield than the check variety BRRI dhan87 (5.3 t/ha). Secondary yield trial (SYT- Zirashail type) under recommended management practices was performed for evaluating yield potential of Zirashail grain type materials (early transplanting by mid-July) season in representative areas. The breeding materials BRH11-7-17-10B (5.2 t/ha), BRH13-9-5-3B (4.9 t/ha), BRH9-3-14-2B (4.9 t/ha) were selected compared to Zirashail (4.2 t/ha).

Development of rice varieties for favourable Boro environment. The aim of this project was to develop improved genotypes with high yield potential (≥8.0 t/ha), earliness (135-145 days) and accepted grain quality for favourable irrigated ecosystem in Bangladesh.

Twenty-four crosses were made using 24 promising lines/varieties as parents targeting to develop high yielding breeding lines enriched with favourable alleles of key target traits, viz. disease resistance (blast and BLB), insect resistance (BPH) and acceptable grain quality (amylose, chalkiness, palatability, zinc content, etc). Twenty-one crosses were confirmed as true F_1 through a hybridity test using QC SNP genotyping. In total 20,692 individual progenies from 72 cross combinations of F_2-F_5 generations were advanced in the RGA nurseries following single seed decent method of breeding. Out of 1,919 lines tested in LST, 415 uniform lines in terms of plant height, days to flowering, grain size and shape were selected based on the presence of the favourable alleles of key target genes for BB (*xa5*, *xa13* and *Xa21*), blast (*Pi9*, *Pita*, *Pita2* and *Pb1*) and BPH (*Bph17* and *BPH32*) resistance, cold tolerance (*qSCT1, qPSST3, qPSST6, qPSST7 and qPSST9), grain quality (Wx-a, Wx-10, chalk5, BADH2*) **(Fig. 3)**.

Thirty-three genotypes out of 558 fixed lines tested in four locations following sparse testing model of genomic selection in OYT were selected based on genomic BLUP for yield. Genomic BLUP values were estimated using genome-wide genotyping data and phenotypic values for yield of training population tested at MLT sites. Figure 4 shows the scattered plots of breeding lines tested at specific sites for standardized mean values (BLUES) and growth duration of the breeding lines indicating that a big chunk of medium duration (145 -155 days) having yield potential more than 7.0 t/ha have been isolated from the OYT. Seventy-nine breeding lines were tested in advanced yield trial (AYT) at three locations under three categories, AYT_Early, AYT_late and AYT_AGGRiNet. In AYT_Early, five genotypes out of 32 entries showing around 0.40-0.80 t/ha yield advantage with similar growth duration over the check variety BRRI dhan96 were selected (**Table 3**). From AYT_Late, two genotypes showing almost similar yield but 5-7 days shorter growth duration compared to the check variety BRRI dhan89 were selected (**Table 4**). Three genotypes produced 1.02-1.45 t/ha yield advantage with 3-5 days shorter growth duration compared to the check variety BRRI dhan81 and the genotype IR18A1398 showed the highest yield 8.52 t/ha with similar growth duration to BRRI dhan89 (7.46 t/ha), were selected from 17 tested entries in AYT_AGGRiNET (**Table 5**).

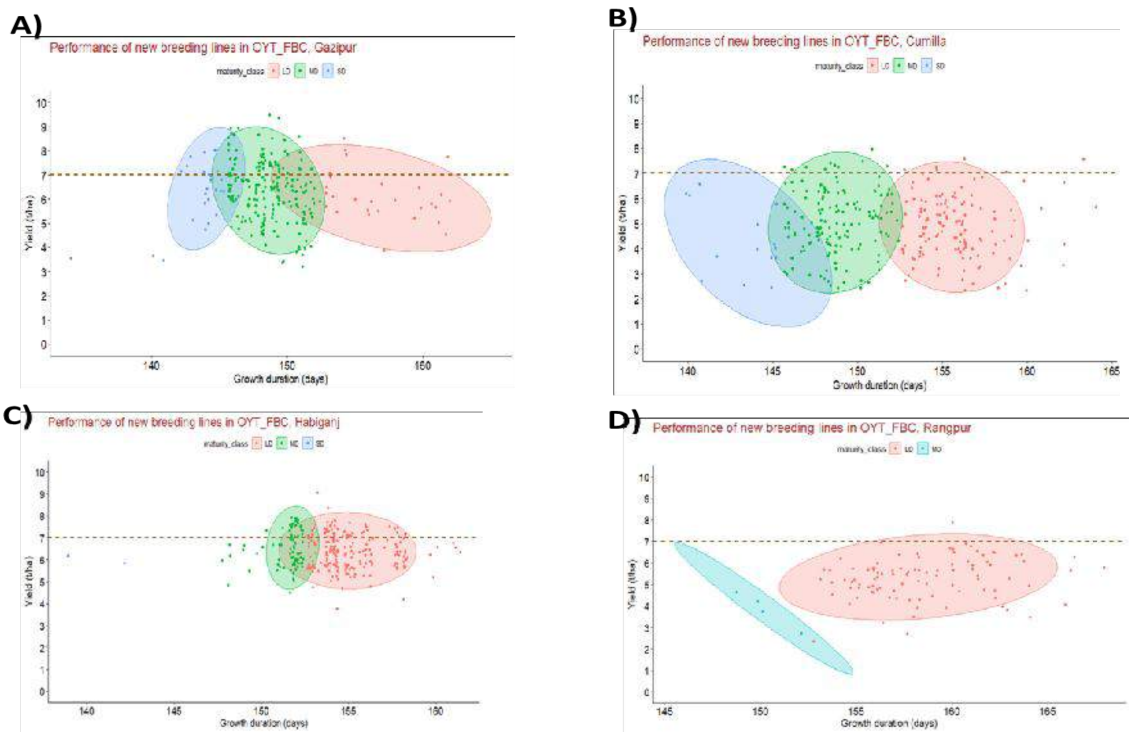


Fig. 3. Performance of 558 advanced breeding lines under OYT_FBC trial evaluated in Gazipur (A), Cumilla (B), Habiganj(C), and Rangpur (D). The genotypes were classified based on days to maturity. It ranged from 135 to 145 days for short duration (SD), 136 to 152 days for medium duration (MD), 153 to 161 days for long duration (LD).

Table 3. Yield performances of the selected breeding lines from AYT#Early conducted at different locations, favourable boro rice, Boro 2021-22.

Designation	Growth duration (day)	Yield (t/ha)				
		Barishal	Cumilla	Gazipur	Habiganj	Average
AYT#Early						
BR11637-5R-140	147	6.22	7.03	6.39	7.97	6.90
BR11894-5R-376	149	6.34	7.96	5.41	6.36	6.52
BR11900-5R-24	150	5.91	7.50	5.63	7.01	6.55
BR11903-5R-56	145	7.02	7.75	5.60	5.85	6.56
BRRI dhan28	145	6.10	6.13	4.44	6.20	6.01
BRRI dhan96	143	6.07	6.62	NA	6.67	6.08
LSD	6.94	0.73	0.96	0.96	1.26	0.90
H2b	0.79	0.69	0.75	0.64	0.38	0.28

Table 4. Yield performances of the selected breeding lines from AYT#late conducted at different locations, favourable Boro rice, Boro 2021-22

Designation	Growth duration (day)	Yield (t/ha)				
		Barishal	Cumilla	Gazipur	Habiganj	Average
AYT#Late						
BR11894-5R-260	152	6.80	6.51	6.04	6.28	6.41
BR11660-5R-6	150	6.45	5.99	5.78	6.80	6.25
BRRI dhan81	155	6.08	6.36	4.37	5.77	5.64
BRRI dhan89	159	6.25	6.75	5.17	6.76	6.23
LSD	8.09	0.25	0.85	0.92	0.82	1.08
H2b	0.89	0.98	0.64	0.79	0.42	0.20

Table 5. Yield performances of the selected breeding lines from AYT#AGGRiNet conducted at different locations, favourable Boro rice, Boro 2021-22.

Designation	Growth duration (day)	Yield (t/ha)			
		Gazipur	Rajshahi	Rangpur	Average
AYT#AGGRiNet					
IR17A1275	142	7.38	6.13	6.48	6.66
IR17A1694	146	6.27	6.40	7.77	6.81
IR17A1735	143	5.68	7.22	6.95	6.62
IR18A1398	153	NA	8.67	8.40	8.52
IR18A1907	154	7.12	8.92	6.45	7.50
IR18A2119	150	5.28	7.63	8.77	7.23
BRRI dhan81	147	5.25	5.49	5.33	5.36
BRRI dhan89	155	7.72	6.84	7.82	7.46
LSD	6.04	0.90	0.98	1.67	1.25
H2b	0.79	0.91	0.92	0.62	0.23

Out of 45 advanced breeding lines tested at nine research stations including HQ in regional yield trial (RYT) under short, medium and long maturity classes, two breeding lines showed 141 days and 146 days growth duration with 0.34 t/ha and 0.79 t/ha higher yield, respectively over BRRI dhan96 (yield 6.03 t/ha growth duration 142 days) (**Table 6**); two breeding lines showing 7.0-7.1 t/ha yield with 148 days growth duration while both the check varieties BRRI dhan81 and BRRI dhan96 yielded 6.0 t/ha in RYT (MD) (**Table 7**). In RYT (LD) the advanced lines BR11318-5R-148 and BR11318-5R-84 produced similar yield to the check variety BRRI dhan89 (7.0 t/ha). Among two varieties BR11318-5R-148 showed four days shorter growth duration than the check variety BRRI dhan89 (**Table 8**), was selected for further advancement. Besides, two entries from RYT (AGGRiNET) of IRRI bred breeding lines showed similar yield but five days shorter growth duration compared to the check variety BRRI dhan89 (6.8 t/ha) (**Table 9**) which were selected for further advancement.

Table 6. Agronomic performances of the selected genotypes out of six tested in RYT (SD), Development of Favourable Boro rice during Boro 2021-22.

Designation	PH (cm)	DM (day)	Yield BLUE (t/ha)									
			L1	L2	L3	L4	L5	L6	L7	L8	L9	Avg.
IR17A1694	102	146	5.6	8.1	6.7	7.1	6.8	5.4	7.6	6.3	6.5	6.8
IR17A1723	89	141	6.4	5.5	5.7	5.3	6.4	5.7	5.7	6.0	6.8	6.4
BRRI dhan81	98	144	5.0	6.1	6.2	6.0	5.8	6.8	6.1	5.1	6.5	6.0
BRRI dhan96	94	142	7.2	5.7	-	-	-	5.8	6.4	4.8	6.3	6.0
LSD	7.72	5.14	0.69	0.90	0.39	0.71	0.41	0.37	0.29	0.78	0.31	1.10
H^2b	0.82	0.84	0.98	0.87	0.84	0.71	0.94	0.97	0.97	0.78	0.73	0.43

L1=Barishal, L2=Bhanga, L3=Cumilla, L4=Gazipur, L5=Habiganj, L6=Kushtia, L7=Rajshahi, L8=Rangpur, L9=Sonagazi, Avg.= Average

Table 7. Agronomic performances of the selected genotypes out of 15 tested in RYT (MD, development of favourable Boro rice during Boro 2021-22.

Designation	PH (cm)	DM (day)	Yield BLUE (t/ha)									
			L1	L2	L3	L4	L5	L6	L7	L8	L9	Avg.
BR11318-5R-63	107	149	5.8	8.6	7.1	7.0	7.2	7.4	7.6	6.9	6.4	7.1
BR11337-5R-72	102	149	6.2	7.9	7.2	6.7	7.6	7.2	7.9	5.3	6.8	7.0
SVIN109	104	148	6.5	7.7	7.3	7.1	8.4	7.6	6.4	6.3	6.6	7.0
BRRI dhan81	100	147	5.1	7.7	6.2	4.6	6.6	5.7	6.1	5.1	6.6	6.0
BRRI dhan96	93	148	5.9	7.4	6.4	6.5	7.3	7.2	6.4	5.7	6.4	6.6
LSD	3.90	4.61	0.39	0.92	0.52	0.82	0.47	0.59	0.35	0.51	0.39	0.55
H2b	0.97	0.70	0.86	0.41	0.69	0.76	0.87	0.93	0.96	0.89	0.53	0.78

***PH=Average plant height, DM= Average days to maturity, BLUE=Best linear unbiased estimation**
L1=Barishal, L2=Bhanga, L3=Cumilla, L4=Gazipur, L5=Habiganj, L6=Kushtia, L7=Rajshahi, L8=Rangpur, L9=Sonagazi, Avg.= Average

Table 8. Agronomic performances of the selected genotypes out of 11 tested in RYT (LD), development of favourable Boro rice during Boro 2021-22.

Designation	**PH (cm)**	**DM (days)**	**BLUE Yield (t/ha)**									
			L1	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**Avg.**
BR11318-5R-148	109	156	6.7	6.7	7.7	6.3	6.6	6.9	7.2	6.5	8.0	7.0
BR11318-5R-84	115	160	6.2	8.4	6.4	6.3	7.2	7.9	8.4	5.8	7.1	7.1
BRRI dhan89	111	160	6.1	6.6	6.6	6.1	7.2	7.8	7.1	6.8	8.3	7.0
LSD	3.86	5.10	0.53	0.61	0.67	1.10	0.45	0.35	0.37	0.47	0.49	0.57
H2b	0.80	0.89	0.71	0.88	0.79	0.03	0.83	0.92	0.97	0.92	0.82	0.73

L1=Barishal, L2=Bhanga, L3=Cumilla, L4=Gazipur, L5=Habiganj, L6=Kushtia, L7=Rajshahi, L8=Rangpur, L9=Sonagazi, Avg.= Average

Table 9. Agronomic performances of the selected genotypes out of 13 tested in RYT (AGGRiNet), development of favourable Boro rice during Boro 2021-22.

Designation	PH (cm)	DM (day)	BLUE yield (t/ha)									
			L1	L2	L3	L4	L5	L6	L7	L8	L9	Avg.
IR 12 A 173	109	153	6.4	5.3	7.4	7.8	6.7	7.5	6.8	6.0	7.2	6.8
IR17A1694	103	152	5.9	5.0	6.9	7.2	6.8	7.7	6.6	6.2	6.8	6.6
BRRI dhan89	111	157	6.8	5.3	6.8	7.0	6.4	7.4	7.6	6.3	8.2	**6.9**
BRRI dhan92	113	158	6.6	5.4	6.8	6.5	6.1	7.9	7.8	5.4	8.5	6.8
LSD	5.88	4.90	0.53	0.74	0.51		0.33	0.53	0.31	0.25	0.37	0.49
h2b	0.90	0.88	0.88	0.31	0.74	0.74	0.88	0.87	0.95	0.98	0.94	0.77

L1=Barishal, L2=Bhanga, L3=Cumilla, L4=Gazipur, L5=Habiganj, L6=Kushtia, L7=Rajshahi, L8=Rangpur, L9=Sonagazi, Avg.= Average

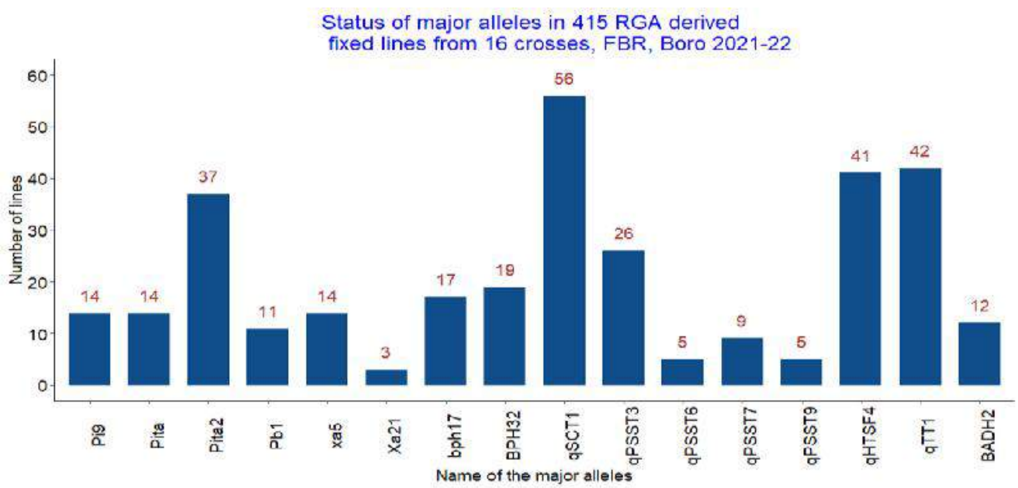


Fig. 4. Status of major alleles in selected LST population (415 lines from16 crosses), FBR, Boro 2021-22.

Development of cold tolerant rice. The major objective of the project was to develop high yielding and short duration (6.0-7.0 t/ha yield and 135-145 days growth duration for haor areas) and high yielding medium duration (6.5-7.5 t/ha yield with 145-150 days growth duration for Northern regions) rice varieties tolerant to cold stress at seedling and reproductive stage. Twenty-three crosses were made using 24 lines/varieties as parents targeting to develop high yielding breeding lines enriched with favourable alleles of key target traits, viz. disease resistance (blast and BLB), insect resistance (BPH) and acceptable grain quality (amylose, chalkiness, palatability, zinc content, etc). Twenty-four crosses were confirmed as true F1 through a hybridity test using QC SNP genotyping. From segregating RGA nurseries, in total 14,578 individual plants were advanced from 56 cross combinations of F_2-F_5 generations following SSD method of breeding. Out of 2,445 lines tested in LST, 278 uniform lines in terms of plant height, days to flowering, grain size and shape were selected based on the presence of the favourable alleles of key target genes **(Table 10 and Fig. 5)**. A set of 180 lines were identified with genes for cold tolerance (*qSCT1 or qPSST*), 79 for blast resistance (*Pi-ta, Pi-9* or *Pita2*), 46 for cold (either seedling or reproductive) and blast, 29 for BPH resistance (*Bph17* and *BPH32*), 923 lines for higher amylose specific markers.

Forty genotypes out of 456 breeding lines and 25 genotypes out of 778 breeding lines tested under natural cold stress (at booting stage) and non-stress conditions at two locations in OYT-1 and OYT-2, respectively were selected based on significantly higher yield than the check varieties of similar growth duration under non-stress condition and minimum yield reduction under cold stress condition for further yield trial. A total of 46 breeding lines were selected from 170 lines tested at four locations in three AYT class trials under two simulated cold-stress (October seeding) and non-stress control environments. From AYT_cold, 19 genotypes out of 43 tested entries showing around 0.70-1.30 t/ha yield advantage with shorter growth duration compared to the check varieties BRRI dhan28, BRRI dhan96 and BRRI dhan67, 11 short to medium duration (146 -154 days) genotypes showing 0.4 -1.44 t/ha higher yield compared to the check variety BRRI dhan96 (146 d) in AYT_Haor set-1, and 12 breeding lines with 146-151 days growth duration and four genotypes with 153-157 days growth duration showing 0.7-1.9 t/ha and 1.6 -2.8 t/ha higher yield over BRRI dhan28 and BRRI dhan89, respectively were selected for further evaluation from AYT_Haor set-2. From RYT-CTR, three genotypes out of six breeding lines/varieties tested at 13 locations including 10 haor sites under Kishoreganj, Sunamganj, and Habiganj districts showed better performance in terms of yield and cold tolerance at reproductive stage. In this trial BR11894-R-R-R-R-169 yielded up to 3.04 t/ha under severe cold stress (<20^0C) for consecutive three weeks during PI to heading stage, while others including moderately tolerant BRRI dhan67 produced no grain.

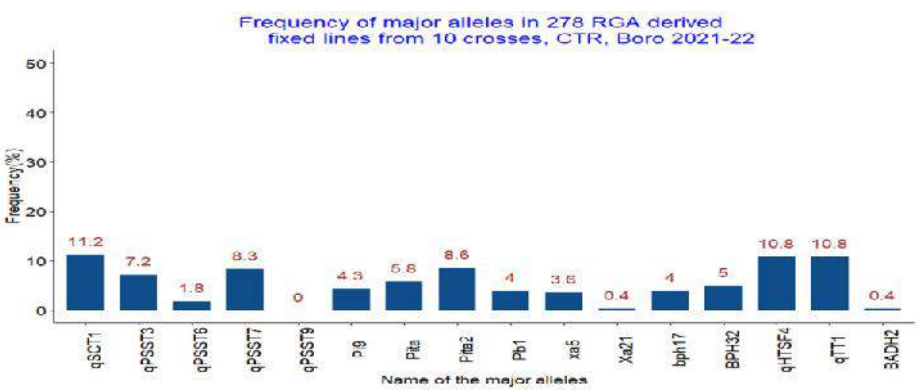


Fig. 5. Status of major alleles in selected LST population (278 lines from 10 crosses), CTR, Boro 2021-22.

Table 10. Allele/gene combination in selected LST population, FBR, Boro 2021-22.

Gene combination	Trait	No. of line
Pi9 +Pita+Pita2+Pb1+qSCT1	Blast, Cold (Seedling)	8
Pi9+Pita+Pita2+Pb1	Blast	13
Pi9+Pita+Pita2	Blast	34
Pi9+Pita2	Blast	37
bph17+BPH32	BPH	61
bph17+BPH32+xa5+Pb1+qSCT	BPH, BLB, blast, cold (Seedling)	12

Development of salt tolerant rice (STR): The objective of this project is to develop high yielding salt tolerant rice cultivars based on product profile. Salinity is one of the major constraints for the rainfed lowland and Boro rice ecosystem in the southern coastal zone of Bangladesh. In T. Aman season, 29 crosses were made using 31 well characterized elite parents. A total of 14 F_1s were confirmed as true hybrids through F_1 verification by quality check (QC) genotyping with purity SNP panel during T. Aman season. In T. Aman season, 1,06,268 segregating progenies derived from 103 crosses were advanced in F_2-F_6 generations using FRGA technique. Yield trials were carried out in Gazipur, and Assasuni, Debnagar, Debhata, Kaliganj and BRRI RS Farm, Satkhira in T. Aman season. In LST, out of 6,199 breeding lines of 30 crosses, 682 lines were selected on the basis of strong culm with good plant ideotype, acceptable grain type and uniformity at heading in field condition (Fig.6). A total of 658 LST lines were genotyped using trait-specific SNP panel (**Fig. 7**) to identify promising breeding lines with trait of interest (ToI) (**Fig.8**).

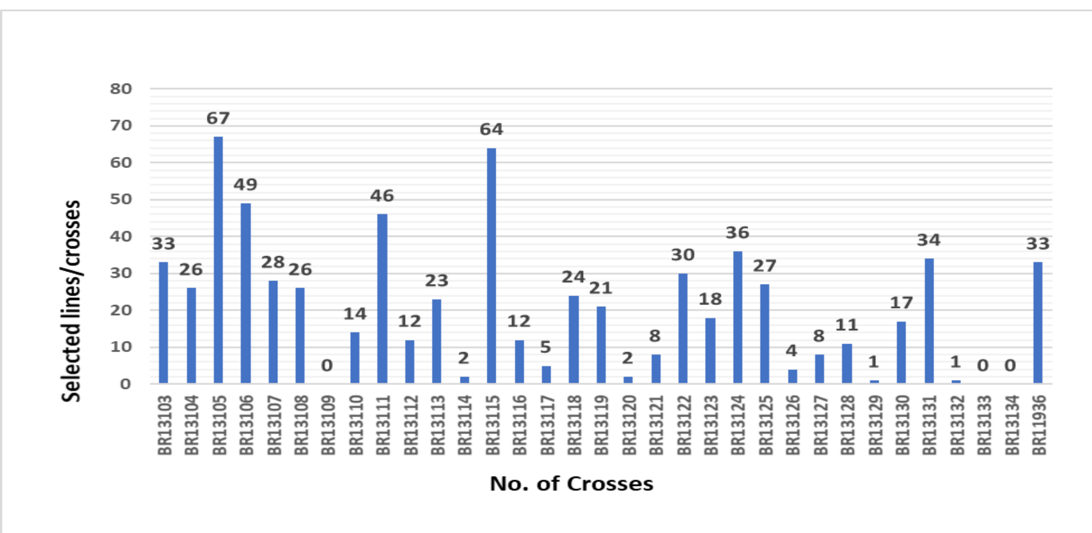


Fig. 6. Number of selelcted lines of LST population, T. Aman 2021-22.

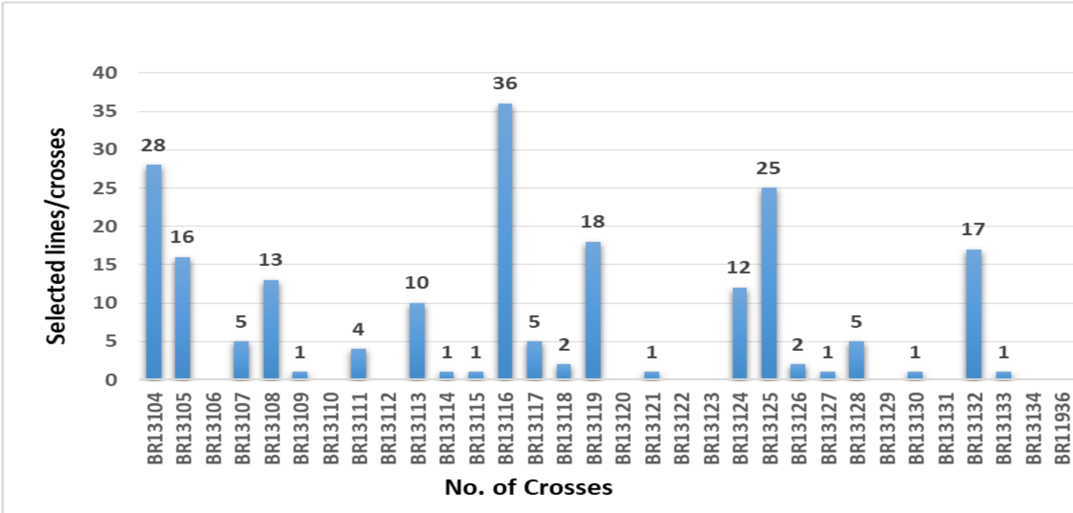


Fig. 7. Number of LST lines per cross genotyped using trait-specific SNP panel, T. Aman 2021-22.

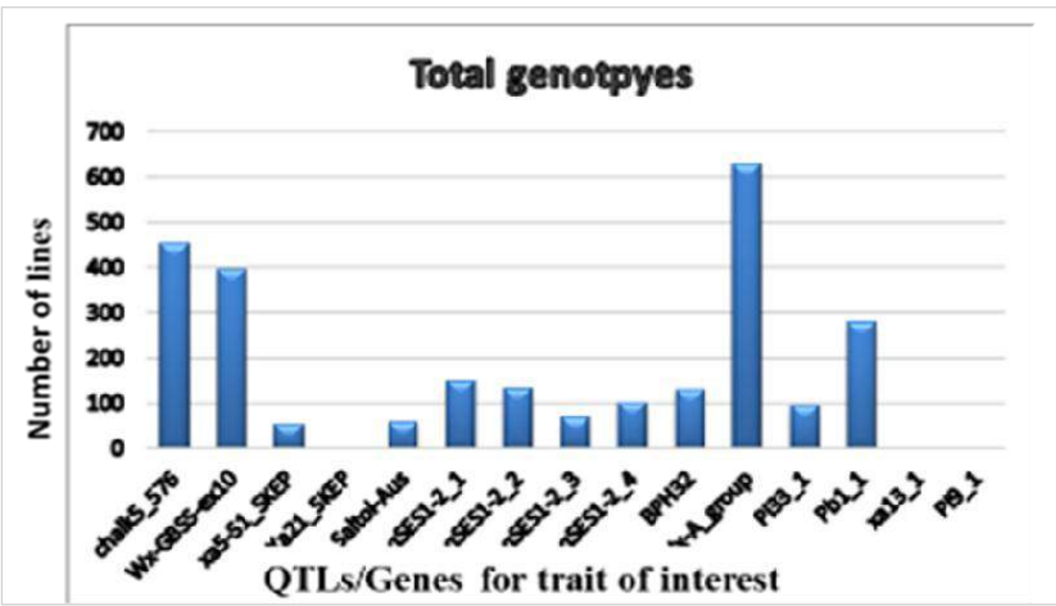


Fig. 8. Selected LST genotypes with QTL/genes for trait of interest, T. Aman 2021-22.

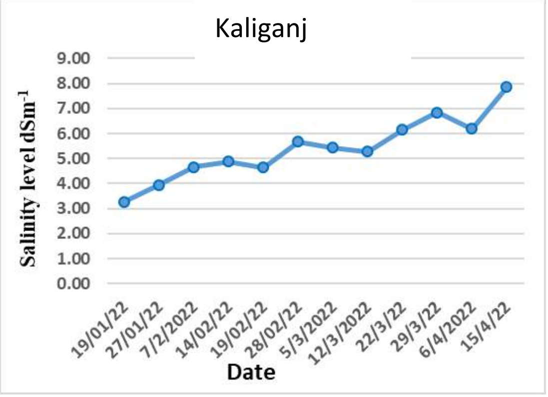
Out of 722 genotypes, 240 genotypes were selected from OYT. Three PYTs (PYT#1 to PYT#3) were conducted using 232 breeding lines. One hundred nine genotypes were selected from these trials depending on grain yield, salinity tolerance and phenotypic acceptability. Sixteen genotypes, out of 42 were selected from SYT/AYT. In RYT#2, a total eight of genotypes were evaluated in ten locations and three genotypes such as BR11712-4R-218, BR11716-4R-102, and BR11723-4R-172 were selected based on grain yield, (**Table 11**). The mean grain yield of selected lines ranged from 5.28 t/ha (BR11712-4R-218) to 5.53 t/ha (BR11716-4R-102) which were higher than the check varieties. These three genotypes such as BR11712-4R-218, BR11716-4R-102 and BR11723-4R-172 were selected for conducting ALART (**Table 11**).

Table 11. Performance of genotypes in RYT#2 STR, salinity breeding, T. Aman 2021-22.

Designation	GD (day)	PH (cm)	Yield (t/ha)										
			Gazi	Com	Deb	Gopal	Kustia	Raj	Rang	Sat	Sona. Chandina	Sona. farm	Mean
BR11712-4R-218	119	110	6.70	5.82	4.92	6.38	5.41	5.74	4.38	6.09	4.06	3.31	5.28
BR11712-4R-227	121	109	5.67	5.66	4.45	6.68	5.30	5.40	4.07	5.14	3.17	3.56	4.91
BR11715-4R-186	119	110	5.09	6.17	4.86	6.64	5.14	5.09	4.65	5.88	3.90	3.39	5.08
BR11716-4R-102	119	107	6.00	6.34	4.89	7.08	5.35	5.84	4.36	6.70	4.42	4.37	5.53
BR11716-4R-105	118	116	4.76	6.31	4.25	6.00	5.83	4.16	3.19	5.71	3.47	5.71	4.94
BR11716-4R-129	121	110	5.79	6.09	4.86	6.80	4.81	5.04	5.33	5.77	3.94	3.93	5.24
BR11723-4R-172	118	109	7.05	6.26	4.35	6.80	5.07	5.65	4.88	5.06	4.33	3.44	5.29
BR11723-4R-27	119	107	5.70	6.38	4.67	6.39	4.96	5.37	4.71	5.68	4.57	4.15	5.26
BRRI dhan73	121	126	5.87	5.78	4.49	5.91	4.87	4.55	3.20	4.61	5.24	2.91	4.74
BRRI dhan87	124	121	6.34	6.10	5.66	6.37	6.02	5.72	3.74	6.18	2.03	1.74	4.99
LSD (5%)	2.31	3.92	0.96	0.37	0.40	0.37	0.42	0.46	0.73	0.78	0.95	1.06	0.39

Gazi= Gazipur, Com= Cumilla, Ded= Debhata, Gopal = Gopalganj, Raj= Rajshahi, Rang = Rangpur, Sat= Satkhira, Sona chandina = Sonagazi chandina, Sona.far = Sonagai farm

In Boro Season, 40 crosses were made using 64 elite parents. A total of 32 F_1s were confirmed as true hybrids through F_1 verification by quality check (QC) genotyping with purity SNP panel. In total 1,13,098 segregating progenies from 113 crosses (F_2-F_5 generation) were harvested from FRGA nursery and grown in the subsequent generation. In LST trial, 320 lines out of 5170 lines were selected on the basis of desirable plant type, grain quality and uniformity at flowering under field condition. A total of 54 genotypes were selected out of 422 from OYT based on growth duration, grain yield, and homogeneity in different morpho-agronomic traits. Out of 112 genotypes, 30 genotypes were selected from two PYTs. Twenty genotypes were selected from three AYT's. Two genotypes from RYT#1 and three genotypes from RTY#2 were selected. The highest level of salinity (EC) was found at Kaliganj being ranged from 3 dS/m to 7.15 dS/m in Boro 2021-22 (**Fig. 9**).



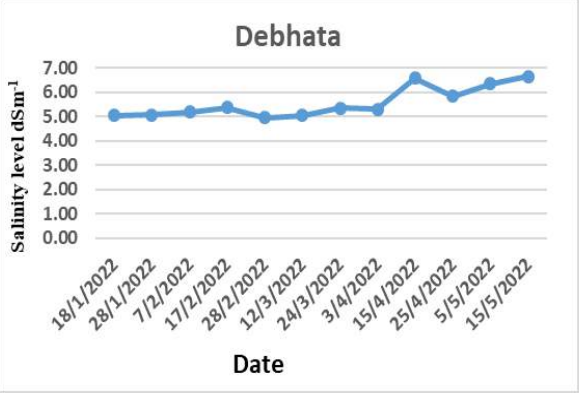


Fig. 9. Salinity dynamics of different experimental fields in coastal saline areas in Boro 2021-22.

Investigators: M Akhlasur Rahman, Hasina Khatun, M Asif Rahman, R Farzana Disha, Avijt Biswas, A.A Shoily and T H Ansari

Development of premium quality rice (PQR)

T. Aman. Efforts were made to develop aromatic and non-aromatic fine quality rice with national and international standards (Kalizira/ Chinigura /Kataribhog /Radhunipagol/Jasmine type), anti-oxidant enriched (black and red) rice and photosensitive rice for domestic use and export. In T. Aman 2021-22, a total of 109 crosses (52 single crosses and 10 backcrosses for PQR, 34 single crosses for anti-oxidant enriched rice and 22 single crosses and one backcross for photosensitive rice) were made and 70 crosses (51 for PQR, eight for anti-oxidant enriched rice and 11 for photosensitive rice) were confirmed as true hybrid using quality control SNP panel analysis. A total of 14,800 progenies (11,038 progenies of 24 F_2 crosses, 1,681 progenies of 12 F_3 crosses, and 2,081 progenies of 14 F_4 crosses) were advanced through RGA under PQR. A total of 5,638 progenies (1,564 progenies of four F_2 crosses, 1,448 progenies from five F_3 crosses, 484 progenies from 10 F_4 crosses and 1,300 progenies from 15 F_5 crosses and 842 progenies from three F_6 crosses) were advanced through RGA under Antioxidant programme. A total of 1,633 progenies (945 progenies of five F_2 crosses, 177 progenies from five F_3 crosses, 484 progenies from five F_4 crosses and 27 progenies from three F_6 crosses) were advanced through RGA under photosensitive programme. Under PQR programme 62 genotypes were selected out of 158 from different yield trials based on growth duration, yield, homogeneity and morpho-agronomic traits. From Observational Yield Trial (OYT) 26 genotypes were selected out of 66 genotypes. From preliminary yield trial (PYT), 23 genotypes were selected out of 64 genotypes. Seven genotypes were selected out of 16 genotypes from secondary yield trial (SYT). In OYT#1, the genotype BR10820-2-3-3-5-3 produced the highest yield (6.5 t/ha) which was non-aromatic whereas the second highest yielder genotype having 5.7 t/ha yield is an aromatic line with 136 days growth duration. In OYT#2, the aromatic genotype BR9178-7-2-4-4 produced the highest yield of 7.0 t/ha with growth duration 130 days. In PYT#1 the genotype BR11224-7-9-4-3 produced the highest yield (6.5 t/ha) which was a non-aromatic genotype having long slender type grain whereas the aromatic genotype BR10062-8-3-2-1-P2 produced 4.4 t/ha yield with growth duration 107 days. In PYT#2, the aromatic genotype BR11811-9-2-2 produced 6.6 t/ha yield but grain was bold while the genotype BR8493-12-7-4-P1 produced 5.6 t/ha yield with grain type almost same with BRRI dhan90**.** In SYT, the aromatic genotype BR10824-5-6-4-1 having BRRI dhan34 type grain produced 4.3 t/ha with a growth duration of 141 days. In AYT, the aromatic genotype BR9126-15-3-4-1 having BRRI dhan34 type grain which produced 5.7 t/ha with growth duration 128 days. Another aromatic genotype BR10813-75-20-10-2 produced 4.0 t/ha with 125 days growth duration with Kalizira grain type. The aromatic genotype BR8493-3-5-1-P1 having BRRI dhan90 type grain produced 6.2 t/ha yield during seed purification stage which were recommended to evaluate in ALART as *polaw* rice whereas a non-aromatic genotype producing 6.5 t/h yield was also recommended to evaluate in ALART as table rice. The growth duration of these two genotypes are 139 days and 135 days, respectively. Under Antioxidant enriched rice breeding programme, 1,075 fixed lines were selected from LST in T. Aman 2021, which were evaluated under OYT in Boro 2021-22. From OYT 152 advanced lines were selected. The yields of the selected lines ranged from 4.0 t/ha to 6.9 t/ha. Most of the selected lower yielder genotypes had very long slender or Katari type grain and possessed aroma. The genotype BR12839-4R-93 produced 6.9 t/ha yield followed by the genotype BR12839-4R-72-1 (6.5 t/ha). Under photosensitive rice programme, 36 genotypes were selected out of 111 from different yield trials. From OYT, 28 genotypes were selected from 86 genotypes based on growth duration, yield, homogeneity and morpho-agronomic traits. From PYT, eight genotypes were selected out of 14 genotypes. Seven genotypes were selected out of 11 genotypes from SYT. In OYT, the genotype BR8845-21-1-10-3-4 produced significantly higher yield (6.5 t/ha) and this was followed by the genotype BR8845-21-1-10-3-5 (6.0 t/ha) whereas the yield of the check varieties was BR22 (4.7 t/ha) and BR23 (4.9 t/ha). Both of the genotypes had similar growth duration with the check varieties. The genotype TL Aus-Gaz10-40-5-11 produced 5.4 t/ha yield which also possesses aroma. In PYT, the genotype BR8845-21-1-10-6-1 produced significantly higher yield (5.4 t/ha) than the check varieties BR22 (4.7 t/ha) and BR23 (4.9 t/ha) possessed aroma having shorter growth duration, which has been transferred to trial under premium quality rice for the next season. In SYT, the genotype TL Aus Kushtia-3 (PR-2)-2 produced significantly higher yield (6.0 t/ha) with bold grain followed by the genotype BR8845-21-1-5-10-3-P4 (5.7 t/ha) with aroma. The heritability obtained for growth duration was ranging from 86% to 96% and grain yield was ranging from 80 % to 88% indicating acceptable level of precision in these experiments.

Investigators: Sharmistha Ghosal, M M Yasmin, Z A Riyadh and K M Iftekharuddaula

Boro: The project aims to develop aromatic and non-aromatic fine quality rice with international (Basmati/Banglamati/SoruBalam type) standards in Boro season for domestic use and export quality. Totally 1,820 F_1 seeds were obtained from 29 crosses. Twenty-six F_1 crosses were confirmed out of 20 crosses as true hybrid. In total 13,210 progenies of 29 crosses from F_2, F_4 and F_5 generations were advanced through RGA method. A total of 623 genotypes were selected from 6,546 progenies of LST trial. A total of 199 genotypes were evaluated in three OYTs in Gazipur, Rajshahi and Rangpur. Figures 10 and 11 present selection intensity and trait marker profile of the genotypes of LST. Among the tested genotypes, 63 genotypes were selected and forwarded in Advanced Yield Trial (AYT). In PYT, none of the genotypes were selected out of seven tested genotypes. From two SYT's, 27 genotypes were evaluated and 12 genotypes were advanced in RYT. In RYT, none of the genotypes was selected to forward in ALART out of two genotypes. None of the genotypes was recommended to advance from ALART by the Adaptive Research Division.

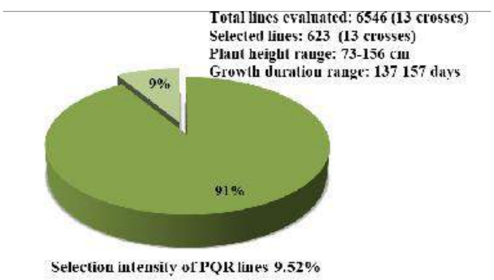


Fig.10. Selection intensity in the genotypes of LST, PQR, Boro 2021-22.

Fig.11. Trait marker profile of the genotypes of LST, PQR, Boro 2021-22.

Investigators: R R Majumder, K Fatema, U R Shaha and M A Kader.

Development of Zinc Enriched Rice (ZER). The project aims to develop high yielding rice varieties with improved nutritional quality with high zinc (Zn≥24 mg/kg) in polished grain. The project also prioritizes development of stress tolerant zinc enriched rice varieties in a combination of submergence + zinc, drought + zinc, salinity + zinc and cold + zinc enriched rice with improved grain yield. The experiments were conducted in both T. Aman and Boro seasons. In T. Aman season, 59 single crosses were made that produced 9906 seeds. A total of 48 crosses were selected and confirmed as true F_1s. In pedigree selection, 1,512 plants were selected from F_2 population of 18 crosses and 2,504 progenies and 69 fixed lines were isolated from 87 crosses from F_2-F_6 generations. From two OYT's, 56 genotypes were selected from 169 genotypes. A total of 11 genotypes were selected from 48 genotypes of two PYT's based on yield performances. Only three promising genotypes were selected out of 23 genotypes of three SYT's. None of the genotypes was selected from RYT. None of the entries was recommended for promoting from ALART by ARD. In Boro season, 20 single crosses were made that produced 1,424 seeds. A total of 58 crosses were confirmed as true F_1s. A total of 29,250 progenies were harvested from F_2 and F_3 generation at the time of maturity. After that seed materials were preserved and processed with proper labels. Following pedigree selection method, 1,310 progenies and 471 fixed lines of 60 crosses were isolated from F_4 and F_6 generation. From OYT, 64 genotypes were selected from 184 genotypes. A total of 15 genotypes were selected out of 53 genotypes from PYT based on yield performances. Three promising genotypes were selected out of seven genotypes from SYT. Zinc enriched IR99285-1-1-1-P2 was approved to release as BRRI dhan102 for cultivation throughout the country for Boro season by National Seed Board (NSB) of Bangladesh in its 106th meeting held on 18 January 2022. The average yield of BRRI dhan102 was 8.11 t/ha with 150 days growth duration and zinc content of the milled rice of the variety was 25.5 mg/kg which was higher than that of BRRI dhan29 (18.2 mg/kg) (**Table 12**). BRRI dhan102 is expected to be very popular in the areas where BRRI dhan29 is cultivated and plays a major role in increasing overall rice production of Bangladesh.

Table 12. Performance of BRRI dhan102 in proposed variety trial, Boro 2020-21.

Designation	Plant height (cm)	Growth duration (day) *	Grain yield (t/ha) *	Grain characteristics						
				Head rice yield (%)	L-B ratio	Size and shape	Elongation ratio	Protein (%)	Amylose (%)	Zinc content (mg/kg)
BRRI dhan102 (BR99285-1-1-1-P2)	101	150	8.11	62	3.1	LS	1.3	7.5	8.0	25.5
BRRI dhan29(Ck)	96	152	7.84	61	3.0	MB	1.4	7.0	6.9	18.2

*Mean of ten locations (BRRI HQ, Gazipur; BRRI RS Rangpur, BRRI RS Faridpur, BINA-Mymensingh; Jashore, Feni, Cumilla, Bogura, Dinajpur, Barishal)

Fig.12. Pictorial view of BRRI dhan102.

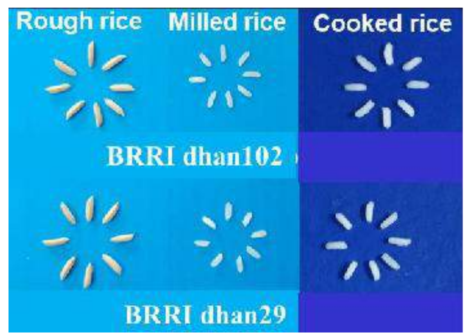


Fig.13. Grains of BRRI dhan102.

Investigators: M A Kader, R R Majumder, S M T Islam, U R Shaha and K Fatema.

Development of disease resistant rice. Efforts were made for developing varieties resistant to bacterial blight (BB), rice tungro virus (RTV) and blast diseases. The experiments were conducted in both T. Aman and Boro seasons. Seven crosses for BB and nine for blast in T. Aman and 12 crosses for BB and 18 for blast were made in Boro season. Sixteen crosses for BB and five for blast in T. Aman and seven crosses for BB and nine for blast in Boro season were confirmed as true F_1. A total of 17,900 progenies for BB and 13,250 progenies for blast were advanced from F_{2-6} generation through Green-house RGA and FRGA. Out of 6,700 lines, 1,150 lines were selected from LST in Boro season based on uniformity in heading, plant height and grain type. Seventeen genotypes for BB were selected from observational yield trial (OYT) in T. Aman season whereas 60 entries out of 750 for BB during Boro season showed better yield potential and agronomic performance over the check varieties and tolerance to BB. From AYT, three advanced lines were promoted based on growth duration, grain yield and BB score compared to the check varieties in T. Aman season and 21 genotypes out of 87 for BB were selected in Boro season. From MLT, three genotypes for T. Aman season and six for Boro were selected compared to yield, growth duration, BB resistance and better grain quality characters and three BB resistant genotypes performed better but yield was not >10% higher than the check variety. Therefore, the high yielding background of BB resistant promising lines will be used as genetic resource to develop high yielding disease resistant varieties. The promising BB resistant line BR8938-19-4-3-1-1-P2-HR3 was released as BRRI dhan101. The average yield of this variety was 7.72 ton per hectare. Growth duration of it was 142 days, which was four days earlier than the popular variety BRRI dhan58. Its grain contains 25.0% amylose and 9.8% protein (**Table 13 and Fig.14**). The variety showed strong resistance to BB (BB score-1) under artificial inoculation with virulent BB pathogens. QTL fingerprinting with functional SNP markers for the BB resistance detected three dominant BB resistant genes *Xa4*, *Xa7* and *Xa21* in this variety.

Table 13. Yield, agronomic performance and physico-chemical properties of the proposed variety BRRI dhan101 (BR8938-19-4-3-1-1-P2-HR3), Boro 2020-21.

Designation	Yield (t/ha)	GD (day)	Amylose (%)	Protein (%)	Head rice yield (%)	Size & shape	ER	IB
BRRI dhan101 (BR8938-19-4-3-1-1-P2-HR3)	7.72	142	25.0	9.8	60.0	LS	1.4	3.0
BRRI dhan58 (Ck)	7.39	146	26.0	7.0	61.3	MB	1.3	3.0

ER-Elongation Ratio IR-Imbibition Ratio

Fig.14. Pictorial view of BRRI dhan101.

Investigators: M Khatun, S K Debsharma, J Ferdousy, M A I Khan and M A Latif

Development of Insect Resistant Rice. The main thrust of the project was to develop varieties resistant to gall midge (GM), brown plant hopper (BPH) and white backed plant hopper (WBPH). The experiments were conducted in both T. Aman and Boro seasons. In the T. Aman season, 12 crosses for forward breeding, three crosses for line augmentation and three crosses for QTL deployment were made and 22 crosses were confirmed as true hybrids using quality check (QC) genotyping with purity SNP panel. In total 62530 segregating progenies from 67 crosses of F_2-F_5 generations were advanced through field rapid generation Advanced (FRGA) technique. Out of 3569 $F_{5:6}$ of LST lines derived from 16 different crosses, 204 genotypes were selected based on strong plant architecture, grain type and uniformity in heading under field condition as well as the presence of the favourable alleles of key target genes for BPH (*bph9, bph17_1, bph17_2, bph17_3 and bph32*), Gm (*Gm4_3* and *Gm4_4*) and grain quality *(Wx-A and Wx-10*). The selected four and 149 LST genotypes had *bph17* and *bph32* favourable alleles, respectively. The favourable alleles for gall midge resistant genes, *Gm4_3* and *Gm4_4* were present in 32 lines. However, two genotypes had both *bph17* and *bph32* as well as one genotype had *bph17*, *bph32* with *GM4* SNP favourable alleles (**Table 14**). The yield trials (OYT and AYT) were conducted at three locations of BRRI HQ, Gazipur, BRRI RS, Cumilla and Rangpur. Ninety-three genotypes were selected from 432 breeding lines in OYT. Nine selected OYT genotypes had both *bph9* and *bph17, and* four had *bph17* with *Gm4* SNP favourable alleles. Eighteen genotypes were selected from 92 lines in AYT. Nine selected AYT genotypes had both *bph17* and *bph32* SNP favourable alleles. Table 15 showed the performance and favourable alleles of selected OYT and AYT genotypes. Two promising lines such as BR9880-40-1-3-34 and BR9880-27-4-1-18 were evaluated in ALART that showed moderate resistance to BPH (SES Score 5.0). None of the entries was recommended from ALART for PVT due to non-competitive performance compared to the standard checks BRRI dhan87 and BRRI dhan93. In Boro season, 16 crosses for forward breeding, three F_1 and three BC_1F_1 crosses for line augmentation were made, and 23 crosses were confirmed as true hybrids through F_1 verification using quality check (QC) genotyping with purity SNP panel. A total of 85,124 individual plants were advanced from 84 crosses in F_2-F_5 generations by FRGA technique. In LST, 257 lines having strong plant architecture, grain quality, uniformity in heading under field condition and the presence of the favourable alleles of key target genes for BPH (*bph9*, *bph17_1*, *bph17_2*, *bph17_3 and bph32*), Gm (*Gm4_3* and *Gm4_4*) and grain quality *(Wx-A and Wx-10*) were selected from 2,350 $F_{5:6}$ breeding lines that are the descendants of 12 crosses. A set of 64 lines were identified with genes for *bph17* (*bph17_1*, *bph17_2*, *bph17_3*), 122 for *bph32*, three for *bph9* and 18 for *Gm4 (Gm4_3, Gm4_4)* specific markers. Fifty-three genotypes out of 542 were selected from OYT that were tested in three locations. Fifteen lines were selected from 87 lines in PYT. Out of 60 genotypes, 10 were selected from AYT for further evaluation. Seven genotypes were evaluated in RYT and two entries showed 0.40 t/ha yield advantage with similar growth duration over the check variety BRRI dhan58. In total 65 parental lines were maintained in insect resistant maintenance breeding programme.

Table 14. Gene combinations of breeding lines selected from LST, IRR, T. Aman 2021-22.

Designation	Gene combination
BR13090-4R-22	*bph32, Gm4_3, Gm4_4, Wx-A_group*
BR13094-4R-221	*bph32, Gm4_3, Gm4_4, Wx-GBSS-ex10, Wx-A_group,*
BR13094-4R-259	*bph17_1, bph17_2, bph17_3, Wx-A_group*
BR13097-4R-76	*bph32, Gm4_3, Gm4_4, Wx-GBSS-ex10, Wx-A_group,*
BR13097-4R-105	*bph32, Gm4_3, Gm4_4*
BR13097-4R-124	*bph32, Gm4_3, Gm4_4*
BR13097-4R-151	*bph32, Gm4_3, Gm4_4*
BR13097-4R-268	*bph32, Gm4_3, Gm4_4*
BR13100-4R-149	*bph17_1, bph17_2, bph17_3, bph32*
BR13100-4R-180	*bph32, Gm4_3, Gm4_4, Wx-A_group*
BR13100-4R-181	*bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-GBSS-ex10, Wx-A_group,*
BR13100-4R-216	*bph32, Gm4_3, Gm4_4,*
BR13100-4R-255	*bph17_1, bph17_2, bph17_3, bph32, Gm4_3, Gm4_4,*

Table 15. Grain yield, agronomic performance and favourable alleles for trait of interest of selected genotypes from OYT and AYT lines, IRR, T. Aman 2021-22.

	Duration (day)	PH (cm)	Yield (t/ha)				Trait of interest (ToI)
			Gaz	Ran	Cum	BLUE	
			OYT				
BR 12193-5 R-63	136	113	5.1	4.8	5.8	5.2	*bph9, bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group*
BR 12193-5 R-66	125	116	3.0	3.7	5.5	4.1	*bph9, bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group*

BR 12193-5 R-219	119	99	4.0	4.7	6.1	4.9	*bph9, bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group*
BR 12193-5 R-148	128	99	3.4	3.9	NA	4.1	*bph9, bph17_1, bph17_2, bph17_2, Gm4_3, Gm4_4, Wx-A_group*
BR 12193-5 R-17	121	109	4.1	NA	NA	4.4	*bph9, bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group, Wx-GBSS-ex10*
BR 12193-5 R-54	126	93	4.6	2.5	5.1	4.1	*bph9, bph17_1, bph17_2, bph17_3, Wx-A_group, Wx-GBSS-ex10*
BR 12193-5 R-88	127	132	3.1	3.8	6.3	4.4	*bph9, bph17_1, bph17_2, bph17_3, Wx-A_group*
BR 12193-5 R-93	130	120	3.1	4.4	6.2	4.6	*bph9, bph17_1, bph17_2, bph17_3, Wx-A_group*
BR 12193-5 R-225	122	119	5.8	3.0	5.9	4.9	*bph9, bph17_1, bph17_2, bph17_3, Wx-A_group*
BR 12193-5 R-23	115	113	4.3	4.0	NA	4.6	*bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group, Wx-GBSS-ex10*
BR 12181-5 R-158	132	108	3.2	3.6	6.0	4.3	*bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group, Wx-GBSS-ex10*
BR 12208-5 R-332	113	109	6.0	4.3	5.8	5.3	*bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group, Wx-GBSS-ex10*
BR 12208-5 R-227	116	108	5.3	5.5	5.7	5.5	*bph17_1, bph17_2, bph17_3, Gm4_3, Gm4_4, Wx-A_group*
AYT							
BR 11044-4 R -33	121	113	3.8	4.1	5.2	4.4	*bph17_1, bph17_2,bph17_3, bph32, Gm4_3, Gm4_4, Wx-A_group*
BR 11035-4 R -101	120	119	3.9	5.2	5.9	5.0	*bph17_1, bph17_2, bph17_3, bph32, Gm4_3, Gm4_4, Wx-A_group*
BR 11052-4 R -251	121	129	4.6	4.3	5.7	4.9	*bph17_1, bph17_2, bph17_3, bph32, Gm4_3, Gm4_4, Wx-A_group*
SVIN308	122	111	4.6	4.6	5.5	4.9	*bph17_1, bph17_2, bph17_3, bph32, Gm4_3, Gm4_4, Wx-A_group*
BR 11035-4 R -190	119	124	5.3	4.7	5.2	5.1	*bph17_1, bph17_2, bph17_3, bph32, Wx-A_group*
BR 11052-4 R -273	114	119	4.6	4.4	4.3	4.4	*bph17_1, bph17_2, bph17_3, bph32, Wx-A_group*
BR 11035-4 R -1	120	118	3.9	4.4	6.0	4.7	*bph17_1, bph17_2, bph17_3, bph32, Wx-A_group*
BR 11052-4 R -234	116	109	4.9	4.4	5.7	5.0	*bph17_1, bph17_2, bph17_3, bph32, Wx-A_group*
IRBPHN-SVIN013-18	118	121	3.3	7.1	5.6	5.3	*bph17_1, bph17_2, bph17_3, bph32,*

Investigators: Md Ruhul Amin Sarker, Hasina Khatun, Ribed Farzana Disha and M Akhlasur Rahman

Development of submergence and water stagnation tolerant rice varieties. The project aims for the development of high yielding rice varieties tolerant to submergence (flash flooding) and medium stagnant water (MSW) stresses. Totally 4885 F_1 seeds were obtained from 33 single and two back crosses. Thirty-four single F_1 crosses were selected and confirmed through QC SNP panel analysis. Panicles of 4,350 from 15 F_2 crosses, 2,510 from nine F_3, 2,324 from ten F_4 progenies, 3,080 from nine F_5 progenies, and 5072 from 22 F_6 progenies were harvested at the time of maturity, processed with proper labels and preserved. The ranges of mortality percentage of different RGA generations were around 15%. From LST population, 2,230 lines from nine crosses were genotyped with trait markers using custom SNP panel among which 178 lines were selected based on uniformity and traits markers like *Sub1*, *Wx-A group*, *Wx-A_NB*, *xa13*, *Xa21* etc. In yield trial, 573 genotypes were tested out of which 122 genotypes were selected based on phenotypic acceptance, growth duration, survivability and higher yield performance. From OYT#1, thirty genotypes out of 148 genotypes, from OYT#2, thirteen genotypes out of 43 genotypes, from OYT#3 (INGER_IRSTN_FP), four genotypes out of 10, from OYT#4 (AGGRi Network trial), 35 genotypes out of 265, from PYT#1_Early, eight genotypes out of 21, from PYT#2_Late, eight genotypes out of 18 genotypes, from AYT#1_Early, nine genotypes out of 28 genotypes, from AYT#2_Late, eleven genotypes out of 29 were selected. Three lines were evaluated in ALART from which one line was recommended to evaluate in PVT. In OYT#1, the genotype BR10211-22-9-2-1 with 89% survivability produced the highest yield 6.7 t/ha under stress condition. In OYT#2 the genotype BR12162-5R-350 showed higher yield (6.6 t/ha) under controlled stress with 95% survivability. In

OYT#3, the genotype SV1170_WS21-FP-5 produced highest yield (5.8 t/ha) under rainfed condition. In OYT#4, the highest yield was 7.2 t/ha given by the genotype IR18T1135 with survivability of 83% followed by the genotype IR19A1914 (7.1 t/ha) with survivability of 73%. In PYT#1, the genotype BR11690-5R-98 produced the highest yield (6.1 t/ha) with survivability of 98% and growth duration of 137 days under 18 days of controlled submergence stress condition. In PYT#2, the genotype BR11686-5R-179 produced the highest yield (5.9 t/ha) with 130 days growth duration in flood prone farmers' field with 100% survivability. In AYT#1 the genotype IR16F1033 produced the highest yield 7.0 t/ha followed by the genotype IR103782-B-B-1-1 (6.1 t/ha) under controlled stress condition. In AYT#2, the genotype BR10212-7-5-1 produced the highest yield 6.9 t/ha with 96% survivability followed by the genotype BR11185-5R-569-3 (5.8 t/ha) with 80% survivability. Table 16 shows that in ALART#1 the genotype IR16F1148 produced significantly higher yield (5.0 t/ha) over both the submergence tolerant check BINA dhan11 (4.06 t/ha) and the susceptible check BRRI dhan71 (4.02 t/ha) with similar growth duration. The genotype also has almost similar growth duration with check varieties. This line was recommended to evaluate in PVT. The ALART#2 trial was recommended for re-trial in tidal submergence ecosystem. The heritability obtained for grain yield under stress of all trials conducted was ranging from 55 % to 99%, whereas that for non-stress trials was ranging from 50 % to 93%, indicating acceptable level of precision in these experiments.

Investigators: Sharmistha Ghosal, Z A Riyadh, A Rahman, R Hassan and K M Iftekharuddaula

Table 16. Grain yield performance of genotypes in advanced line adaptive research trial (ALART), development of submergence tolerant rice, T. Aman 2021-22.

	Under rainfed condition			**Yield under submergence stress condition**								
Designation	Plant height (cm)	Growth duration (days)	Yield (t/ha) at Gazipur	Gazipur Water Tank	Rangpur Water Tank	Rangpur Sadar	Lalmonirhat Sadar	Aditmari Lalmonirhat	Gaibandha	Kurigram	Chittagong	Mean
IR16F1148	120	124	**5.31**	5.66	5.44	5.64	4.95	5.05	4.04	3.84	5.57	**5.02**
BRRI dhan71 (Sus. Ck)	118	117	**4.37**	0.00	5.2	5.18	4.15	4.72	3.65	1.43	3.43	**3.47**
Binadhan11 (Tol.Ck)	111	120	**3.99**	4.76	4.7	5.15	4.45	4.26	3.91	3.02	3.0	**4.16**
$LSD_{0.05}$	5.28	1.17	0.60	0.68								**0.24**
CV (%)	2.76	0.56	8.5	9.52								

Development of drought tolerant rice (DTR). The project aims to develop high yielding drought tolerant rice varieties under rainfed lowland rice ecosystem in T. Aman season. In, T. Aman 2021-22, 1,916 F_1 seeds were obtained from 14 crosses using 22 parents and 19 crosses were confirmed as true hybrids using 10 SNP *indica* QC panel. A total of 2,398 individual panicles from 20 crosses of F_4 and F_5 were harvested through RGA. The materials were advanced in Boro 2021-22, a total of 4,543 progenies were harvested from 19 crosses of F_3 generations through RGA method. From LST, 620 lines were selected from 7,634 progenies of 45 crosses. Figures 15 and 16 present selection intensity and trait marker profile of the genotypes of LST. A total of 717 genotypes were evaluated in three OYTs in Gazipur, Rajshahi and Rangpur. Among the tested genotypes. 23 were selected and forwarded in AYT. In OYT, 12 genotypes were selected from 181 genotypes based on yield performances. Two genotypes were selected from RYT for advancing in ALART.

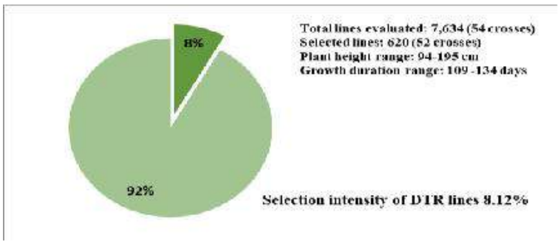


Fig. 15. Selection intensity in the genotypes of LST, DTR, T. Aman 2021-22.

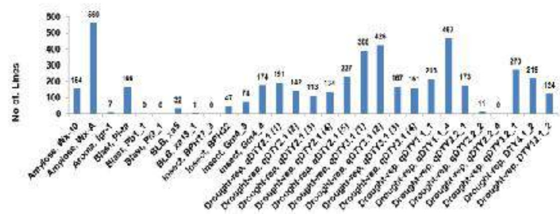


Fig. 16. Trait marker profile of the genotypes of LST, DTR, T. Aman 2021-22.

Investigators: M A Kader, R R Majumder, M E Haq, U R Shaha and K Fatema

Development of water saving and aerobic rice varieties. The objective of the project was to develop short duration water-use-efficient rice genotypes with 10% more yield than the check varieties under transplanted alternate wetting and drying (AWD) and aerobic conditions. A total of 18 crosses were made using 23 parents and 1,670 F_1 seeds were obtained, and 13 single crosses were selected and confirmed through QC SNP panel analysis. Panicles of 292 F_3 from four crosses were advanced through FRGA. From advanced yield trial (AYT) conducted under AWD condition, seven genotypes were selected from 12 genotypes tested. In OYT, 53 genotypes were selected from 140 genotypes. In AYT, the genotype BR11206-5B-351 produced the highest yield (6.6 t/ha) under AWD condition however it was not significantly higher than the check variety BRRI dhan89 (6.2 t/ha). In OYT, yield of the genotype IR18R1109 (7.5 t/ha), IR18R1179 (7.3 t/ha) and IR18R1176 (7.3 t/ha) were significantly higher than the check variety BRRI dhan81 (5.5 t/ha) with similar growth duration. The heritability obtained for grain yield under stress condition was ranging from 74 % to 99% indicating acceptable level of precision in these experiments.

Investigator: Sharmistha Ghosal, Z A Riyadh and K M Iftekharuddaula

Deployment and validation of high beta-carotene rice and high iron as well as zinc rice varieties (Healthier Rice). The main objective of the project was to develop high yielding transgenic rice varieties with enhanced provitamin-A, iron and zinc content in polished rice grain. A total of 2,280 F_1 seeds were obtained from six crosses in T. Aman 2021-22 to develop high iron and zinc enriched rice (HIZR). For developing provitamin-A enriched rice, 123 homozygous plants were selected from six backcrosses from BC_3F_1 generations through marker assisted selection (MAS) method. Twelve genotypes from contained trial (CT) were selected based on the yield performances from 24 transgenic lines of provitamin-A enriched GR2E BRRI dhan49 and GR2E BRRI dhan62.

In Boro 2021-22, 782 BC_1F_1 seeds were obtained from six backcrosses to develop high iron and zinc enriched rice. In total 349 plants were selected from BC_3F_1 generation for developing provitamin-A enriched golden rice through MAS selection method. Ten genotypes from CT were selected based on the yield performances from 70 transgenic lines of provitamin-A enriched GR2E BRRI dhan28. Among 11 genotypes, three genotypes were selected from three events IRS1030-039, IRS1030-031, IRS1027-059 from the confined field trial (CFT) conducted at Gazipur, Rajshahi, Barishal, Satkhira and Habiganj districts of Bangladesh under Healthier Rice project.

Investigators: M A Kader, R R Majumder, U R Shaha and K Fatema.

International network for genetic evaluation of rice (INGER): This project focused on sharing and use of germplasm and breeding lines through international platform for the acceleration of genetic improvement of rice varieties. Totally 28 genotypes out of 116 from six INGER nursery sets of T. Aman 2021-22 and five genotypes out of 62 from two INGER nursery sets of Boro 2021-22 seasons were selected to be used in different breeding programmes for direct use in the breeding pipeline or as parents.

National Coordinator: K M Iftekharuddaula, **Key Cooperator**: Sharmistha Ghosal

Biotechnology Division

SUMMARY

A total of 31 experiments were conducted during the year 2021-22. A doubled haploid line BR (Bio)8961-AC26-16 was approved by National Technical Committee of Bangladesh as BRRI dhan103 for T. Aman season. Thirteen doubled haploid lines derived from a cross between BRRI dhan29 and Kanaklata for developing low glycemic index (GI) rice variety were grown as PYT in T. Aman 2021. Among them, five lines were selected. In total 126 calli were obtained from four different crosses for premium quality rice variety and 94 green plants were regenerated. Among them seeds were harvested from 19 regenerated double haploid plants of BRRI dhan90/Kataribhog cross. Besides 842 F_1 seeds were harvested from ten crosses for future anther culture programme. Seven plants were selected for backcross progeny (BC_2F_3) of BRRI dhan50*^{2} /(Bashful/BRRI dhan50 (DH_1)). During Aus 2021 a total of 261 F_1 seeds were harvested from ten crosses for high yielding Aus varieties. During Boro 2021-22, 3 and 19 lines for antioxidant enriched black rice were selected from PYT and OT respectively. Twelve lines were also selected during T. Aman 2021. One line was selected from three doubled haploid lines in T. Aman 2021 for the development of intermediate amylose rice. These lines were also evaluated by Plant Breeding Division in hilly areas. During Boro 2021-22, five antioxidant enriched black rice were developed using anther culture were evaluated as PYT and four lines were selected for RYT. Forty antioxidant enriched black rice developed by using both seed and anther culture were evaluated as OT in T. Aman 2021 and 12 lines were selected for further evaluation. Twenty-one lines were selected for PYT from sixty-nine antioxidant enriched black rice lines developed by using both seed and anther culture in Boro 2021-22. Eighty-four plants were selected from 38 lines of four different wide crosses. Besides, nine backcrosses were done with previously embryo rescued plants to reduce hybrid sterility and nine plants (BC_2F_2) were selected. One QTL (q7.1 TSH) on chromosome 7 was identified for taller seedling height from a F_2 population of BR11 x Sadamota (acc. no. 1576). One hundred and seven F_5 progenies were selected based on aroma, growth duration and plant height from the cross between BRRI dhan87 and Kalijira for the development of high yielding aromatic rice. All tested aromatic lines were confirmed by using functional marker of fragrance gene *BADH2*. Two hundred and forty-nine F_1 seeds were harvested for both blast and bacterial blight resistant rice. BRRI dhan29 was transformed with salt tolerant genes (*GlyI and GlyII).* Seventeen fixed lines were harvested from T_5 plants. Transgenic plant containing mangrove salt tolerant gene, *AeMDHAR* was crossed with BRRI dhan28 and three BC_2F_3 plants are now growing in transgenic net house for further evaluation. Drought and heat tolerant *TaCRT* gene was isolated from wheat to develop drought tolerant rice by *Agrobacterium* mediated transformation. During T. Aman 21, seven lines were selected from 20 fixed lines of EMS treated somaclonal variants of BR11. A total of 7000 M4 lines of Kaoun (*Setaria italica*) have been developed to observe loss of C4 functions under low concentration (20 ppm) CO_2 for 72 hours. DNA of seven aromatic and two non-aromatic rice were amplified with a functional marker of *BADH2* gene and sequenced. Multiple alignment of seven aromatic and two non-aromatic rice was done with functional *BADH2* gene. Eight bp deletion was observed in aromatic rice Kalijira, Radhunipagol, BR5, BRRI dhan34 and in BRRI dhan70.

DEVELOPMENT OF DOUBLE HAPLOID RICE THROUGH ANTHER CULTURE

High yielding rice variety for Aman season

The proposed line BR (Bio)8961-AC26-16 was approved by National technical committee of Bangladesh as BRRI dhan103 for T. Aman season. The variety produced 17.71% higher yield than BRRI dhan87 with similar growth duration. The average yield of proposed BRRI dhan103 is 6.2 ton/ha.

Low glycemic index (GI) rice variety

Six and seven doubled haploid lines were grown as two PYT in T. Aman 2021. Among them two and three lines were selected respectively depending on the growth duration and yield compared with the check variety (Tables 1and 2). During Boro 2021-22, two doubled haploid lines derived from a cross between BRRI dhan29 and Kanaklata were evaluated as a regional yield trial (RYT). None of them was selected.

Table 1. Agronomic characteristics of selected anther culture derived materials. PYT-1, T. Aman 2021.

	Designation	Plant height (cm)	Growth duration (day)	Yield (t/ha)
	BR(Bio)10381-AC11-1-1	129	125	5.41
	BR(Bio)10381-AC11-5-1	122	108	4.82
	BR(Bio)10381-AC11-6-1	140	125	5.26
	BR(Bio)10381-AC11-7-1	139	127	6.07
	BR(Bio)10381-AC11-8-1	102	106	5.10
	BR(Bio)10381-AC11-9-1	136	125	5.03
	BRRI dhan71(ck)	138	118	5.71
	CV			4.61
	LSD			0.43

Table 2. Agronomic characteristics of selected anther culture derived materials. PYT-2, T. Aman 2021.

	Designation	Plant height (cm)	Growth duration (days)	Yield (t/ha)	Remark
	BR(Bio)13031-AC1-2	109	119	5.62	
	BR(Bio)13031-AC1-3	107	109	3.22	
	BR(Bio)13031-AC1-4	104	105	3.39	
	BR(Bio)13031-AC1-5	108	109	4.73	
	BR(Bio)10381-AC34-1	108	112	3.21	
	BR(Bio)10381-AC30-2	104	118	6.32	
	BR(Bio)10381-AC11-1	109	114	5.82	
	BRRI dhan71(ck)	129	112	5.58	
	BRRI dhan87 (ck)	134	126	3.602	lodging
	CV			12.48	
	LSD			0.96	

Bold = Selected

Investigators: Jannatul Ferdous, Shahanaz Sultana and Md Enamul Hoque

Development of salt tolerant rice variety through anther culture

Two doubled haploid fixed lines from BRRI dhan28/BRRI dhan61 cross were evaluated along with the checks BRRI dhan28, BRRI dhan96 and BRRI dhan86 during Boro 2021-22 as SYT (Table 3). Among them no lines were selected due to lower yield than the check varieties. On the other hand 7,171 hybrid anthers from 13 crosses were plated on N6 media. In total 17 calli were obtained from different crosses and no green plants were regenerated yet. Ten crosses were done and 470 F_1 seeds were collected during Boro 2021-22 for further anther culture.

Table 3. List of double haploid (DH) lines evaluated as SYT during Boro 2021-22.

	Designation	Plant height (cm)	Growth duration (day)	Yield (t/ha)
	BR(Bio)11310-AC2-1	91	142	5.94
	BR(Bio)11310-AC2-2	93	144	5.80
	BRRI dhan28	96	143	6.60
	BRRI dhan96	95	142	7.11
	BRRI dhan86	96	142	6.89
	CV			7.12
	SD			0.68

*Parentage: BRRI dhn28/ BRRI dhan61

Investigators: Nilufar Yasmin Shaikh and Ripon Kumar Roy

Development of premium quality rice variety through anther culture

During T. Aman 2021, a total of 4,969 and 7,776 hybrid anthers from nine crosses were plated on N6 and M10 media. In a total of 126 calli were obtained from different crosses and 94 green plants were regenerated from BRRI dhan90/Kataribhog, BRRI dhan90/Kalijira, BRRI dhan90/BRRI dhan34, and BRRI dhan90/Tulshimala crosses (Table 4). Among them seeds were harvested from **18** regenerated doubled haploid plants of BRRI dhan90/Kataribhog cross. Ten crosses were done for future anther culture programme. In total 842 F_1 seeds were harvested for future anther culture programme. During T. Aman 2021, two OT was conducted with double haploid plants from BRRI dhan38/Bashful and BRRI dhan50/Bashful cross. None of them was selected due to lodging. Backcross progeny ($BC2F_3$) of BRRI dhan50/Bashful(DH1)//*^{2} BRRI dhan50 were grown in T. Aman 2021 as pedigree. Seven plants were selected for further evaluation.

Table 4. Number of anthers plated, calli obtained and plants regenerated in T. Aman 2021.

	Cross	No. of Anther plated		No. of calli obtained	No. of plant regenerated
		N6	M10		
	BRRI dhan70/ Tulshimala (Acc. 1870)	857	1055	7	
	BRRI dhan87/ Tulshimala (Acc. 1870)	509	254	-	
	BRRI dhan90/ Kataribhog	487	676	94	91
	BRRI dhan87/ Kalizira (B)	950	1475	-	
	BRRI dhan90/ Kalizira (B)	442	975	10	1
	BRRI dhan90/ BRRI dhan34	942	1645	7	1
	Kalizira/ Shakkorkhana	72	320	5	
	BRRI dhan87/ Radhunipagol (Acc. 6711)	507	1036		
	BRRI dhan90/ Tulshimala (Acc. 1870)	203	340	3	1
Total		4969	7776	126	94

Fig. 1. Regenerated plants from BRRI dhan90/Kataribhog by Anther culture.

Investigators: Nilufar Yasmin Shaikh, Jannatul Ferdous and Md Enamul Hoque

Development of Aus variety through anther culture

Ten crosses were made. A total of 261 F_1 seeds were harvested for future anther culture programme.

Investigators: Shampa Das Joya, Shahanaz Sultana, Jannatul Ferdous and Md Enamul Hoque

Development of antioxidant enriched black rice variety through anther culture

During Boro 2021-22, five antioxidant enriched black rice were developed using anther culture were evaluated as PYT. Four lines were selected for RYT (Table 5). Forty antioxidant enriched black rice developed by using both seed and anther culture were evaluated as OT in T Aman 2021. Twelve lines were selected for further evaluation. Sixty-nine antioxidant enriched black rice lines developed by using both seed and anther culture were evaluated as two OT in Boro 2021-22. Among them 21 lines were selected for PYT (Tables 6 and 7). Moreover 46 somaclonal (SC4) variants of antioxidant enriched black rice were evaluated as pedigree. Among them 32 somaclonal (SC4) variants of antioxidant enriched black rice were evaluated as pedigree.

Table 5. Agronomic characteristics of selected anther culture derived materials. PYT, Boro 2021-22.

	Designation	Plant Height (cm)	Growth Duration (days)	Yield (t/ha)
	BR(Bio)13028-AC24-1-2	120	141	6.42
	BR(Bio)13028-AC24-2-3	101	142	5.97
	BR(Bio)13028-AC24-2-4	106	143	6.82
	BR(Bio)13028-AC24-3-3	113	142	6.03
	BR(Bio)13028-AC11-3-1	104	140	4.27
	BRRI dhan86	97	142	6.39
	BRRI dhan96	97	141	7.04

Table 6. Agronomic characteristics of selected anther culture derived materials. OT, Boro 2021-22.

	Designation	Plant height (cm)	Growth duration (day)	Yield (t/ha)
	BR(Bio)13028-AC24-4-4-2	106	142	8.48
	BR(Bio)13028-AC11-2-1-1	135	143	7.17
	BR(Bio)13028-AC15-3-1-2	107	143	6.88
	BR(Bio)13028-AC24-3-2-4	101	141	7.31
	BR(Bio)13028-AC24-4-2-2	104	148	6.86
	BR(Bio)13028-AC24-4-3-3	110	143	7.45
	BR(Bio)13028-AC24-4-4-2	110	142	6.99
	BRRI dhan86 (Ck)	96	143	6.47

Table 7. Agronomic characteristics of selected anther culture derived materials. OT, Boro 2021-22.

	Designation	Plant height (cm)	Growth duration (days)	Yield (t/ha)
	BR28/Podi chelum-AC 4-1-2	123	141	5.24
	BR28/Podi chelum-AC 6-2-6	105	143	5.17
	BR28/Podi chelum-AC 6-3-2	131	143	5.05
	BR28/Podikool-AC1-2-2	101	144	5.41
	BR28/Podikool-AC1-2-3	103	141	6.27
	BR28/Podikool-AC1-2-4	112	145	5.79
	BR28/Podikool-AC1-2-6	110	143	4.86
	BR28/Podikool-AC1-2-7	111	141	5.39
	BR28/Podikool-AC2-2-2-1	126	141	5.27
	BR28/Podikool-AC2-2-2-3	124	145	5.18
	BR28/Lansan-AC 5-2-1	128	144	5.53

	BR28/Lansan-AC13-2-2	98	141	5.11
	Lansan-2-1	127	141	5.10
	Lansan-2-2	108	146	5.22
	BRRI dhan86(CK)	91	141	4.29
	BRRI dhan96(CK)	94	141	7.03

Investigators: Jannatul Ferdous, Shahanaz Sultana and Md Enamul Hoque.

Development of doubled haploid rice variety for high yield

Four doubled haploids were grown as SYT in T. Aman 2021. None of them was selected for further evaluation because amylose content of these materials were less than 20%.

Investigators: Shahanaz Sultana**,** Jannatul Ferdous and Md Enamul Hoque.

Development of doubled haploid photoperiod sensitive rice variety through anther culture

A total of 6,067 anther were plated in two media. Two calli were obtained from the cross BRRI dhan87/BR22 and each BRRI dhan87/ BR23. BRRI dhan87/BRRI dhan46 produced single callus. Seven crosses were done in T. Aman 2021. A total of 273 F_1 seeds were harvested for anther culture in T Aman 2021

Investigators: Md Arafat Hossain, S M Hisam Al Rabbi, Shahanaz Sultana, Md Enamul Hoque

Development of doubled haploid rice variety through anther culture for intermediate amylose rice

Three doubled haploid lined were grown as SYT in T. Aman 2021. Among them one line was selected for further evaluation (Table 8). These materials were given to Plant Breeding division for evaluation under hilly areas.

Table 8. Agronomic and physic-chemical characteristics of selected anther culture derived materials, SYT-1, T. Aman 2021.

	Designation	PH	GD	Yield (t/ha)	Amy (%)	Pro (%)	Shape and size
	BR (Bio)10376–AC4-1-3	105	110	3.59	20.7	9.5	LS
	BR (Bio)10376–AC9-1-3	107	108	3.61	20.4	9.0	LS
	BR (Bio)10376–AC11-3-1	108	111	5.01	20.9	9.0	LS
	BRRI dhan71	131	115	4.36	24.3	9.3	LB

Investigators: Jannatul Ferdous, Shahanaz Sultana, and Md Enamul Hoque

DEVELOPMENT OF RICE VARIETY THROUGH SOMACLONAL VARIATION

Development of premium quality (Kalijira type) variety through somaclonal variation

Fourteen lines somaclonal variants (SCV_1) of Kalijira rice were grown in T. Aman 2021. One hundred and twenty-six plants were selected for further evaluation.

Investigators: Shahanaz Sultana, Jannatul Ferdous and Md Enamul Hoque

Development of rice variety through wide hybridization followed by embryo rescue

Thirty-eight lines from different generation of wide hybridization followed by embryo rescue programme were evaluated in T. Aman 2021 and Boro 2021-22 (Table 9). Among them, eighty-four plants were selected from BRRI dhan28/*O. nivara* (IRGC103821), BRRI dhan28/*O. glaberrima* (IRGC105190), BRRI dhan87/*O. glaberrima* (IRGC105190), BRRI dhan48/*O. glaberrima* (IRGC105190) for generation advancement. Besides those, five backcrosses were done with previously embryo rescued plants to reduce hybrid sterility. Seeds were harvested from those and evaluated in T. Aman 2021. Among them nine plants (BC_2F_2) were selected for generation advancement.

Table 9. Number of plants selected from embryo rescued rice lines during T. Aman 2021.

	Cross	Generation	No. of lines evaluated	No. of plants selected
	BRRI dhan28/*O. nivara* (IRGC103821)	BC1F2 - BC1F6	13	54
	BRRI dhan28/*O. glaberrima* (IRGC105190)	F5	11	15
	BRRI dhan87/*O. glaberrima* (IRGC105190)	F5	1	2
	BRRI dhan48/*O. glaberrima* (IRGC105190)	F5	13	13
	Total		38	84

Investigator: Nilufar Yasmin Shaikh and Ripon Kumar Roy

SELECTION BREEDING OF RICE THROUGH MARKER ASSISTED SELECTION

Identification of QTLs for taller seedling height

Genotyping was done using 55 polymorphic primers with 184 F_2 individuals developed from a cross between BR11 x Sadamota (acc. no. 1576).

One QTL (q7.1 TSH) on chromosome 7 was identified for taller seedling height in rice (Figs. 2 and 3).

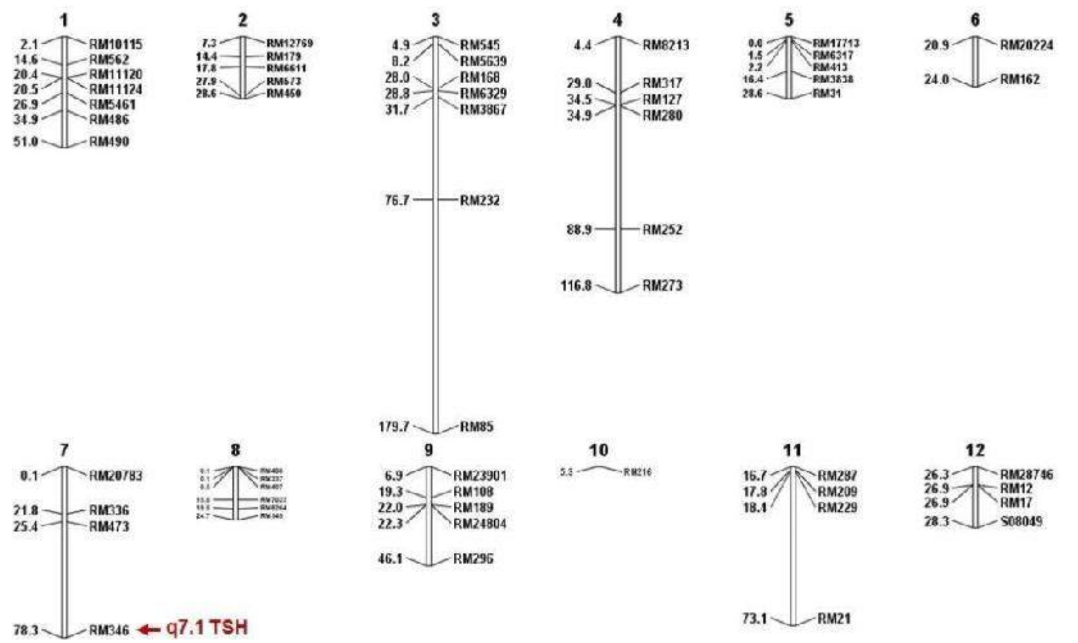
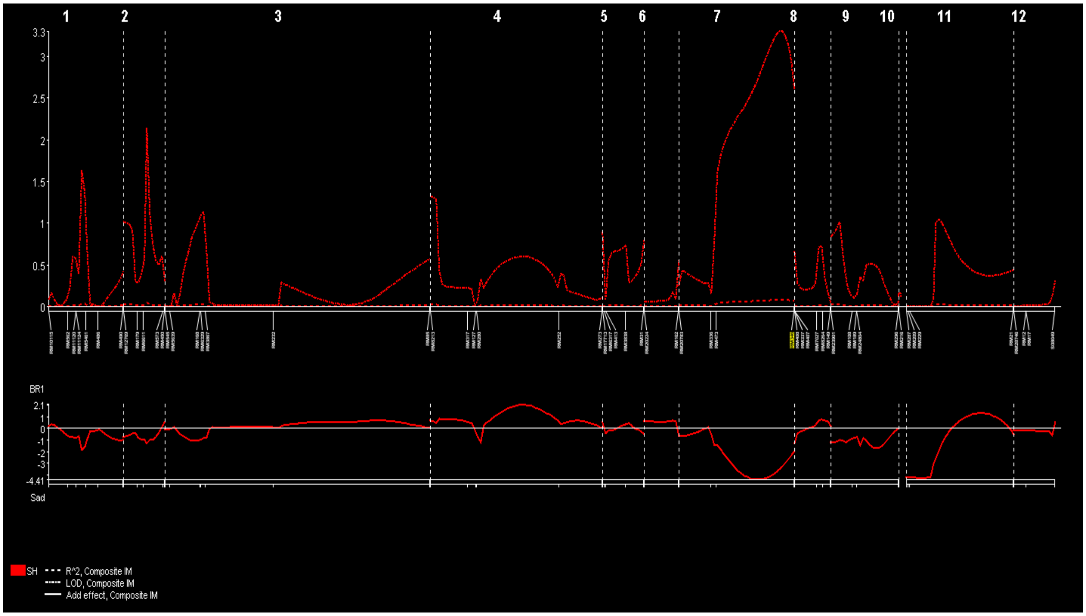


Fig. 2. A genetic linkage map of the 12 chromosomes of rice constructed based on selected individuals of F2 population of a cross between BR11/Sadamota. The map was constructed using 55 SSR markers.



Significant threshold level of LOD=3

Fig. 3. Chromosomal location of QTL q7.1 TSH for taller seedling height by CIM.

Investigators: Nilufar Yasmin Shaikh, Jannatul Ferdous, Md Arafat Hossain, S M Hisham Al-Rabbi and Md Enamul Hoque.

Marker assisted selection for fragrance in F_5 Population of BRRI dhan87 and Kalijira.

Seventy two pedigree lines developed from a cross between BRRI dhan87 and Kalijira were evaluated. Among them 107 plants were selected on the basis of aroma, growth duration and plant height. All the tested aromatic lines were confirmed by using functional marker of fragrance gene *BADH2* (Fig. 4). The primers combination of ESP and IFAP amplified the fragrance specific allele at 257 bp. On the other hand, the primers combination of INSP and EAP amplified the expected non-fragrance-specific allele (355 bp).

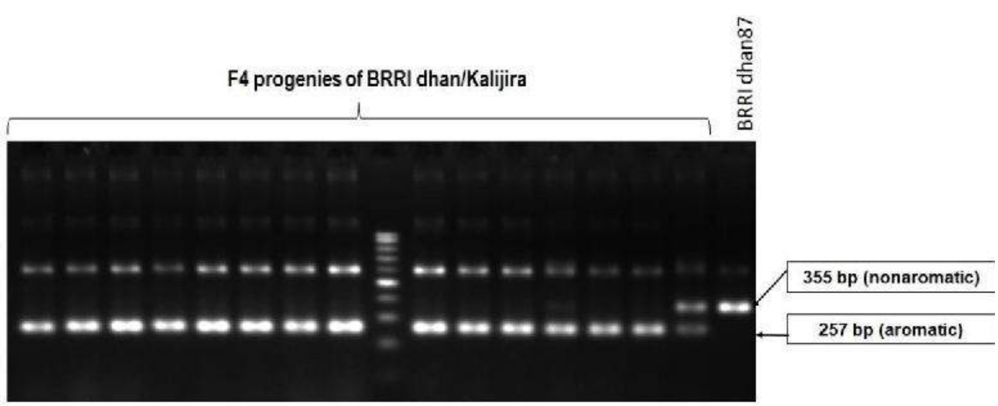


Fig. 4. Confirmation of F_4 progenies of BRRI dhan87/Kalijira with functional marker of *BADH2* gene.

Investigators: Jannatul Ferdous, S M Hisham Al-Rabbi and Md Enamul Hoque.

Marker assisted selection for aromatic and submergence tolerance rice genotype

Hybridization between BRRI dhan90/Kalijira and BRRI dhan52/Kalijira were done. Ninety-three and 185 F_1 seeds were harvested from BRRI dhan90/Kalijira and BRRI dhan52/Kalijira

Investigators: Jannatul Ferdous, Shahanaz Sultana and Md Enamul Hoque.

Development of multiple disease resistant (blast and bacterial blight) rice varieties using marker assisted selection

For both BB and blast resistant four crosses such as BR (Bio)11447-1-28-14-3/IR64Pi9 (L), BR (Bio)11447-1-28-14-3/IR64Pi9 (E), BR (Bio)11447-3-10-7-1/IR64Pi9 (L), BR (Bio)11447-3-10-7-1/IR64Pi9 (E) were made. A total of 28, 103, 90 and 28 F_1 seeds were harvested from four crosses respectively

Investigators: Jannatul Ferdous, Shahanaz Sultana, Md Enamul Hoque, Ashik Ikbal Khan.

Association mapping for rice photosensitivity

An association mapping panel of 147 was raised in two replications in short-day condition. Heading dates were scored for each.

Investigators: S M Hisam Al Rabbi, Md Arafat Hossain, Ripon Kumar Roy, Munnujan Khanam

Production of Transgenic Plants that are Resistant to Different Biotic and Abiotic Stresses

Development of salt tolerant transgenic rice

BRRI dhan29 was transformed with salt tolerant genes (*GlyI and GlyII).* After transformation with *GlyI and GlyII* genes, plants were confirmed by GlyI and GlyII primers and sequencing. Seed from 17 T_5 plants were harvested. Now these are growing in transgenic net house for further evaluation.

Investigators: Shahanaz Sultana, Jannatul Ferdous, Shampa Das Joya and Md Enamul Hoque

Introgression of salt tolerant mangrove gene

Transgenic plant containing mangrove salt tolerant gene *AeMDHAR* was crossed with BRRI dhan28 for the introgression of salt tolerant gene *AeMDHAR* . *AeMDHAR* salt tolerant gene (from mangrove plant) containing transgenic was crossed with BRRI dhan28 to introgress *AeMDHAR salt* tolerant gene. Three BC_2F_3 plants of BRRI dhan28 are now in in transgenic net house for further evaluation and confirm ation by gene specific primer.

Investigators: Shahanaz Sultana, Jannatul Ferdous, Shampa Das Joya and Md Enamul Hoque.

Development of salt tolerant transgenic rice with *PVA1*

A construct was made at Biotechnology Division of BRRI by using vacuolar ATPase (*PVA1*) from a wild rice. *Porteresia coarctata* to develop salt toleranted transgenic rice variety. Twenty-one day Old calii of BRRI dhan86 were used transform with *PcPVA1 through Agrobacterium.* Calli were co-cultured with *PVA1*

Investigators: Shahanaz Sultana, Jannatul Ferdous, Shampa Das Joya and Md Enamul Hoque.

Development of high yielding aromatic rice lines through genome editing

For deactivation of Function of *BADH2* gene, two primers were designed for construct preparation. Vector pRGEB31 was used in this experiment. DNA was extracted from pRGEB31. Both primer and vector pRGEB31 were digested with *Bsa1* and ligated for construct preparation

Investigators: Shahanaz Sultana, Jannatul Ferdous, S M Hisam Al Rabbi, Shampa Das Joya, Md Enamul Hoque, Hirendro Nath Barman

Isolation and cloning of stress tolerant gene from Wheat

cDNA was synthesized from RNA of wheat to isolate and clone heat and drought tolerant gene. *TaCRT* gene was isolated from wheat (Fig. 5) and send for sequencing

Investigators: Jannatul Ferdous, Shahanaz Sultana, Md. Enamul Hoque and Hisam Al Rabbi, Md Sentu Rahman, Sadia Jafrin

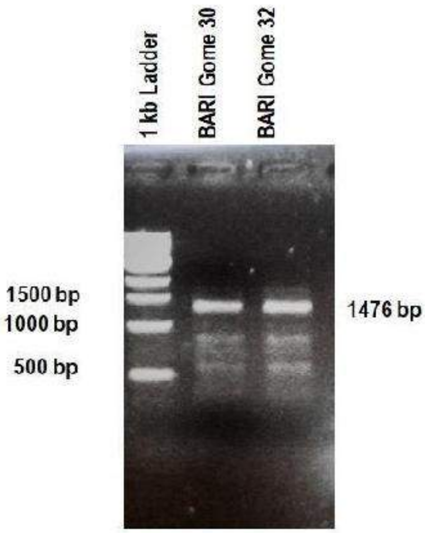


Fig. 5. Targeted T*aCRT* gene isolated from wheat.

Development of rice variety through mutation breeding

Development of variants using EMS of BRH-11-9-11-4-5B having reduced sterility

In total 500 BRH-11-9-11-4-5B seeds were treated with 20 mM EMS solution for six hrs to create variation. Six M_2 lines along with check were transplanted in Boro 2021-22 and 31 plants were selected for further evaluation

Investigators: Shahanaz Sultana, Md Enamul Hoque, Jannatul Ferdous.

Development of Kilijira type rice variety through mutation by NMU

Seed from 215 M_2 Kilizira lines were transplanted in T. Aman 2021. Seeds from 91 M_3 plants were harvested during T. Aman2021 for further evaluation.

Investigators: Shahanaz Sultana, Md Enamul Hoque, Jannatul Ferdous

Development of high yielding sheath blight resistant rice variety

During T. Aman 2021, 500 seeds of BRRI dhan87 were treated by 20 mM EMS solution for six hrs to create variation. Twenty-two M_2 plants were selected for further evaluation

Investigators: : Md Arafat Hossain, Md S M Hisam Al Rabbi, Shahanaz Sultana, Jannatul Ferdous, Md Enamul Hoque, Shamima Akter

Development of somaclonal variants of BR11 using EMS treaded rice seed

During Aus 2021, twenty fixed lines of EMS treated somaclonal variants of BR11 were grown as OT-1 with check variety BRRI dhan48. None of them was selected. During T. Aman 20 21, one OT as OT-4 was conducted with 20 fixed lines of EMS treated somaclonal variants of BR11 with the check variety BR11 and among them seven lines were selected for further evaluation. Besides, during T. Aman 2021, 116 pedigree lines were evaluated as pedigree. Fifty fixed lines were selected for further evaluation.

Table 10. Agronomic Characteristics of selected lines, OT. T Aman 2021.

	Designation	PH	GD	Yield t/ha
	T6-BR11-14-1-46-2	112	107	2.16
	T6-BR11-16-1-47-1			-
	T5-BR11-19-3-5-1	115	107	2.96
	T5-BR11-15-1-51-2	115	107	6.64
	T5-BR11-19-4-52-1	116	107	-
	T5-BR11-19-4-52-2	128	139	2.73
	T5-BR11-19-5-53-1	136	143	4.61
	T5-BR11-19-5-53-2	130	143	4.65
	T5-BR11-19-6-54-1	109	109	5.70
	T4-BR11-32-1-62-2	114	109	3.78
	T4-BR11-37-1-65-1	117	109	3.74
	T4-BR11-81-1-80-4	130	139	4.28

	T4-BR11-81-1-80-5	126	139	5.14
	T4-BR11-82-1-82-2	122	140	6.35
	T4-BR11-96-1-93-2	137	141	5.72
	T4-BR11-96-3-95-1	128	141	5.86
	T4-BR11-97-1-99-1	124	140	6.36
	T4-BR11-97-1-99-3	131	143	5.65
	T4-BR11-99-101-1	116	124	4.93
	T4-BR11-99-107-2	137	139	3.86
	BR11 (Ck)	122	143	4.58
	BRRI dhan87(Ck)	137	124	4.57

Fig. 6. Panicles of somaclonal variants of BR11.

Investigators: Shahanaz Sultana, Jannatul Ferdous and Md Enamul Hoque

INNOVATIVE RESEARCH

Identification of major regulators for C4 rice

Generation advancement for high-throughput screened for loss of C4 functions. A total of 7,000 M4 lines Kaoun (*Setaria italica*) have been developed for further study. These lines are gradually raised, subjected to CO2 stress in low concentration (20 ppm) CO2 chamber for 72 hours and high-throughput screened for loss of C4 functions.

Investigators: S M Hisam Al Rabbi, Shahanaz Sultana, Munnujan Khanam, Sazzadur Rahman, Md Enamul Hoque

BASIC RESEARCH

Study on Kernel Elongation of Rice

Fifty-seven selected genotypes were grown in T. Aman 2021 from single plant to make genetic purity. Purified seed from single hill were harvested

Investigators: Shahanaz Sultana, Jannatul Ferdous, Shampa Das Joya, Md Enamul Hoque, Habibul Bari Sojib

Variation of *BADH2* gene sequences in rice genotypes

DNA of seven aromatic and two non-aromatic rice were amplified with a functional marker of *BADH2* gene and sequenced. Multiple alignment of seven aromatic and two non-aromatic rice was done with functional *BADH2* gene. Eight bp deletion was observed in aromatic rice Kalijira, Radhunipagol, BR5, BRRI dhan34 and in BRRI dhan70, which is similar with Pakistani Basmati rice (Fig. 6). Interestingly, 8 bp deletion was not observed in Raniselut and Tulshimala indicating deletion of *BADH2* gene in some other location of the gene.

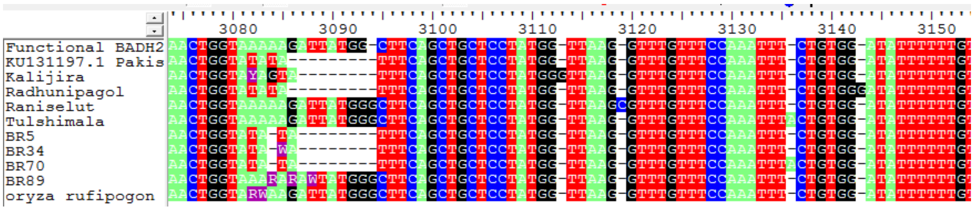


Fig. 6. Muliple alignment of *BADH2* gene sequence of aromatic and nonaromatic rice with reference sequence of functional *BADH2.*

Investigators: Jannatul Ferdous, Shahanaz Sultana, Md Enamul Hoque

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Sadia Jafrin, MS
Scientific Officer

Genetic Resources and Seed Division

SUMMARY

In total, 126 rice germplasm of which three in Aus, 20 *Jhum* rice, 38 in T. Aman and 65 in Boro seasons were collected from different districts of Bangladesh. One hundred and thirty-six germplasm accessions of which 28 germplasm in T. Aus 2020-21, 50 in T. Aman 2021-22 and 58 in Boro 2021-22 were morphologically characterized using 'Rice Germplasm Descriptors and Evaluation Form' of Genetic Resources and Seed Division (GRSD).

Rejuvenation of 2,848 accessions was completed of which 734 in T. Aus 2020-21, 1,440 in T. Aman 2021-22 and 674 in Boro 2021-22 seasons. A total of 2,119 accessions of which 700 in Aus 2020-21 and 1,419 in T. Aman 2021-22 were processed and stored in short-term storage. Similarly, 454 accessions of which 207 in Aus 2020-21 and 247 in T. Aman 2021-22 were processed and stored in medium and 287 accessions of which 78 in Aus 2020-21 and 209 in T. Aman 2021-22 seasons were processed and stored in long-term storages respectively. Apart from this, 41 new germplasm were registered as new accessions (from accession number 8,655 to 8,695) in BRRI Genebank. Besides, 2,399 samples of rice germplasm and BRRI developed varieties were supplied to 47 different users.

One hundred and sixteen BRRI developed and recommended rice varieties were maintained along with nucleus seed. Besides, nucleus seed stocks of 63 varieties were produced for the source of breeder seed. In total, 218.72 tons of breeder seed with tags of which 143.44 tons of 20 Boro varieties, 16.36 tons of ten Aus varieties and 58.92 tons of 35 T. Aman varieties were produced. At the same time, 198.994 tons of breeder seed of which 131.341 tons of 20 Boro varieties, 16.215 tons of ten Aus varieties and 51.438 tons of 34 T. Aman varieties were distributed among 718 partners (GO, NGO and PS) of BRRI 'Rice Seed Network'. Breeder and foundation seed producing plots and farms were also visited to observe the varietal purity and performance of respective seed.

RICE GERMPLASM CONSERVATION AND MANAGEMENT

Germplasm collection and acquisition. Three collection missions were made during the reporting year and 126 rice germplasm of which three in Aus, 20 *Jhum* rice, 38 in T. Aman and 65 in Boro seasons were collected from different districts of Bangladesh including hilly areas (Fig. 1).

PI: Mohammad Khalequzzaman and Mir Sharf Uddin Ahmed.

Fig. 1. Pictorial views of collecting rice germplasm from hilly areas of Bangladesh.

Germplasm rejuvenation for storage. Rice germplasm were rejuvenated to increase the seed for safe storage in the Genebank. The experiment was carried out under transplanted conditions using double rows of 5.4 m long per accession with 20 × 20 cm spacing between rows and plants respectively. Fertilizers were applied @ 60:20:40 kg NPK/ha in T. Aus and T. Aman and @ 80:20:40 kg NPK/ha in Boro seasons.

A total of 2,848 germplasm of which 734 accessions (between Acc. 6201 to 8600) in T. Aus 2020-21; 1,440 accessions (between Acc. 4001 to 6000) in T. Aman 2021-22 and 674 accessions (between Acc. 4601 to 8650) in Boro 2021-22 were rejuvenated in field for getting fresh seed and on average 500 g of seeds per accession were produced.

PI: Armin Bhuiya (T. Aus), Tonmoy Chakrabarty (T. Aman) and Md Humayun Kabir Baktiar (Boro).

Morphological characterization of germplasm. Three experiments were conducted to characterize 136 rice germplasm (accessions as well as new collections) of which 28 in T. Aus 2020-21, 50 in T. Aman 2021-22 and 58 in Boro 2021-22 through 52 agro-morphological traits (both 21 quantitative and 31 qualitative characters) using the Rice Germplasm Descriptors and Evaluation Form (2018), GRSD, BRRI, Gazipur. The experiments were conducted using a single row of 5.4 m long for each entry/accession with 25 × 20 cm spacing in T. Aman and 20 × 20 cm spacing in Boro between rows and plants respectively. Fertilizers were applied @ 60:20:40 kg NPK/ha in T. Aus and T. Aman and @ 80:20:40 kg NPK/ha in Boro seasons. Appropriate control measures were taken for insect, pests, diseases and weeds when necessary.

In T. Aus 2020-21, a total of 28 germplasm along with new collections were characterized. Among them, feight had short (<116 days), 13 had medium (116-131) and seven had long (>131) growth duration (Table 1). On the other hand, five germplasm had short (<90 days), 19 had medium (90-110) and four had long (>110) duration to the 50% flowering. In case of plant height, out of 28, eight germplasm were found with the shortest (<90 cm) and four with the longest (>130) height. Similarly, ten germplasm had very lowest (<4.08 mm) and seven possessed with the highest (>4.88 mm) culm diameter. Chakma Chikon and 576 possessed the lowest (3.50) and the highest (10) effective tiller number respectively. NBR9005-53-1-1 and PY84 possessed the lowest (2.70) and the highest (5.02) grain length breadth ratio respectively.

PI: Armin Bhuiya

In T. Aman 2021-22, all 50 NC germplasm were characterized. Among them, 10 had short (≤117 days), 12 had medium (118-125), 23 had moderate (126-133) and five had long (≥134) growth duration (Table 2). In case of plant height, out of 50, 12 germplasm were found with short (≤98 cm) and eight with long (≥135). Similarly for TGW, ten germplasm had very low (≤15 g) and two with high (≥28 g) grain weight at 14% moisture. Eleven germplasm had low (≤15 g/hill) and three possessed high yields (≥36 g) per hill. The shortest growth duration (110 days) was observed in FulKuri, Indian, BR10538-2-1-2-3-2. The shortest plant height (81.8 cm) was observed in the Indian and the longest (152.6 cm) in Kala Biruin. Debmoni had the highest (32 g) and Kala Biruin had the lowest (10 g) thousand grain weight (TGW). The highest yield per hill (42.18 g) was observed in BR10005-25-8-4-7-20. PI: Tonmoy Chakrabarty.

In Boro 2021-22, among the 58 germplasm accessions, one germplasm had short (<140 days), 33 had medium (140-150 days) and 24 had long (>150 days) growth duration (Table3). Similarly, nine germplasm were found with short (<110 cm), 44 medium (110-130 cm) and five with long (>130 cm) plant height. In case of panicle length, 14 germplasm had long (26-30 cm) panicle. For TGW, one germplasm had very low (≤15 g), 21 had high (24-27g) and four had very high (>27 g) TGW. For yield, 18 germplasm had higher (>20 g) yield per hill. The shortest growth duration (139 days) was observed in Habataki (Acc. 4190). The shortest plant height (70 cm) was observed in Habataki (Acc. 4190) and the longest (134 cm) in Muirol (Acc. 4014). GachiBoro (Acc. 4204) had the lowest (15.0 g) and Saita (Acc. 1794) had the highest (29.66 g) TGW. The highest yield per hill (28.42 g) was observed in GuchiBoro (Acc. 1796).

PI: Nashirum Monir.

Table 1. Some important features of characterized germplasm in T. Aus 2020-21.

Growth duration (day)		Plant height (cm)		Culm diameter (mm)		Total no. of tiller		No. of effective tiller		Grain LB ratio		Brown rice LB ratio		50% flowering (day)	
Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries
<116	8	<90	8	<4.08	10	<5	1	<5	2	<3.0	15	<2.0	1	<90	5
116-131	13	90-130	16	4.08-4.88	11	5-10	19	5-9	19	3.0-4.0	10	2.0-3.0	22	90-110	19

>131	7	>130	4	>4.88	7	>10	8	>9	7	>4.0	3	>3.0	5	>110	4
Shortest (102)	NC/25 (PY84)	Shortest (59.80)	NC/25 (PY84)	Shortest (3.28)	NC/25 (PY84)	Lowest (3.80)	NC/1 (Chakma Chikon)	Lowest (3.50)	NC/1 (Chakma Chikon)	Lowest (2.70)	NC/6 (NBR9005-53-1-1)	Lowest (1.66)	Acc. 4954 (BIR PALA-2)	Lowest (74)	NC/25 (PY84)
Longest (145)	NC/16 (Sundori Binni)	Longest (160.10)	Acc. 4944 (CN (Indian))	Longest (5.66)	NC/20 (My Wachha)	Highest (11.30)	NC/26 (576)	Highest (10)	NC/26 (576)	Highest (5.02)	NC/25 (PY84)	Highest (4.18)	NC/25 (PY84)	Highest (118)	NC/16 (Sundori Binni)
Mean	124.36		105.25		4.38		8.27		7.37		3.18		2.63		98.21
Std. Dev.	11.33		23.13		0.68		2.07		1.87		0.57		0.52		10.33
CV	9.11		21.97		15.55		25.08		25.44		17.91		19.95		10.52
LSD	4.20		8.57		0.25		0.77		0.69		0.21		0.19		3.83

Table 2. Some important features of characterized germplasm in T. Aman 2021-22.

Growth duration (day)		Days to 50% flowering		Plant height (cm)		Panicle length (cm)		No. of tiller		Filled grain/panicle		1000-grain weight (g)		Yield/hill (g)	
Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries
≤117	10	≤82	8	≤98	12	≤21	1	≤10	17	≤73	6	≤15	10	≤15	11
118-125	12	83-91	5	99-116	6	22-25	22	11-13	23	74-105	23	16-21	21	16-25	24
126-133	23	92-100	31	117-134	24	26-29	24	14-16	9	106-137	17	22-27	17	26-35	12
≥134	5	≥101	6	≥135	8	≥30	3	≥17	1	≥138	4	≥28	2	≥36	3
Shortest (110)	FulKuri, Indian, BR10538-2-1-2-3-2	Shortest (74)	BR-H15-24-7-B, BR14-9-13-16-B	Shortest (81.80)	Indian	Shortest (19.73)	Indian	Lowest (8.00)	Debmoni, Borodigha, FulKuri	Lowest (41.60)	Borodigha	Lowest (10.00)	Kala Biruin	Lowest (5.98)	Borodigha

Longest	(141)	Black Rice	Longest (108)	Black Rice	Longest (152.60)	Kala Biruin	Longest (32.20)	Kala Biruin	Highest (17.00)	Gandi Shail	Highest (167.80)	Pani Biruin	Highest (32.00)	Debmoni	Highest (42.18)	BR10005-25-8-4-7-20
Mean	123.88		94.42		118.20		25.88		11.72		101.18		19.76		21.68	
S. Dev.	7.52		8.24		19.67		2.70		2.22		27.45		5.00		7.58	
CV	5.6		6.9		14.3		14.9		24.9		39.8		15.0		53.4	
LSD	2.08		2.28		5.45		0.75		0.62		7.61		1.39		2.10	

Table 3. Some important features of characterized germplasm in Boro 2020-21.

Growth duration (day)		Plant height (cm)		Panicle length (cm)		No. of tiller		No. of effective tiller		Grain LB ratio		1000-grain weight (g)		Yield/hill (g)	
Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries	Range	No. of entries
<140	1	<110	9	≤20	1	<10	11	<6	1	<1.1	0	≤15	1	<10	1
140-150	33	110-130	44	21-25	43	10-15	47	6-10	54	1.1-2.0	0	16-19	5	10-20	39
>150	24	>130	5	26-30	14	>15	0	>10	3	2.1-3.0	49	20-23	27	>20	18
				>30						>3.0	9	24-27	21		
												>27	4		
Shortest (139)	Habataki (Acc. 4190)	Shortest (70)	Habataki (Acc. 4190)	Shortest (20)	Tulsi Boro (Acc. 1968)	Lowest (6)	Habataki (Acc. 4190)	Lowest 5	Habataki (Acc. 4190)	Lowest (2.15)	Lali Boro (Acc. 4210)	Lowest (15)	Gachi Boro (Acc. 4204)	Lowest (8.96)	Bash Boro (Acc. 1818)
Longest (160)	Iratom, LalDhan (Acc. 4201, 4211)	Longest (134)	Muirol (Acc. 4014)	Longest (29)	Raj Bhog (Acc. 4216)	Highest (12)	Pankaij, Rata Topa, KhairaBoro (Acc. 1817, 4016, 4207)	Highest (11)	Pankaij, Rata Topa, KhairaBoro (Acc. 1817, 4016, 4207)	Highest (4.38)	Super Fast (Acc. 4367)	Highest (29.66)	Saita (Acc. 1794)	Highest (28.42)	Guchi Boro (Acc. 1796)
Mean	150.19		117.12		24.12		10.31		9.28		2.76		22.84		18.11
S. Dev.	4.92		16.70		2.09		1.08		1.09		0.38		2.95		4.91
CV	3.27		14.26		8.69		10.47		11.74		13.67		12.92		27.11
LSD	1.27		4.30		0.54		0.28		0.28		0.10		0.76		1.26

Germplasm processing, registration and storage. In total 2,860 germplasm were processed and conserved with respective accession number in different storages of BRRI Genebank during the reporting year. The germplasm were cleaned and dried with a seed moisture content of less than 9% for short-term storage.

In details, 2,119 accessions of which 700 in Aus 2020-21 and 1,419 in T. Aman 2021-22 were processed and stored in short-term storage. Similarly, 454 accessions of which 207 in Aus 2020-21 and 247 in T. Aman 2021-22 were processed and stored in medium and 287 accessions of which 78 in Aus 2020-21 and 209 in T. Aman 2021-22 seasons were processed and stored in long-term storages respectively. Therefore, 985 accessions in Aus 2020-21 and 1,875 in T. Aman 2021-22 seasons were processed and stored. Apart from this, 41 new germplasm were registered as new accessions (from accession number 8,655 to 8,695) in BRRI Genebank during 2021-22.

Viability testing, periodic evaluation and routine monitoring of stored germplasm. The seed viability of the stored germplasm in short-term storage of BRRI Genebank was monitored from randomly selected germplasm in three seasons. One hundred and fifteen accessions in Aus, 175 in T. Aman and 110 in Boro seasons were checked and monitored randomly for viability (germination %) test in short-term storage. Among the randomly selected 400 stored germplasm, 191 had viability between 80-90% and 172 had above 90%. Viability was also monitored in mid and long-terms storage using five tester varieties namely Dharial (Acc. no. 649), Hashikalmi (Acc. 3575), Purbachi (Acc. 6207), Nizersail (Acc.1229) and Patnai-23 (Acc. 52.) to predict the viability of germplasm in respective storages. The viability was measured on six month interval usually on October and March of each year. The germination percentages of the five test samples/testers in the medium-term storages were found ranging from 79 to 92% in October 2021 and 82 to 94% in March 2022. Similarly, the germination percentages of the test samples/testers in the long-term storages were found ranging from 83 to 95% in October 2021 and 79 to 95% in March 2022. The germination percentages of the five test samples/testers indicating the probable viability condition of stored germplasm in respective storages.

The seed viability of the germplasm just before storage in the Genebank was also monitored. The germination tests of 410 germplasm just before short-term storage were carried out of which 110 were for Aus, 200 were for T. Aman and 100 were for Boro seasons. Among them, 226 had germination between 80-90% and 140 had above 90%. The germplasm that possessed less than 80% germination will be grown again in the following season for safe keeping.

Germplasm distribution and exchange. A total of 2,399 samples were supplied to 47 different users in the reporting year. Among the samples, 1,946 germplasm accessions were supplied for research purpose and 453 samples of BRRI developed rice varieties were supplied to the researchers, Department of Agricultural Extension (DAE) personnel and university students for research, demonstration as well as other purposes.

PI: Mohammad Khalequzzaman and Mir Sharf Uddin Ahmed.

SEED PRODUCTION AND VARIETY MAINTENANCE

Variety maintenance and nucleus seed production. One hundred and sixteen BRRI developed and recommended rice varieties including 16 locally improved varieties (LIVs) were maintained using panicle to row method, implementing time isolation and performing thorough roguing (Table 4). After harvest, both the intact panicles and nucleus seed of each variety were stored (20°C with 40% RH) for variety maintenance and distribution to researchers, DAE personnel and students respectively.

PI: Ebna Syod Md Harunur Rashid (T. Aman) and Mir Sharf Uddin Ahmed (Boro) for BRRI varieties and Tonmoy Chakrabarty (T. Aman) and Mir Sharf Uddin ahmed (Boro) for LIVs.

Table 4. List of BRRI developed and recommended rice varieties maintained during 2021-22.

Season	Type	Number	Variety
T. Aman	MV	55	IR64, BR4, BR5, BR10, BR11, BR21, BR22, BR23, BR24, BR25, BRRI dhan27, BRRI dhan30, BRRI dhan31, BRRI dhan32, BRRI dhan33, BRRI dhan34, BRRI dhan37, BRRI dhan38, BRRI dhan39, BRRI dhan40, BRRI dhan41, BRRI dhan42, BRRI dhan43, BRRI dhan44, BRRI dhan46, BRRI dhan48, BRRI dhan49, BRRI dhan51, BRRI dhan52, BRRI dhan53, BRRI dhan54, BRRI dhan56, BRRI dhan57, BRRI dhan62, BRRI dhan66, BRRI dhan70, BRRI dhan71, BRRI dhan72, BRRI dhan73, BRRI dhan75, BRRI dhan76, BRRI dhan77, BRRI dhan78, BRRI dhan79, BRRI dhan80, BRRI dhan82, BRRI dhan83, BRRI dhan85, BRRI dhan87, BRRI dhan90, BRRI dhan91, BRRI dhan93, BRRI dhan94, BRRI dhan95, BRRI dhan98
	LIV	10	Nizersail, Latisail, Rajasail, Kalijira, Kataribhog, Basmati-D, Patnai23, Tilockkachari, DA29, DA31
Boro	MV	45	BR1, BR2, BR3, BR6, BR7, BR8, BR9, BR12, BR14, BR15, BR16, BR17, BR18, BR19, BR26, BRRI dhan28, BRRI dhan29, BRRI dhan35, BRRI dhan36, BRRI dhan45, BRRI dhan47, BRRI dhan50, BRRI dhan55, BRRI dhan58, BRRI dhan59, BRRI dhan60, BRRI dhan61, BRRI dhan63, BRRI dhan64, BRRI dhan65, BRRI dhan67, BRRI dhan68, BRRI dhan69, BRRI dhan74, BRRI dhan81, BRRI dhan84, BRRI dhan86, BRRI dhan88, BRRI dhan89, BRRI dhan92, BRRI dhan96, BRRI dhan97, BRRI dhan98, BRRI dhan99, Bangabandhu dhan100
	LIV	6	Hbj Boro II, Hbj Boro IV, Hbj Boro VI, Hbj Boro VIII, Purbachi, IR8
Total		116	

Nucleus seed stock production. Sixty-three BRRI developed rice varieties of which 42 in T. Aman and 21 in Boro were grown following panicle to row method to produce nucleus seed stocks for breeder seed (BS) production. The objective for nucleus seed production was to maintain genetic purity and homogeneity of morphological characteristics of a variety and subsequently breeder seed production.

'Panicle to row' method was used to maintain nucleus stocks, where intact panicles were sown instead of threshed seeds. If off-type plants were identified in a row then whole row was discarded or rogued out for variety maintenance. At maturity, panicles from 'true to type' plants of all the varieties were harvested and both intact panicles for BRRI HQ, Gazipur and nucleus seed stocks for BRRI regional stations were stored in controlled temperature (20°C with 40% RH).

Breeder seed production and distribution. GRS Division, Farm Management Division and nine regional stations of BRRI were engaged in breeder seed production as per national demand. The BS plots were visited to monitor the varietal purity and performances. Off-type plants were identified and rogued out in every growth stage. After harvesting of a variety, the seeds were separately threshed, dried, cleaned and stored in controlled temperature (20°C with about 40% RH) at BRRI HQ, Gazipur. The harvested seeds then offered as seed lot for getting 'tag' from Seed Certification Agency (SCA) which is required for distribution.

A total of 218.72 tons of breeder seed with tags of which 143.44 tons of 20 Boro varieties, 16.36 tons of ten Aus varieties and 58.92 tons of 35 T. Aman varieties were produced during 2021-22 (Tables 5, 6 and 7). At the same time, 198.994 tons of breeder seed of which 131.341 tons of 20 Boro varieties, 16.215 tons of ten Aus varieties and 51.438 tons of 34 T. Aman varieties were distributed among 718 partners (GO, NGO and PS) of BRRI 'Rice Seed Network'. Breeder and foundation seed producing plots and farms were also visited to observe the varietal purity and performance of respective seed.

PI: Md Adil Badshah (T. Aman) and Ebna Syod Md Harunur Rashid (Boro).

Table 5. Production and distribution of rice breeder seed for Boro 2021-22.

Variety	Production(with tag)		Distribution	
	Favourable variety (kg)	Stress tolerant variety (kg)	Favourable variety (kg)	Stress tolerant variety (kg)
BR14	160		130	
BR16	440		445	
BR26	1470		1470	
BRRI dhan28	29360		28121	
BRRI dhan29	19660		19734	
BRRI dhan36		160		120
BRRI dhan47		1140		951
BRRI dhan50	3910		3229	
BRRI dhan58	9010		7247	
BRRI dhan63	4620		3666	
BRRI dhan67		5900		5281
BRRI dhan74	7520		7547	
BRRI dhan81	5950		5507	
BRRI dhan84	10000		8086	
BRRI dhan88	2800		2854	
BRRI dhan89	23370		20907	
BRRI dhan92	17530		15621	
BRRI dhan96	120		130	
BRRI dhan97		220		190
Bangabandhu dhan100	100		105	
Total	**136,020**	**7,420**	**124,799**	**6,542**
Grand Total	**143,440**		**131,341**	

Table 6. Production and distribution of rice breeder seed for Aus 2021-22.

Variety	Production (with tag) (kg)	Distribution (kg)
BR14	30	0
BR26	110	110
BRRI dhan42	90	30
BRRI dhan 43	60	10
BRRI dhan 48	4510	4535
BRRI dhan 65	190	60
BRRI dhan 82	5130	5230
BRRI dhan 83	70	70
BRRI dhan85	80	80
BRRI dhan98	6090	6090
Total	**16,360**	**16,215**

Table 7. Production and distribution of rice breeder seed for T. Aman 2021-22.

Variety	Production (with tag)		Distribution	
	Favourable variety (kg)	Stress tolerant variety (kg)	Favourable variety (kg)	Stress tolerant variety (kg)
BR10	1250		1250	
BR11	3700		3700	
BR22	120		120	
BR23	3530		3225	
BRRI dhan30	780		730	
BRRI dhan32	300		290	
BRRI dhan33	510		500	
BRRI dhan34	3180		3150	
BRRI dhan39	210		210	
BRRI dhan41		30		30
BRRI dhan44	20		10	

BRRI dhan46	70		70	
BRRI dhan49	15870		14382	
BRRI dhan51		2010		2000
BRRI dhan52		3870		3690
BRRI dhan56		120		88
BRRI dhan57		50		45
BRRI dhan62	190		197	
BRRI dhan66		40		0
BRRI dhan70	50		37	
BRRI dhan71		530		542
BRRI dhan72	1880		250	
BRRI dhan73		80		80
BRRI dhan75	2830		2877	
BRRI dhan76	2170		2161	
BRRI dhan77	800		801	
BRRI dhan78		60		60
BRRI dhan80	420		250	
BRRI dhan87	12460		8879	
BRRI dhan90	240		272	
BRRI dhan91		30		20
BRRI dhan93	440		430	
BRRI dhan94	420		420	
BRRI dhan95	510		522	
Nizersail	150		150	
Total	52,100	6,820	44,883	6,555
Grand total	58,920		51,438	

Sending SMS to SeedNet partners for breeder seed distribution. Text message (SMS) with variety name and allotted quantity of breeder seed were sent through mobile apps to 10, 8 and 170 partners before Boro 2021-22, Aus 2022 and T. Aman 2022 seasons, respectively for distributing breeder seed through BRRI 'Rice Seed Network'.

PI: Armin Bhuiya.

Monitoring seed production plots and farms. Breeder seed production plots of BRRI regional stations (RSs) at Cumilla, Sonagazi, Sirajganj, Kushtia, Rajshahi and Bhanga along with foundation seed production farm of BADC at Dinajpur, Chuadanga, Jhenaidah and Meherpur were visited. During the visit, no major insect-pest damage, varietal impurity (<1%) and no obnoxious weeds were observed. Isolation distances and crop conditions were satisfactory. The seed producers were advised for thorough roguing by themselves for one more time before harvesting.

PI: Mir Sharf Uddin Ahmed.

EXPLORATORY AND GENETIC STUDIES

Regional yield trial (RYT) of Balam rice germplasm. Balam (Acc. 516) and Jesso-Balam TAPL (Acc. 2472, 2473) along with BRRI dhan80 as the standard check variety were evaluated at BRRI HQ, Gazipur and BRRI RS, Barishal during T. Aman 2021-22. The highest panicle length (29.9 cm) and plant height (150.7 cm) were observed in Balam (Acc. 516). The highest grain yield from 6 sq. m plot was observed in Balam (Acc. 516) as 4.0 t ha^{-1}, which was significantly different from the check. Therefore, acc. 516 along with BRRI dhan80 will be evaluated at BRRI HQ, Gazipur and BRRI RS, Barishal in T. Aman 2022-23 as regional yield trial (RYT).

PI: Mir Sharf Uddin Ahmed.

Regional yield trial (RYT) of Sada Mota and Lal Mota rice germplasm. Sada Mota (Acc. 7888) and Lal Mota (Acc. 7889) along with BRRI dhan77 as standard check were evaluated at BRRI HQ, Gazipur and BRRI RS, Barishal during T. Aman 2021-22. The highest panicle length was found as 27.2 cm in BRRI dhan77, followed by 23.5 in Sada Mota (Acc. 7888) and 23.2 cm in Lal Mota (Acc. 7889) (Table 8). The highest grain yield from 6 sq. m plot was observed in BRRI dhan77 and Sada Mota (Acc. 7888) as 4.0 t ha^{-1}, followed by 3.4 t ha^{-1} in J Lal Mota (Acc. 7889). Therefore, acc. 7888 along with BRRI dhan77 will be evaluated at BRRI HQ, Gazipur and BRRI RS Barishal in T. Aman 2022-23 as RYT.

PI: Mir Sharf Uddin Ahmed.

Table 8. Agronomic performances of Sada and Lal Mota rice germplasm from RYT, T. Aman 2021-22.

Name	Acc. no.	Panicle length (cm)	Plant height (cm)	Growth duration	1000-garin weight (g)	Yield/ plot (g) at 14%	Yield/ hill (g)	Yield (ton/ha)
Sada Mota	7888	23.5	140.4	156	30.0	4322.2	35.0	4.0
Lal Mota	7889	23.2	144.1	153	31.2	3629.9	29.5	3.4
BRRI dhan77	--	27.2	129.9	139	23.7	4274.1	35.3	4.0
Mean		24.6	138.2	149	28.3	3629.9	29.5	3.4
Std. Dev.		2.2	7.4	9.3	4.0	4075.4	33.3	3.8
CV		9.1	5.3	6.2	14.3	386.6	3.3	0.4
LSD (0.05)		1.9	6.5	8.2	3.5	9.5	9.9	9.5

Secondary yield trial (SYT) of aromatic rice germplasm. The best yield performing eight aromatic rice germplasms (Chinigura, Chinisail, Chiniatop, Khatobabu, Subal lota, Kalijira, Dudhsail, Ranisalute and Radhunipagol) from the last three years' experiments along with BRRI dhan34 as standard check were evaluated at BRRI Gazipur as SYT. Table 9 presents the detailed yield performance of the germplasm for the studied parameter. The highest grain yield (2.5 t ha^{-1}) was observed in Chinisail, Subal Lata and BRRI dhan34, followed by 2.4 t ha^{-1} in Khatobabu and Ranisalute, 2.2 t ha^{-1} in Chinigura and Dudsail.

PI: Armin Bhuiya.

Table 9. Performance of nine aromatic rice germplasm for various yield contributing traits.

Acc. no.	Germplasm	GD (day)	Yield (t ha^{-1})
4867	Chinigura	119	2.2
7343	Chinisail	114	2.5
5093	Chiniatop	121	0.8
8675	Khatobabu	101	2.4
7680	Subal Lata	102	2.5
247	Kalijira	119	1.8
4840	Dudsail	127	2.2
5286	Ranisalute	134	2.4
6711	Radhunipagal	114	1.5
Check	BRRI dhan34	125	2.5

DNA finger printing of Kalijira rice germplasm. Forty-eight Kalijira accessions were studied using 59 SSR markers for all 12 chromosomes. Among the 59 primers, three primers (RM273, RM223 and RM282) were used for evaluating aroma and four primers (RM170, RM190, RM253 and RM314) were used for evaluating amylose. Figure 2 presents the DNA profiles of 42 Kalijira accessions with SSR marker RM209.

PI: Armin Bhuiya.

Legend: L=Ladder, 1=Kalijira (3) (Acc.247), 2=Kalajira (305), 3=Kaliajira (607), 4=Kalijira (2) (856), 5=Kalijira (3) (857), 6=Kalijira (858), 7=Kalajira (971), 8=Kalojira (2) (1129), 9=Kalojira (1130), 10=Kalojira (1303), 11=Kali Zira (1589), 12=Kaliajira (1937), 13=Kalijira Tapl-64 (2492), 14=Kalijira Tapl-65 (2493), 15=Kalijira Tapl-66 (2494), 16=Kalijira Tapl-67 (2495), 17=Kalijira Tapl-68 (2496), 18=Kalijira Tapl-70(2497),19=Kalijira Tapl-71 (2498), 20=Kalijira Tapl-72 (2499), 21=Kalijira Tapl-73 (2500), 22=Kalijira Tapl-74 (2501), 23=Kalijira (3200), 24=Kalijira (3429), 25=Kalijira (Short Gracn) (4357), 26=Kalikira (Hong Grain) (4358), 27=Kalijira (Short Gracn) (4359), 28=Kaliajira (4540), 29=Kalijira (4755), 30=Kalijira (4814), 31=Kalijira (Finer) (4815), 32=Kalijira (4820), 33=Kalijira (4832), 34=Kalijira (4862), 35=Kalijira (4872), 36=Kali Jira (7066), 37=Kali Jira (7073), 38=Kalojira (7290), 39=Kalijira (7505), 40=Kalijira (Lal) (7551), 41=Kalojira (7879), 42=Kali Jira (7945).

Fig. 2. DNA profile of 42 Kalijira accessions with SSR marker RM209.

Evaluation of photosensitive rice germplasm collected from northern districts. A total of 13 photosensitive germplasm along with three checks were grown late (transplanting 15 September) in T. Aman season to identify germplasm suitable for late transplanting after flood in northern region of Bangladesh (Bogura, Kurigram, Lalmonirhat, Gaibandha, Rangpur and Jamalpur). One Malshira, one Bindi Pakri accession and Indur Sail showed better performance on the basis of their morpho-agronomic traits among the tested entries (Table 10). Grain weights per hill of Malshira (Acc. 545), Bindi Pakri (Acc. 4810) and Indur Sail (Acc. 3661) germplasm were 22.97 g, 22.54 g and 20.16 g, respectively. Longer panicle length (27 to 28 cm), higher number of filled grain per panicle (98 to 122) and medium growth duration (122 to 127 days) were observed in selected three local germplasm and will be tested further in Rangpur region in the next T. Aman 2022.

PI: Ebna Syod Md. Harunur Rashid.

Table 10. Performance of ten photosensitive T. Aman rice germplasm from BRRI Genebank.

Name	Acc. no.	Effective Tiller per hill	Culm length (cm)	Panicle length (cm)	Days to maturity	TGW (g)	Filled grain/ panicle	Unfilled grain/ panicle	Grain weight / hill	Decort grain length (mm)	Decort grain breadth (mm)	L/B ratio
Mal Shira	545	11	101.2	27	127	19	122	17	22.97	5.52	2.02	2.73
Mal Shira	299	10	95	27.6	127	19	107	10	13.02	6.09	2.24	2.72
Mal Shira	360	11	93	24	127	22	80	17	13.96	6.08	2.25	2.70
Ganjia	287	10	98.8	28.8	139	16	75	20	12.44	5.17	1.87	2.76
Ganjia	520	11	102	27.6	134	17	98	18	13.38	5.69	1.93	2.95
Ganjia	531	10	101.6	27.6	134	16	103	13	14.94	5.58	2.19	2.19
Bindi Pakri	285	10	101.2	29.2	125	17	93	15	11.49	5.46	1.81	3.02
Bindi Pakri	4810	10	102.8	28	127	19	103	13	22.54	5.47	2.19	2.50
Indur Sail	3661	10	105.2	27	122	19	98	10	20.16	5.56	2.31	2.41
Joy Shail	5969	9	102	27.6	121	21	122	14	15.92	5.71	2.27	2.52
BR22 (ck)		10	83.2	26.6	140	21	101	10	17.92	5.65	2.32	2.44
BR23 (ck)		9	75.2	27.6	140	25	92	15	16.90	6.85	2.36	2.90
Nizersail(ck)		10	103.4	28.4	139	18	123	18	19.20	6.1	2.28	2.68
Mean		10.07	97.28	27.46	130.92	19.15	101.32	14.72	16.53	5.76	2.16	2.65
Std. Dev.		0.47	8.83	1.27	7.01	2.58	14.84	3.38	3.80	0.43	0.18	0.24
CV		4.71	9.08	4.61	5.35	13.45	14.65	22.96	17.03	7.41	8.57	8.92
LSD (0.05)		0.35	6.23	0.89	4.94	1.82	10.47	2.38	2.10			

Characterization of similar named Banshful group of rice germplasm. Twenty-eight similar named Banshful group of rice germplasm were characterized through 33 qualitative agro-morphological traits for developing core collections in T. Aman 2021-22 at BRRI HQ, Gazipur. The experiments were conducted using a single row of 5.4 m long for each entry with 20 × 20 cm spacing between rows and plants respectively in RCBD with three replications. Fertilizers were applied @ 60:20:40 kg NPK/ha. Appropriate control measures were taken for insect, pests, diseases and weeds when necessary. The frequency distributions of 31 main characters revealed that seven main characters had no variation and five main characters were most diversified and further divided into more than three sub characters. Moreover, 13 sub characters were most dominated (more than 72% of the total frequency) and 27 sub characters had the rare genotypes (less than 8% frequency).

Identification and selection of sticky rice from *Jhum* rice germplasm. Fifty-six *Jhum* rice germplasm were characterized to study the selection criteria in Aus 2020-21. The highest grain yield/hill (31.52 g) was observed in Katak Tara, followed by 28.11 g in BR 84-4-1-2-P2, 27.02 g in Guri Galon, 25.69 g in BR 8781-16-1-3-P2, 25.14 g in Galong and the lowest (7.8 g) in Parangi (Table 11).

PI: Armin Bhuiya.

Table 11. Mean performance of 28 Jhum germplasm for growth duration and yield.

Acc. no.	Variety	Growth duration (day)	Yield/hill (g) @14%M
4928	Koisramuri	123	17.18
4936	Katak Tara	124	31.52
4940	Kalo Soti	115	14.25
4944	CN (Indian)	132	17.55
4946	Lota Bhog	131	13.13
4948	Nuncha	134	12.37
4954	Bir Pala -2	115	8.93
4975	MTD 7029	132	23.92
5020	Aus Dhan	122	22.40
5021	IET -4049	127	11.42
N/C/1(809)	Chakma Chikon	124	9.14
N/C/2(445)	Parangi	115	8.41
N/C/3(450)	76 Dhan	130	9.81
N/C/4(452)	Parangi	121	7.80
N/C/5(480)	Parangi	120	22.59
N/C/6(400)	NBR 9005-53-1-1	120	24.90
N/C/7(401)	NBR 9006-40-2-3-1	121	20.46
N/C/8(402)	BR 84-4-1-2-P2	133	28.11
N/C/9(403)	BR 8781-16-1-3-P2	146	25.69
N/C/10(1)	Boushakhi Aus/20	131	21.93
N/C/11(2)	Guri Galon	130	27.02
N/C/16 (7)	Sundori Binni	146	24.03
N/C/17 (8	Bojha Dhan	141	12.45
N/C/18 (9)	Hamarong Dhan	139	20.25
N/C/19 (10)	Galong	143	25.14
N/C/20 (11)	My Wachha	115	22.84
N/C/25 (16)	PY84	102	14.29
N/C/26 (17)	576	121	16.13
	CV%	8	37.36
	LSD	4	2.54
	Max	146	31.52
	Min	102	7.80

Dormancy and storage ability of newly released BRRI rice varieties. Freshly harvested 13 new BRRI released rice varieties of T. Aman season (Fig. 3) were tested for germination to check the dormancy and storage ability. After sun-drying and grading, the seeds (<12% moisture) of all the varieties were stored at 20˚C in 50% RH. One hundred healthy seeds were set in each Petri dish in three replications. Germination data were collected starting from 20 December 2021 and continued with maintaining a 15 days interval from the initial date of storage.

No dormancy period was observed in any of the studied varieties (Fig. 3). Over all, the germination percent decreased over the time. But BRRI dhan77, BRRI dhan82, BRRI dhan85, BRRI dhan87, BRRI dhan91 and BRRI dhan94 continued with 100% germination rate up to interval 6. The experiment needs to continue for another six months with maintaining a 15 days interval for making conclusion.

PI: Tonmoy Chakrabarty.

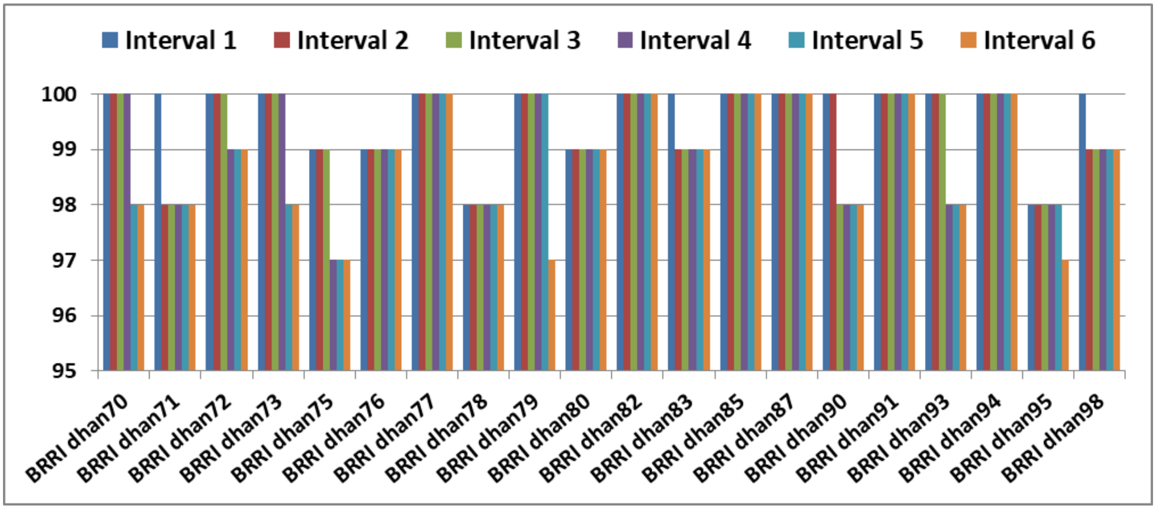
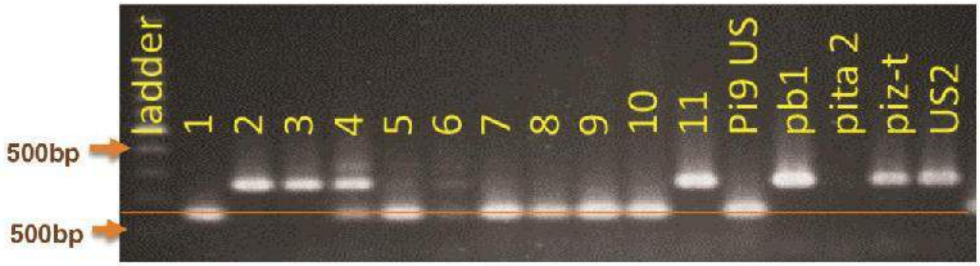


Fig. 3. Bar diagram of germination fluctuations of stored BRRI developed varieties.

Conformation of selected blast resistant materials using blast isolates and molecular markers.

A total of 303 rice germplasm were first screened against two blast isolates along with their morphological characterization and 117 genotypes were selected. Then, selected 117 genotypes were again screened against seven SDBIs (Standard differential blast isolates) and 11 genotypes were selected. Finally, DNA finger printings of selected 11 genotypes with linked markers were completed. The result revealed that nine genotypes contained *Piz*-t gene but genotype "Duria Sashpai" and "Lara" contained all of the target genes (*Pi9*, *Pb1* and *Piz*-t). Genotypes Beti Chikon, Voratain, Dingamoni and Holde Barud possessed *Pi9* and *Piz*-t genes, whereas genotypes Lal Jamai Babu, Bowaldar and Kambui possessed *Pb1* and *Piz*-t genes only (Fig. 4, 5 and 6).

PI: Md. Humayun Kabir Baktiar.



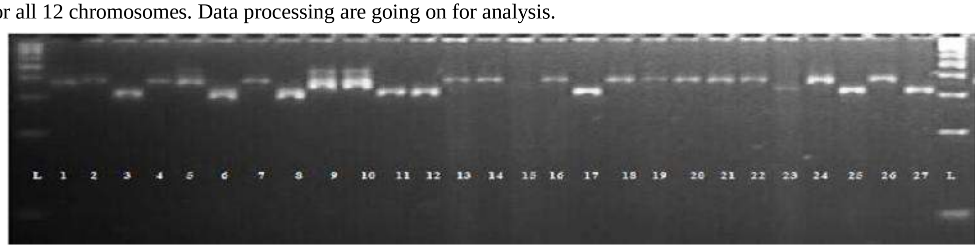
Legend: The numeric numper stpresents, 1= BetiChikon, 2= LalJamaiBabu, 3 = SadaJamaiBabu, 4 = PartikiDhan, 5 = Voratain, 6 = Bowaldar, 7 = DingaMoni, 8 = DuriaSashpai, 9 = HoldeBarud, 10 = Lara, 11= Kambui, Pi9 US = monogenic line IRBL9-W for Pi9 gene, Pb1= monogenic line Pb-1 (BD64) for Pb-1 gene, Pita-2 = monogenic line IRBLta2-Pi(LT) for pita-2 gene and Piz- t = monogenic line IRBLzt-T for Piz-t gene.

Fig. 4. DNA profile of selected 11 genotypes using Pi9 gene-specific marker NMSMPi9.

Fig. 5. DNA profile of selected 11 genotypes using Pb1 gene-specific marker RM206.

Fig. 6. DNA profile of selected 11 genotypes using Piz-t gene-specific marker RM1359.

DNA finger printing of latest BRRI varieties. A total of 27 BRRI varieties has been studied (Fig. 7) with about 50 polymorphic primers for all 12 chromosomes. Data processing are going on for analysis.



Legend: L:Ladder, 1:BRRI dhan74, 2:BRRI dhan75, 3:BRRI dhan76 : BRRI dhan77, 5: BRRI dhan78, 6: BRRI dhan79, 7: BRRI dhan80, 8:BRRI dhan81 , 9:BRRI dhan82, 10: BRRI dhan83, 11: BRRI dhan84, 12: BRRI dhan85, 13: BRRI dhan86, 14: BRRI dhan87, 15:BRRI dhan88, 16: BRRI dhan89, 17: BRRI dhan90, 18: BRRI dhan91, 19: BRRI dhan92, 20: BRRI dhan93, 21: BRRI dhan94, 22: BRRI dhan95, 23: BRRI dhan96, 24: BRRI dhan97, 25: BRRI dhan98, 26: BRRI dhan99, 27: Bangabandhu dhan100

Fig. 7. DNA profile of 27 BRRI varities with SSR marker RM 12.

Grain Quality and Nutrition Division

SUMMARY

A total of 359 breeding lines were analyzed and among them 88 had more than 70% milling outturn, 38 had more than 60% head rice recovery, 10 have shown translucent (Tr) grain, five had Extra and 175 had long grain, 103 had more than 3.0 L/B ratio, 155 had more than 25.0% amylose content, 11 had more than 10.0% protein content, four had more than 1.7 elongation ratio and 180 had between the range of (4.0-5.0) volume expansion ratio. Some of the promising lines were identified for higher milling and head rice recovery, size and shape, amylose content, protein content, elongation ratio and acceptable other physicochemical properties .On the other hand 8,532 transforming breeding lines were evaluated for physicochemical and cooking properties for superior quality. Based on the performance on grain quality, we recommended 36 lines and among them two lines for CTR, Haor (AYT#3,4), three lines for (SYT#1,2,3) Boro, 13 lines for FBR and CTR, four lines for IR (AYT) Boro, seven lines for IR (AYT) T. Aman and seven lines for FBR and CTR for further advancement.

Black pericarp rice has recently become popular among rice consumers for its diverse health benefits especially anti-cancer effect. Cyanidin-3-Glucosides (C3G), a prominent bioactive component of anthocyanins which is abundantly present in black pericarp rice. We investigated, how effectively it can be used to fortify Cyanidin-3-Glucosides (C3G) content in red and white pericarp polished rice or rice-based bakery products for more nutritional value. In the present study, we have characterized several black pericarp rice cultivars along with some red pericarp and white pericarp rice cultivars by physiochemically including mineral profiling, and quantified the C3G by UPLC and LCMS. C3G content was significantly reduced from raw rice to cooked rice condition. All the black pericarp rice cultivars synthesized C3G, while this content was not detected in red and white pericarp rice cultivars. However, when 25% of black pericarp rice were mixed with 75% red or white pericarp polished rice, C3G content was significantly retained in cooked rice conditions. Formulation of rice-based bakery food product using black pericarp rice powder was also remarkably retained the C3G content as compared to that of cooking. Black rice is harder in texture, difficult to digest and needs higher energy for cooking. Therefore, we tried to circumvent these challenges by fortifying 25% of black pericarp rice with white or red pericarp rice. Fortification of C3G enriched black rice (25%) with red or white pericarp rice (75%) might bring a better nutritional quality in both cooking and baking condition. This may lead a way to the effective management of the non-communicable disease such as cancer for common rice consuming population.

Eleven methods including nine HPLC and two GCMS methods were developed and validated using Shimadzu Prominence-i Modular HPLC and Shimadzu Nexis GC2030 equipped with MS-QP2020NX at GQN and BCL laboratory respectively. HPLC methods for detection and quantification of rice phytohormones including 3-Indoleacetic acid (IAA), Gibberellic Acid (GA_3) and Abscisic Acid (ABA), Water soluble rice vitamins such as Thiamine ($VitB_1$), Riboflavin ($VitB_2$), Niacin ($VitB_3$), Thyroxine (Vit B_6), Folic acid (Vit B_9) and Cyanocobalamin (Vit B_{12}). GCMS methods include detection and quantification of rice volatile aromatic compounds such as 2AP (2 Acetyl-1-Pyrroline) and rice fatty acid profiling (C14:0 Myristic acid, C14:1 Myristoleic acid, C16:0 Palmitic acid, C16:1 Palmitoleic acid, C18:0 Stearic acid, C18:1 Oleic acid, C18:2/Omega-6 Linoleic acid, C18:3/Omega-3 Linolenic acid, C20:0 Arachidic acid, C20:1 Eicosanoic acid, C22:0 Behenic acid).

Puffed, popped and flattened rice were produced from BRRI varieties to evaluate the quality products. Comparing few parameters (fully puffed rice, length and breadth increased percentage) with BR16 (Std), it is ascertained from the results that BRRI dhan99 and Bangabandhu dhan100 are better in producing whole puffed rice followed by BRRI dhan97 and BRRI dhan98. Considering physical parameters, BRRI dhan99 and Bangabandhu dhan100 show excellent performance for whole, partial broken, broken and unpopped

rice. Among the tested varieties, in terms of weight of whole, partial broken and broken flattened rice as well as percentage of length increased, BRRI dhan98 showed the best performance comparing with BR16.

GRAIN QUALITY CHARACTER

Determination of physicochemical and cooking properties of breeding lines

PI: M A S; **CI:** M A H, S S D, N F, H B S, S H and M R A

After yield, grain quality of rice is important parameter for researchers and consumers. Consumer acceptance of rice depends on its physicochemical quality. Physical parameters were measured by milling outrun, head rice yield and size and shape. Cooking quality were determined by cooking time, elongation ratio and volume expansion ratio. Chemical parameters were determined by amylose content, protein content and alkali spreading value. New HYR varieties that have better benefits than the existing ones will be more accepted if their characteristics are in accordance with consumers' preferences (Zen 2007). High quality rice, uniform shape, whiteness and translucency are major factors defining market value of rice (Fitzgerald et al. 2008). Rice is a very rich source of carbohydrate followed by protein. A total of 128 samples were provided from different divisions of BRRI and outside of BRRI to find out the desirable characteristics. In Bangladesh, long slender type translucent grains prefered by consumers as premium quality rice with higher price. But medium bold type grains are most suitable for milling. Total 359 samples were analyzed. Out of 287 samples, 88 had more than 70% milling outturn and 38 had more than 60% head rice recovery. Out of 235 samples, 10 have shown translucent (Tr) grain that means 0% chalkiness, 38 have shown less than 10% chalkiness, 70 have shown between the range of 10-20% chalkiness, 111 have shown more than 20% chalkiness and only six have shown opaque grain. Out of 356 samples, only five had Ex-long grain, 175 had long grain, 145 had medium grain and 31 had short grain. Among these samples 103 had more than 3.0 L/B ratio, whereas 250 had between the range of (2.0-3.0) L/B ratio. Out of 280 samples, only one sample had more than 30.0 g 1000-grain TGW., 38 had between the ranges of 25-30 g 1000-grain wt., 140 had between the ranges of 21-25 g TGW., 99 had between the ranges of 15-20 g TGW. and only two had less than 15 g 1000-grain wt. (Table 1). Amylose is the most important trait for eating quality, which indicates the texture of cooked rice and also volume expansion. Out of 359 samples, 155 had more than 25% amylose, 178 had between the range of 20-25% amylose, 25 had between the range of 10-20% amylose and only one had less than 10% amylose. Nutritional quality is measured by protein content. Out of 287 samples, 11 had more than 10% protein, 96 had between the range of 9-10% protein, 120 had between the range of 8-8.9% protein, 55 had between the range of 7-7.9% protein and only five had less than 7% protein. Less than 7% protein content in brown rice, which is not normally recommended for variety release. Grain with high gelatinization temperature is not desirable. Out of 287 samples, 39 had more than 20 minutes. cooking time, 117 had between the range of 18-20 minutes. cooking time, 129 had between the range of 15-17 min. cooking time and only two had less than 15 minutes. cooking time. The samples, having more than 20 min. cooking time may give comparatively hard cooked rice. Among 287 samples, only four had between the range of 1.7-2 elongation ratio, 188 had between the range of 1.4-1.6 elongation ratio and 95 had less than 1.4 elongation ratio. Higher elongation ratio is desirable factor. High volume expansion of cooking is still considered to be a good quality for the working class people who do not care whether the expansion is lengthwise or crosswise. Among these samples, no one had more than 5.0 volume expansion ratio, 180 had between the range of 4-5 volume expansion ratio and 107 had between the range of 3.0-3.9 volume expansion ratio. Out of 113 samples, two had intermediate aroma, six had low aroma but 105 had no aroma (Table-2).

Some of the promising samples were identified for higher milling and head rice recovery, amylose content, protein content, elongation ratio and other acceptable physicochemical properties (Table-3).

Table 1. Physical properties of rice samples.

Range	Properties and sample number
Milling Outturn (%) (Total sample 287)	
>70.0	88
68.0-70.0	151
<68.0	48
Head rice recovery (%) (Total sample 287)	
>60.0	38
50.0-60.0	135
<50.0	114
Chalkiness (%) (Total sample 235)	
0 (Chalk)	10
<10.0	38
10.0-20.0	70
>20.0	111
100 (Chalk)	6
Length (mm) (Total sample 356)	
>7.4	5
6.1-7.4	175
5.0-6.0	145
<5.0	31
L/B ratio (Total sample 356)	
>3.0	103
2.1-3.0	250
<2.0	3
Size & Shape (Total sample 356)	
>6.0 mm ; >3.0	107
>6.0 mm ; 2.1-3.0	74
5.0-6.0 mm ; >3.0	27
5.0-6.0 mm ; 2.1-3.0	117
<5.0 mm ; 2.1-3.0	28
<5.0 mm ; <2.0	3
1000-grain wt. (g) (Total sample 280)	
>30.0	1
25.0-30.0	38
21.0-25.0	140
15.0-20.0	99
<15	2

Table 2. Chemical and cooking properties of rice samples.

Range	Properties and sample number
Alkali spreading value (Total sample 287)	
6-7	38
4.1-5.9	130
<4	119
Amylose content (%) (Total sample 359)	
>25.0	155
20.0-25.0	178
10.0-20.0	25
<10.0	1
Protein content (%) (Total sample 287)	
>10.0	11
9.0-10.0	96
8.0-8.9	120

7.0-7.9	55
<7.0	5
Cooking time (min.) (Total sample 287)	
>20.0	39
18.0-20.0	117
15.0-17.0	129
<15.0	2
Elongation ratio (Total sample 287)	
>2.0	-
1.7-2.0	4
1.4-1.6	188
<1.4	95
Volume expansion ratio (Total sample 287)	
>5.0	-
4.0-5.0	180
3.0-3.9	107
<3.0	-
Aroma (Total sample 113)	
+++	-
++	2
+	6
-	105

Table 3. Physicochemical properties of promising samples.

AC #	Variety/Line	Milling outturn (%)	Head rice recovery (%)	Size & Shape	1000 grain wt. (g)	Amylose (%)	Protein (%)	ER	IR
16371	BRH14-9-13-16B	71	58	LS	14.4	26.4	10	1.4	4.3
16444	BR10247-14-18-4	71	51	LS	20.9	20.8	9.9	1.5	4.3
16552	BRH17-23-8-2-7B	69	53	LS	16.6	25.9	9	1.5	4.3
16566	BR(Path)12452-SL-53	70	63	MS	20.3	25.5	8.7	1.5	3.9
16810	BR12248-5R-37	69	49	LS	22.7	24.4	8.1	1.4	4.5
16827	BR12266-5R-22	69	50	LS	23	26.6	8.8	1.4	4.3
16907	Ranqui	69	55	LS	22.2	27.7	8.1	1.4	4.5
16908	Gunda	69	55	MB	22	26.5	8.2	1.6	4
16910	Bish Number	70	59	MB	24.4	26.8	8	1.6	4.8
16912	YAAS-V5	70	59	MB	21.7	27.2	7.3	1.6	4.3

Determination of Physicochemical and Cooking properties of Transforming Rice Breeding lines

PI: S S D CI: M A S

Grain quality is an important component for consumer's preference and profitability. For the transforming rice breeding project on rice grain quality screening, a total of 8532 (LST- Line Stage Trial 3817, OYT-Observational Yield Trial 2228 and PYT-Preliminary Yield Trial 2487) were received, processed and evaluated.

Three thousand eight hundred seventeen (3817) LST and OYT materials were analyzed for size, shape. Grain length and length to breadth ratio determines the grain size and shape. Among them three thousand eight hundred seventeen (3817) LST (Salinity tolerance, Boro, Salinity tolerance T. Aman, T. Aus, Favorable and cold tolerant Boro and cold tolerant Boro) lines 44 were extra long slender (ELS), followed by 1 was extra long medium, 729 were long slender, 1486 were long medium, one was long bold, 83 were medium slender, 884 were medium medium, 144 were medium bold, one was medium round, 285 were short medium, 144 were short bold, 12 were short round and three were short short.

Among two thousand two hundred twenty eight (2228) OYT materials, (Salinity tolerance, Boro, Salinity tolerance T. Aman, T. Aus, Favorable and cold tolerant Boro and cold tolerant

Boro) 85 were long slender, 873 were long bold, 455 was medium slender, 759 were medium bold, three were medium round and 53 were short bold.

In Bangladesh, medium slender and medium bold grains are suitable for milling. But long slender rice is sold at high price in the market. Rice contains two types of starch namely amylose and amylopectin. Amylose content of rice grain determines the hardness and stickiness of cooked rice. More than 25% amylose content gives nonsticky cooked rice; 20-25% amylose containing rice gives soft and comparatively sticky cooked rice. Out of 2,228 LST and OYT lines, 1,784 were more than 25.0% amylose, 380 lines were amylose content between the range of 20-25% and 64 lines had less than 20% amylase (**Table-4**).

Milling is one of the parameters determining milled rice yield per unit paddy weight. Among 2,487 PYT lines, 1,387 lines had more than 70% and 877 had 68-70% total milled rice percentage. 223 had less than 68% milling outturn. Less than 68% milled rice is not desirable. One thousand sixty one lines had more than 60% followed by 906 within 50-60% and 520 with less than 50% head rice recovery percentage. Out of 2,487 lines, 1,567 were translucent (Table-2). Appearance or colour of milled rice is one of the important physical properties to attract consumer's attention. All of the lines were brown in colour. The consumers in our country prefer long and medium slender grain. Grain length and length to breadth ratio determines the grain size and shape. Out of 2,487 PYT lines, 348 were long slender, followed by 1,107 were long bold, seven were medium slender, 991 were medium bold, 25 were medium round. In Bangladesh, medium slender and medium bold grains are suitable for milling. But long slender rice is sold at high price in the market (**Table-5**).

Amylose content determines the quality of cooked rice. Out of 2,487 lines, 2,031 were more than 25% amylose, 385 lines were amylose content between the range of 20-25% and 71 lines had less than 20% amylose (Table 3). Protein content is measure the nutritional value of rice. In total 1,592 lines had high (>9%) and 846 lines had intermediate (7.0-9.0%) protein content. Generally, a variety, having less than 7% protein content in brown rice, is not recommended for release as a variety (Table-3). Alkali spreading value has inverse relationship with gelatinization temperature. Among the 2,487 breeding lines 671 had alkali spreading value ranging 6.0-7.0 and 1,442 had 3.1-5.9. Grain with high gelatinization temperature is not desirable. In total 2,164 lines had cooking time between the ranges of 15-20 minutes. Imbibition ratio (Volume expansion) is one of the important parameters for rice quality. It shows the value of expansion of rice after cooking. Hard working people of our country prefer rice having more volume expansion.

Out of 2,487 PYT lines, volume expansion ratio of 2,263 lines were less than 3.5 (Table 3). The elongation ratio is one of the important parameters for cooked rice. Elongation ratio is responsible for fine or coarse cooked rice. If rice elongation is more, it gives a finer appearance, but if expands in breadth, gives a coarse look. Long slender and medium slender rice should elongate more, as they are consumed mostly by people having comparatively a higher income. The elongation ratio of most of the lines varied between 1.3-1.5 (**Table-6**).

Table 4 Physicochemical properties of Transforming Rice Breeding (LST and OYT) lines.

Parameter and total number of sample	Classification	Number of Sample
Size and Shape (Brown rice) (Total sample no. 3,817)	Extra long slender	44
	Extra long medium	1
	Long Slender	729
	Long medium	1486
	Long Bold	1
	Medium slender	83
	Medium medium	884
	Medium bold	144
	Medium round	1

	Short medium	285
	Short bold	144
	Short round	12
	Short short	3
Size and Shape (Milled rice) (Total sample no. 2,228)	Long slender	85
	Long bold	873
	Medium slender	455
	Medium bold	759
	Medium round	3
	Short bold	53
Amylose content (%) (Total sample no. 2,228)	High	1784
	Intermediate	380
	Low	64

Table -5 Physical properties of Transforming Rice Breeding (PYT) sample

Range	Properties and sample number
	Milling Outturn (%) (total sample no. 2,487)
>70.0	1387
68.0-70.0	877
<68.0	223
	Head rice recovery (%) (Total sample no. 2,487)
>60.0	1061
50.0-60.0	906
<50.0	520
	Length (mm) (Total sample no. 2,487)
>6.0	1455
5.0-6.0	1023
<5.0	9
	L/B ratio (Total sample no. 2,487)
3.0>	355
2.0-3.0	2098
<2.0	34
	Chalkiness (%) (Total sample no. 2,487)
(0) Tr	1567
<10	597
10.0-20.0	199
>20.0	100
Opaque	24

Table-6 Chemical and cooking properties of Transforming Rice Breeding (PYT) samples

Range	Properties and sample no.
	Amylose content (%) (Total sample no. 2,487)
>25.0	2031
20.0-25.0	385
<20.0	71
	Protein content (%) (Total sample no. 2,487)
>9.0	1592
7.0-9.0	846
<7.0	49
	Alkali spreading value (Total sample no. 2,487)
1.0-3,0	374
3.1- 5.9	1442
>6.0	671
	Cooking time (min.) (Total sample no. 2,487)
>20	25
15-20	2164

<15	298
	Elongation ratio (Total sample no. 2,847)
>1.5	96
1.3-1.5	2306
<1.3	85
	Volume expansion ratio (Total sample no. 2,847)
>4.0	50
3.4-4.0	174
<3.5	2263

This study identified 36 of the promising lines for high milling and acceptable other physicochemical properties (**Tables 7, 8,9,10,11 and 12**)

Table 7. Promising genotypes for (AYT# 3, 4), CTR, Haor.

Genotype	Head rice Recovery (%)	Size and shape	Amylose Content (%)
BR8910-B-6-3-CS1-5-CS2-P3-1-5	65.3	LS	27.5
BR8938-30-2-4-2-1	61.2	LS	26.8

Table 8. Promising Genotypes for (SYT# 1, 2.3), Boro

Genotype	Head Rice recovery (%)	Size and shape	Amylose content (%)	Elongation ratio
IR2-8-L15-S2-L2	47.8	MB	25.8	1.5
IR1-DQ189-R1-L2	54.1	LB	27.4	1.5
GSR IR 1-DQ125-R4-Y1	46.2	MB	27.1	1.5

Table 9. Promising genotypes for favorable Boro and cold tolerant rice

Genotype	Head rice Recovery (%)	Size and shape	Amylose content (%)	Elongation ratio
BR11894-R-R-R-R-94	61.6	MB	27.7	1.6
BR11894-R-R-R-R-187	63.7	MB	24.3	1.6
BR11894-R-R-R-R-328	58,6	MB	27.0	1.6
BR11894-R-R-R-R-220	65,0	LB	29.5	1.6
BR11662-18-3-3	59.6	MB	30.0	1.6
BR11894-R-R-R-R-258	59.2	LB	27.3	1.6
BR11337-5R-151	60,3	MR	29.3	1.6
BR11337-5R-37	57.6	MR	26.5	1.6
BR11337-5R-166	61.3	MB	26.7	1.6
BR11338-5R-48	67.6	MR	26.8	1.6
BR11338-5R-96	59.8	MB	26.3	1.6
BR11338-5R-30	61.5	SR	27.0	1.8
BR11338-5R-114	63.0	MB	27.4	1.6

Tabl 10. Promising genotypes for IR (AYT) Boro

Genotype	Head rice recovery (%)	Size and shape	Amylose content (%)	Elongation ratio
BR11583-5R-13	62.2	LB	28.4	1.5
BR11587-5R-45	60.5	MB	26.6	1.5
BR11593-5R-55	55.5	LB	27.2	1.5
BR9667-54-2-2-97	59.6	LB	28.7	1.5

Table11. Promising Genotypes for IR (AYT) T. Aman

Genotype	Milling outturn (%)	Size and Shape	Amylose content (%)	Elongation ratio
BR11302-4R-197	69.2	MB	25.7	1.5
BR11044-4R-82	65.5	LS	24.6	1.5
BR11302-4R-75	70.1	MB	26.2	1.5
BR11301-4R-10	70.2	MB	27.9	1.5
BR10774-4R-8	69.8	MB	29.2	1.5
BR10766-4R-6	68.5	MB	28.2	1.5
IRBPHN-SVIN049-18	71.6	LS	28.1	1.5

Table12. Promising genotypes for favorable Boro and cold tolerant rice

Genotype	Head Rice recovery (%)	Size and shape	Amylose content (%)	Elongation ratio
BR11338-5R-109	57.0	MB	28.3	1.6
BR11332-5R-204	60.2	LS	27.0	1.6
BR10599-5R-91	52.8	LB	28.3	1.6
BR11330-5R-35	66.0	MB	30.1	1.6
BR10296-5R-1	60.9	MB	27.5	1.6
BR10589-5R-145	63.8	MB	28.0	1.6
BR10600-5R-168	60.9	MB	29.4	1.6

STUDY ON ANTI-CANCER PROPERTIES OF PIGMENTED (BLACK, RED, PURPLE) RICE VARIETIES IN BANGLADESH.

Black pericarp rice has recently become popular among rice consumers for its diverse health benefits especially anti-cancer effect. Cyanidin-3-Glucosides (C3G), a prominent bioactive component of anthocyanins which is abundantly present in black pericarp rice. We investigated, how effectively it can be used to fortify C3G content in red and white pericarp polished rice or rice-based bakery products for more nutritional value. In the present study, we have characterized several black pericarp rice cultivars along with some red pericarp and white pericarp rice cultivars by physiochemically including mineral profiling, and quantified the C3G by UPLC and LCMS. C3G content was significantly reduced from raw rice to cooked rice condition. All the black pericarp rice cultivars synthesized C3G, while this content was not detected in red and white pericarp rice cultivars.

However, when 25% of black pericarp rice were mixed with 75% red or white pericarp polished rice, C3G content was significantly retained in cooked rice conditions. Formulation of rice-based bakery food product using black pericarp rice powder was also remarkably retained the C3G content as compared to that of cooking. Black rice is harder in texture, difficult to digest and needs higher energy for cooking. Therefore, we tried to circumvent these challenges by fortifying 25% of black pericarp rice with white or red pericarp rice. Fortification of C3G enriched black rice (25%) with red or white pericarp rice (75%) might bring a better nutritional quality in both cooking and baking conditions. This may lead a way to the effective management of the non-communicable disease such as cancer for common rice consuming population.

Fifteen rice cultivars comprised of 11 black pericarps (such as BK1, BK2, BK3, BK4, BK5, BK6, BK7, BK8, BK9, BK10 and BK11), two red pericarp (such as Laxmideega, and BRRI dhan84) and two white pericarp (such as BRRI dhan80 and Gabura) rice were collected and used in this study. We collected black pericarp rice cultivars from hilly regions of Sylhet, Bandarban and Khagrachori districts of Bangladesh and rest of the white red pericarp rice and white pericarp rice were collected from GQN Division. In order to increase the seeds, all these germplasm were grown at area of 5 x 5 square meter for each in BRRI west byed farm located in Gazipur, Bangladesh (BRRI Latitude: 23.99, BRRI Longitude: 90.40) during Aman and Boro 2020-21 season (i.e., Aman season July to November 2020 and Boro season November 2020 to April 2021). Standard agronomic practices were followed to ensure high quality seeds. After maturation, crop was harvested, and seeds were collected. The collected seeds were dried and stored at -20ºC for further use at GQN Division, BRRI. Each sample was milled unparboiled and analyzed for physicochemical properties according to GQN grain quality procedure. Amylose content was determined by the method described in Juliano. Alkali spreading value was determined according to the method of Little etal. Protein contents were calculated from nitrogen, and were determined by the method of Micro Kjeldahl. Each sample was digested, and estimated by the method of the Association of Official Agricultural Chemists. Iron (Fe), zinc (Zn), and calcium (Ca) were determined by the atomic absorption spectrometry (Shimadzu Atomic Absorption Spectrophotometer AA-7000) using a different standard curve at 348.3, 213.8 and 422.7 nm respectively. Only selected germplasm including BK11 (black pericarp rice), BRRI dhan80 (white pericarp rice) and BRRI dhan84 (red pericarp rice) were used in this case. The 5%, 10%, and 25% of BK11 was mixed with both BRRI dhan80 and BRRI dhan84 then cooked at boiling temperature up to respective cooking time (until 90% of gelatinization). These rice samples were cooked using a consistent ratio of 1:1.5 (w/w) using 113 g of deionized distilled water to 75 g of rice. This rice to water ratio resulted in the complete absorption of water by the rice at the end of the cooking time. Rice was cooked using a commercial National view rice cooker (model NV-1 1.8L, 220-240V, 50/60 Hz). A series of rice samples were presoaked in 113 g of water for one hour before cooking in the rice cooker to compare the effects of presoaking rice on anthocyanidin retention. Rice was cooked for 90 min in the rice cooker. All cooked rice was allowed to steam-cool for five minutes. after the heating stopped. Two aliquots of cooked rice, about 20 g each, were randomly selected from each sample and immediately frozen at -80°C before freeze-drying. Each cooking test was performed three times on independent samples. Rice-based bakery product such as rice cakes were prepared at GQN bakery laboratory at BRRI, Gazipur with a minimum of 10 g of protein 100^{-1}g. Ingredients were used as a mixture of rice and sago flours (4:1), vegetable fat or butter, rice bran oil, powder sugar, salt, milk, and egg. In adding the rice powder portion, we used 25% black rice powder with 75% white rice powder (4:1). In the mixing process, all the ingredients were put together for batter formation. The ingredients were fed into the dough mixer, where they were mixed properly for 10-15 minutes. In the baking process, cake batter was put into the baking pan at 190°C for 30 minutes. After baking cakes, they were passed on to cooling conveyors for natural cooling. We preferred natural cooling as it helps to maintain the texture quality of the cake.

Shimadzu UFLC system (Japan) was used to identify the anthocyanins from black rice extraction. The diode array detector (SPD-M20A) was set at 520 nm. The anthocyanins were separated by a Prevail C18 (4.6 mm × 250 mm) with an average particle size of 5.0 µm at 0.2 mLmin-1. at room temperature. The mobile phase consisted of A (water: formic acid = 99:1, v: v) and B (acetonitrile: formic acid = 99:1, v:v), with a binary gradient elutions. UFLC peak of Cyanidin-3-glucoside (Retention Time; 12.99±0.2 min.) in raw black pericarp rice (BK11) and cooked rice were monitored at 520 nm and 280 nm, respectively.

In this study, we used different pigmented rice cultivars along with high-yielding varieties (HYVs) (Fig.1). Among them, BK1 was a mixture of both black and white pericarp rice, while BK2, BK3, BK4, BK5, BK6, BK7, BK8, BK9, BK10 and BK11 were solely black pericarp rice. Laxmidigga was the mixture of black and red pericarp rice, while BRRI dhan84 was exclusively red pericarp rice. On the other hand, BRRI dhan80 and Gabura were white pericarp rice. The decorticated brown rice length ranged from 5.9 to 7.6 mm (Table 1). BK2 and BK11 exhibited the highest length (7.6 mm) of brown pericarp rice, and these cultivars were also extra-long slender and extra-long bold type grain, respectively. BK3, BK4. BK5. BK6, BK8, BK9, BK10, BRRI dhan84 and Gabura were categorized as long bold type rice grains, while BK1 and Laxmideega were medium bold type rice grain. Among the tested cultivars and HYVs, only BK6 and BK9 have strongly scented aroma (Table 13 and Fig.1).

The protein content was significantly varied in these cultivars and HYVs (Fig.2A). This content varied from 8.52 to 12.16% (g 100-1g). Remarkably the highest protein content was obtained in BK7 (12.16%) followed by BK9 (11.43%) and BK2 (11.30%). Indeed, more than 10% (g 100-1g) protein content was detected in all the black pericarp rice cultivars except BK6 (9.44%) (Fig.2A). However, BRRI dhan80 contained the lowest protein content. Like protein content, AAC was also incredibly different in these cultivars which ranges from 2.97% to 25.74% (Fig. 2B). BRRI dhan84 produced the maximum AAC (25.74%) followed by Laxmidigga (24.61%) and BK10 (24.14%). Overall, black pericarp rice cultivars contained very low to intermediate level of AAC. Among the black pericarp rice cultivars, BK10 constructed the highest level of AAC (24.14%) which resembles intermediate AAC. We did not find any high AAC (>25.0%) in black pericarp rice cultivars (Fig.2B). The minimum AAC was found in BK3 (2.9) which resemble very low or waxy type rice.

We quantified different mineral contents including Fe, Zn and Ca in all the rice cultivars. Fe, Zn and Ca content were found to be considerably varied in these cultivars. The content of Fe, Zn and Ca fluctuated from 18.51 to 32.06, 3.65 to 20.15 and 8.63 to 72.71 $mgKg^{-1}$, respectively (Fig. 3). BK5 contained the highest level of Zn (32.06 $mgKg^{-1}$), Fe (20.15 $mgKg^{-1}$), and Ca (72.71 $mgKg^{-1}$) followed by BK11 (28.11, 19.28 and 33.2 $mgKg^{-1}$, Zn, Fe, and Ca, respectively mg) among the tested rice samples. BRRI dhan84 exhibited the highest mineral enriched HYV inbred (Zn 27.55 mgKg-1, Fe 10.21 mgKg-1, and Ca 33.24 $mgKg^{-1}$). Thus, black pericarp rice might contain higher level of Zn, Fe, and Ca as compared to that of inbred HYVs and local germplasms.

The C3G content was considerably varied in the rice cultivars. The C3G content was not detected in both red and white pericarp rice (such as Laxmideega, BRRI dhan84, BRRI dhan80 and Gabura), while all the black pericarp rice synthesized this compound (Fig. 4). Among the tested black rice cultivars, the highest C3G (806.17 $mgKg^{-1}$) was obtained in BK11 which is popularly grown in Khagrachori district, Bangladesh followed by BK10 (608.81 $mgKg^{-1}$) and BK8 (337.89 $mgKg^{-1}$) (Fig. 4).

Cooking has a significant effect on C3G content. While cooking, C3G content was significantly reduced from raw rice to cooked rice. In this study, C3G content in BK11 was reduced 48.05% while cooking. In order to retain the C3G while cooking, we mixed 5%, 10%, and 25% BK11 with red pericarp rice BRRI dhan84 and white pericarp rice BRRI dhan80. We found fortification of 25% in both red and white pericarp rice, the C3G content retained 13.34% and 12.98%, respectively (Table 14), while fortification of 5% in both red and white pericarp rice, the C3G content retained only 3.24% and 3.76%, respectively (Table 14). On the other hand, 4.66 and 6.75% of C3G retained in both red and white pericarp rice, respectively when fortified up to 10%.

We compared the retention of C3G in the baked cake of black and white pericarp rice, and cooked rice (Fig. 6). Interestingly, the retention of C3G in the baked cake of black and white pericarp rice was higher than the cooked rice. We also prepared the rice-based cake using 25% BK11 (black rice) with 75% BRRI dhan80 (white rice) as an active ingredient of carbohydrate source. In this case, C3G content was found to be 196.4± 1.65 mgKg-1in the rice-based cake which resemble higher content than the cooked rice of similar proportion (Table 2 and Fig. 6). We also examined C3G at 520 nm for raw rice and 280 nm for cooked rice and baked cake in UFLC, and m/z (499.0) of C3G has validated in LCMS accordingly (Data not shown).

Rice is an important source of energy, hypoallergenic, easily digested, providing protein with higher nutritional quality, and has versatile functional nutraceutical properties. Rice has an important role in the relation between diet and health. Black rice is especially rich in anthocyanin pigments, phytochemicals, protein, vitamins, minerals and antioxidant properties. The bran hull of black rice is the outermost layer of the rice grain which contains one of the highest levels of the anthocyanin found in any known food. Anthocyanins are the flavonoid pigments of black rice and are the source of antioxidants that have the ability to inhibit the formation or to reduce the concentrations of reactive cell damaging free radicals. Anthocyanin antioxidants help to prevent cardiovascular disease, protecting against cancer that can be caused by free radical damage, improving brain function, reducing inflammation. Black rice rich in Cyanidin 3-Glucoside (C3G) and has hypolipidaemic effects through regulating hepatic lipogenic enzyme activities [18]. It also ameliorates diabetic nephropathy via reducing blood glucose, suppressing oxidative stress and inflammation. Chen, P.N., et al. (2006) gave molecular evidence associated with the anti-metastatic effects of Peonidin 3-Glucoside and cyanidin 3-glucoside, major anthocyanins extracted from black rice (Oryza sativa L. indica), by showing a marked inhibition on the invasion and motility of SKHep-1 cells. This effect was associated with a reduced expression of matrix metalloproteinase (MMP)-9 and urokinase-type plasminogen activator (u-PA). C3G is the active component of anthocyanin in black rice. In our study we were aimed to estimate C3G content in our Bangladeshi available black rice cultivars from different parts of Bangladesh. We also brought some red and white pericarp rice for comparative analysis along with black rice. We characterized our black rice cultivars and found very high level of protein content (≥10%) and low to intermediate level of apparent amylose content (AAC) compared to the other red and white rice. Black rice cultivars possess higher mineral contents such as Zn, Fe and Ca than the other rice. Zinc content of Black rice cultivars varied ranges from 21.44 ppm ($mgKg^{-1}$) to 32.06 ppm (mgKg-1). Our data reveals diverse range of C3G content in black rice cultivars in Bangladesh. C3G content in black rice cultivars varied ranges from 2.58 ppm to 806.17 ppm. BK11 is the highest C3G content black rice cultivars in Bangladesh followed by BK10, BK8, BK9. But we could not get confirm C3G content in both red and white pericarp rice by UFLC and LCMS in this study. Due to the nutraceutical enriched properties black rice has got immense potential both in domestic as well as overseas market and become expensive to purchase. Since black rice yield is lower than modern HYVs, so expenses of cultivating black rice is costlier than HYVs.

Thermal effect reduces the concentration of C3G in cooking condition than raw. Considering this into account we aimed to investigate whether proportionate use of black rice with other red and white pericarp rice could bring effectiveness regarding availability of C3G as consumption of red and white rice is not able to provide C3G alone. Our data revealed that the proportionate mixture (1:3) of the highest C3G enriched black rice

(BK11) and white (BRRI dhan80) or red (BRRI dhan84) pericarp rice retained 12.98 and 13.34% of C3G, respectively at cooked rice condition. In addition, we investigated whether C3G can effectively be used in baking condition over cooking condition. Our data suggested that black rice would be used as active ingredient of rice flour in baking condition it can retain higher C3G than cooking alone which resemble black rice flour can effectively be utilize in rice-based baking industries.

Our data concluded that black rice should be consumed with white or red polished rice so that the nutraceutical properties of common rice will be fortified which ultimately bring better nutritional value to humans. The use of black rice flour can fortify more bioactive compounds such as C3G in rice-based bakery products than rice. A combination of black rice along with red or white pericarp rice will be able to play a significant role in managing non-communicable diseases. Since black rice cultivars have poor yield gain so, BK11 can further be utilized as a superior crossing parent in the molecular breeding of indica-type black HYV rice research programme.

Figure 1. Pigmented rice including black, red and white pericarp rice of both local and HYVs.

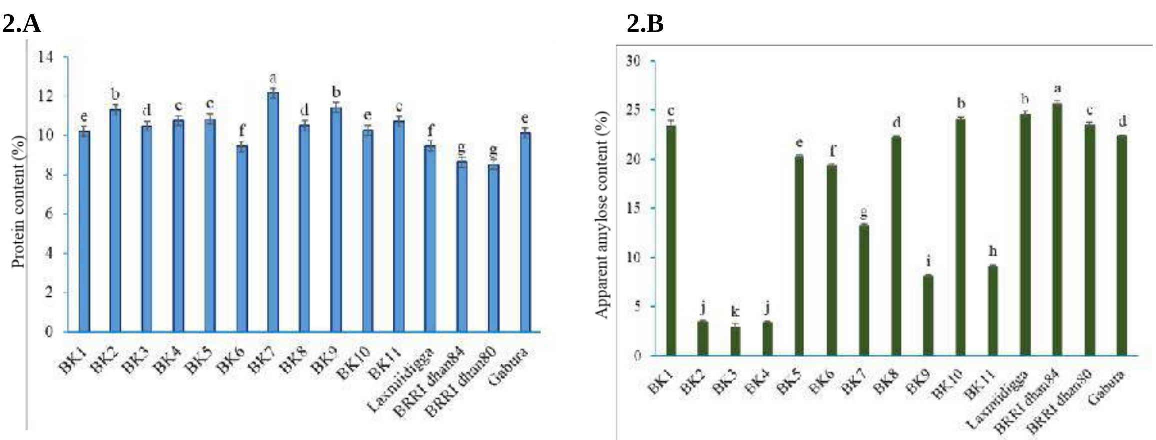


Figure 2. Chemical properties of selected rice samples (Protein content Fig. 2.A and AAC % in Fig.2.B).

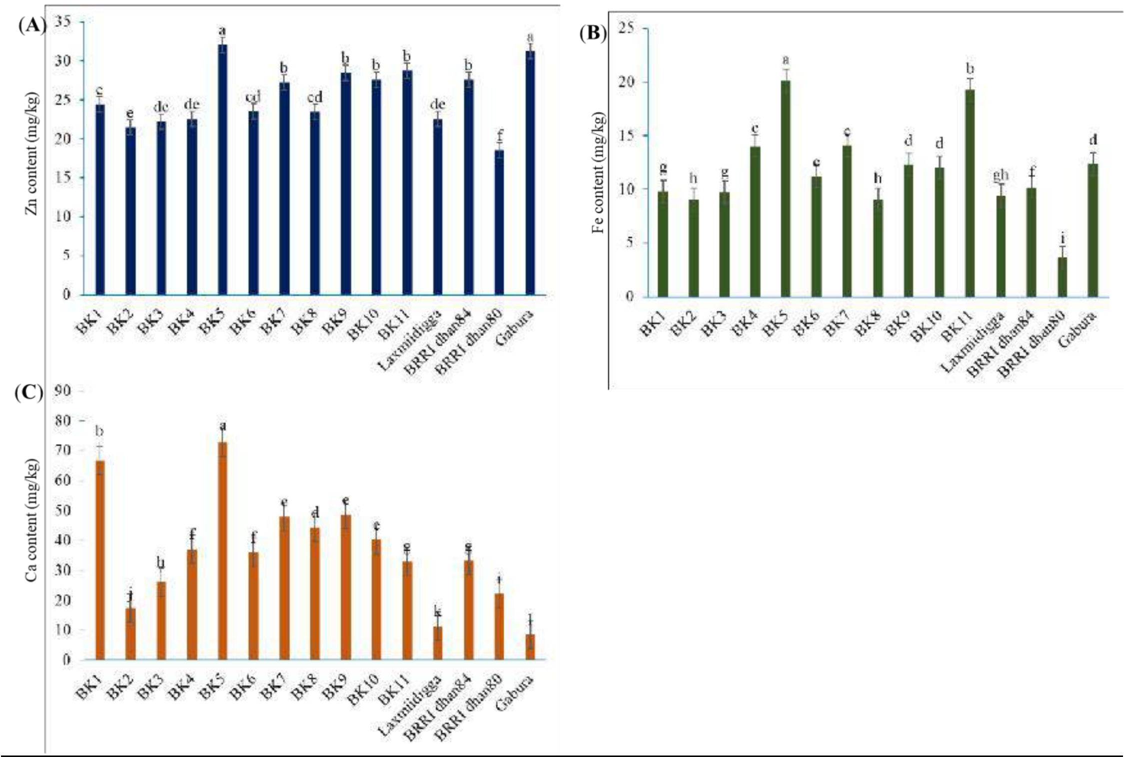


Fig. 3. Mineral profiling of selected rice samples of Zn (mg/Kg or ppm, Fig. 3A), Fe (mg/Kg or ppm, Fig.3B) and Ca (mg/Kg or ppm, Fig. 3C).

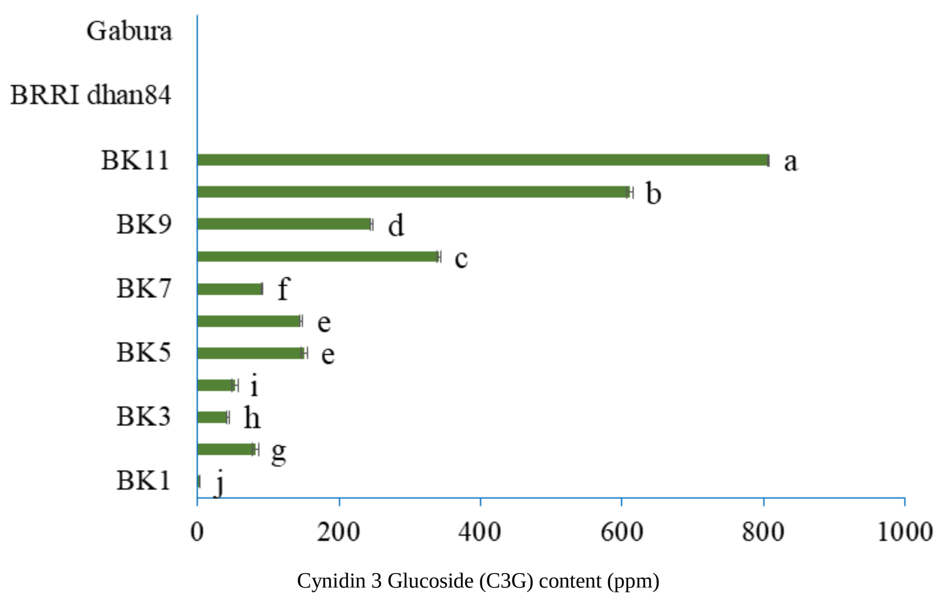


Figure 4. Cynidin 3 Glucoside (C3G) content (mg/kg) of selected rice samples.

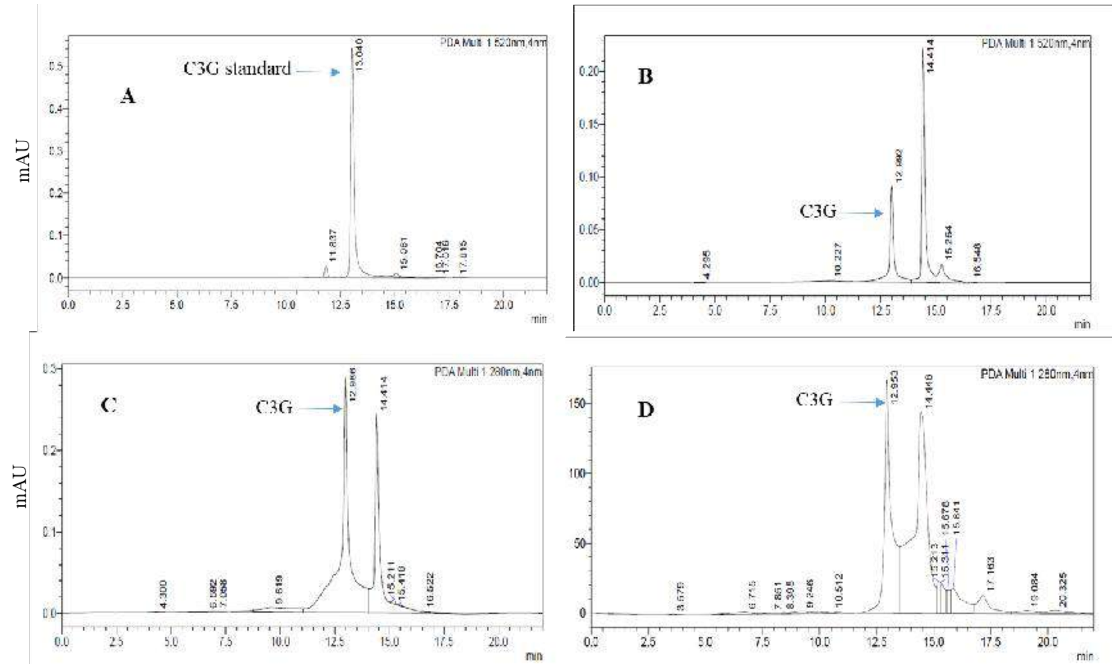
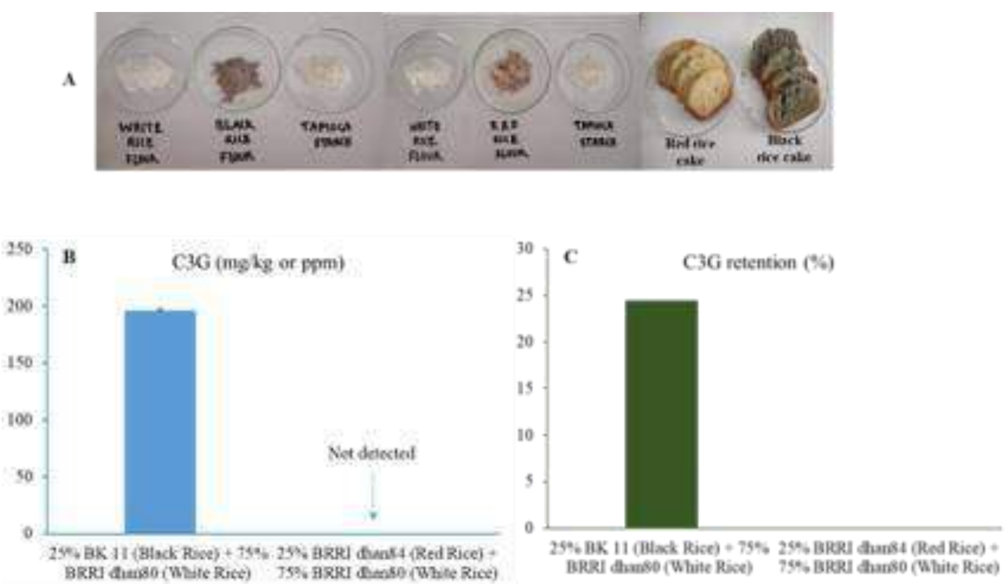


Figure 5. UFLC peak of Cyanidin-3-glucoside (RT;13.04 mins) in standard solution (A) at 520 nm. UFLC peak of Cyanidin-3-glucoside (RT;12.99 mins) in raw and cooked rice (BK11) was monitored at 520 nm (B) and 280 nm (C) respectively.UFLC peak of C3G in black rice (BK11) based cake (D).



FigFig. 6. Pictorial view of brown rice flour powder of red (BRRI dhan84), black (BK11), and white (BRRI dhan80) pericarp rice including Tapioca starch powder (Fig. 6.A) and Pictorial view of black and red pericarp rice flour in preparation of rice based cake (Fig. 6.A). Graphical representation of C3G content in proportionate mixture of black and white rice, and red and white rice at cooking condition.

Table 13. Physicochemical parameters of local germplasms and HYVs.

Germplasms	Pericarp color	Length (mm)	Breath(mm)	L/B ratio	Grain size and shape	Aroma
BK1	Black and white	5.9	2.5	2.4	Medium bold	-
BK2	Black	7.6	2.2	3.4	Extra-long slender	-
BK3	Black	6.7	2.5	2.7	Long bold	-
BK4	Black	6.5	2.5	2.6	Long bold	-
BK5	Black	6.5	2.3	2.8	Long bold	-
BK6	Black	6.5	2.6	2.5	Long bold	+
BK7	Black	6.6	2.1	3.1	Long slender	-
BK8	Black	6.2	2.3	2.6	Long bold	-
BK9	Black	6.5	2.1	3.0	Long bold	+
BK10	Black	6.3	2.5	2.5	Long bold	-
BK11	Black	7.6	2.5	3.0	Extra long bold	-
Laxmideega	Black and red	5.7	2.4	2.3	Medium bold	-
BRRI dhan84	Red	6.5	2.2	3.0	Long bold	-
BRRI dhan80	White	6.8	2.1	3.2	Long slender	-
Gabura	White	6.6	2.7	2.5	Long bold	-

Table 14. Retention of C3G in cooked black rice and mixed with red and white pericarp HYVs.

Sample	C3G (mg kg^{-1})	C3G retention (%)
100% BRRI dhan80 (cooked)	Not detected	Not detected
5% BK 11 + 95% BRRI dhan80 (cooked)	25.04 ± 0.99f	3.24
10% BK 11 + 90% BRRI dhan80	38.94 ± 1.51e	4.66
25% BK 11 + 75% BRRI dhan80 (cooked)	109.26 ± 5.24c	12.98
100% BK11 (raw)	806.17 ±1.06a	Not applied
100% BK11 (cooked)	387.40 ±1.44b	47.85
100% BRRI dhan84 (cooked)	Not detected	Not detected
5% BK 11 + 95% BRRI dhan84 (cooked)	36.38 ±5.33e	3.76
10% BK 11 + 90% BRRI dhan84 (cooked)	55.78 ±2.67d	6.75
25% BK 11 + 75% BRRI dhan84 (cooked)	109.46 ±6.53c	13.34
Any two-means having common letter (s) are not statistically different at a P <0.05, as measured by the Duncan Multiple Range Test (DMRT).		

METHOD DEVELOPMENT AND VALIDATION FOR DETECTION OF BIOACTIVE COMPOUNDS, PHYTOHORMONES, VITAMINS AND AROMA IN RICE GRAIN

A total of 11 methods including nine HPLC and two GCMS methods were developed and validated using Shimadzu Prominence-i Modular HPLC and Shimadzu Nexis GC2030 equipped with MS-QP2020NX at GQN and BCL laboratory respectively. HPLC methods for detection and quantification of rice phytohormones including 3-Indoleacetic acid (IAA), Gibberellic Acid (GA_3) and Abscisic Acid (ABA), Water soluble rice vitamins such as Thiamine ($VitB_1$), Riboflavin ($VitB_2$), Niacin ($VitB_3$), Thyroxine (Vit B_6), Folic acid (Vit B_9) and Cyanocobalamin (Vit B_{12}). GCMS methods are detection and quantification of rice volatile aromatic compounds such as 2AP (2 Acetyl-1-Pyrroline) and rice fatty acid profiling (C14:0 Myristic acid, C14:1 Myristoleic acid, C16:0 Palmitic acid, C16:1 Palmitoleic acid, C18:0 Stearic acid, C18:1 Oleic acid, C18:2/Omega-6 Linoleic acid, C18:3/Omega-3 Linolenic acid, C20:0 Arachidic acid, C20:1 Eicosanoic acid, C22:0 Behenic acid).

The HPLC prominence-i LC2030C Shimadzu machine was equipped with Shim pack GISS RP C18 column (3µm 4.6x150 mm). Methanol (HPLC grade):0.1% Acetic acid >99.0%): Water (MQ) (40:40:20 v/v) were used as mobile phase. The separation was carried out by isocratic elution with a flow of 0.8 ml/min, oven temperature was set at 30°C and injection volume was 10 µl. The standard solution of the individual phytohormones (ABA, GA_3 and IAA) was dissolved in HPLC grade methanol. Signal of the compounds was monitored at 280, 208 and 265 nm by using PDA detector for the detection of specific peak of ABA, GA_3 and IAA respectively (Fig. 1, Fig. 2 and Fig. 3).

Mobile Phase for $VitB_1$ was Methanol: 0.05 M CH3C00Na, pH 6.0 (40:60) in an isocratic solution. Mobile Phase for $VitB_2$, $VitB_3$, $VitB_6$, $VitB_9$ and $VitB_{12}$ was Methanol: 0.05 M NaH_2P0_4

with 0.005 M Hexanesulfonic acid, pH 3.0 in a gradient solution. The standard solution of the individual water soluble vitamins ($VitB_1$,$VitB_2$, $VitB_3$, $VitB_6$,$VitB_9$ and $VitB_{12}$) was dissolved in HPLC grade methanol. Signal of the compounds was monitored at 270, 268, 260, 291, 283 and 362 nm by using PDA detector for the detection of specific peak of $VitB_1$,$VitB_2$,$VitB_3$,$VitB_6$,$VitB_9$ and $VitB_{12}$ respectively (Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8 and Fig. 9).

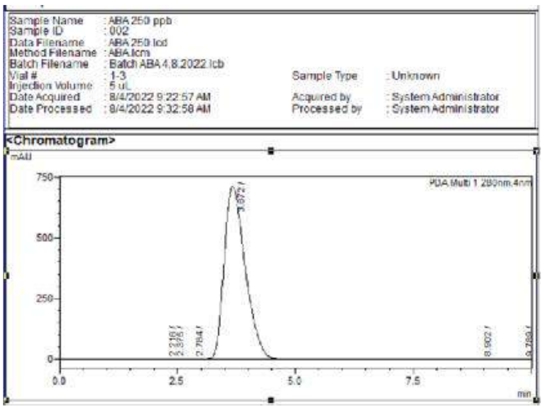


Fig. 1 HPLC peak of ABA (RT 3.67 mins, PDA detector at 208 nm).

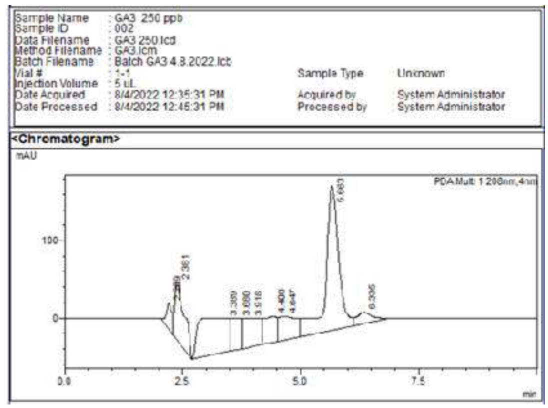


Fig. 2 HPLC peak of GA_3 (RT 5.66 mins, PDA detector at 280 nm).

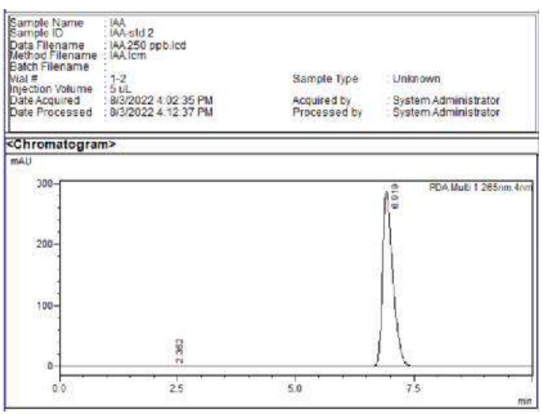


Fig. 3 HPLC peak of IAA (RT 6.91 mins, PDA detector at 270 nm). PDA

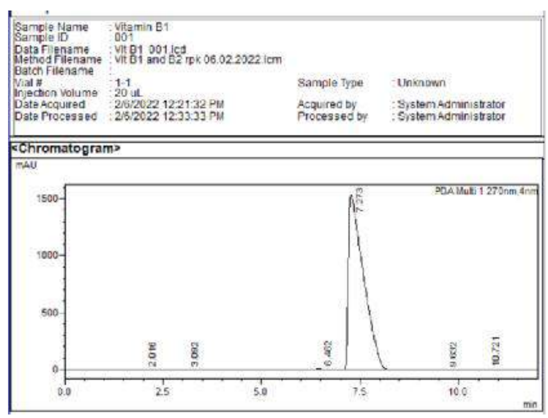


Fig. 4 HPLC peak of $VitB_1$ (RT 7.27 mins, detector at 265 nm).

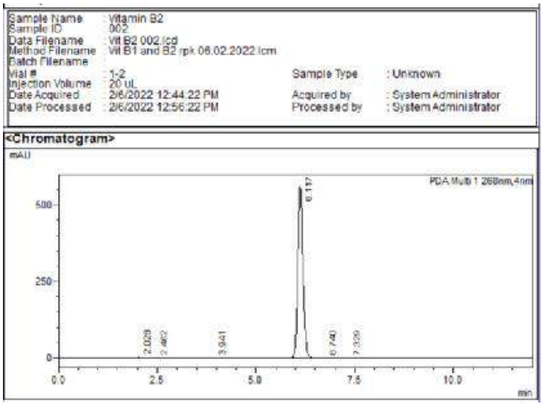


Fig. 5 HPLC peak of $VitB_2$ (RT 6.11 mins, PDA PDA detector at 268 nm).

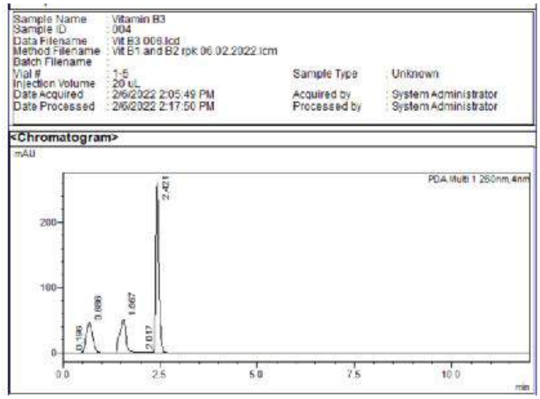


Fig. 6 HPLC peak of $VitB_3$ (RT 2.42 mins, detector at 260 nm).

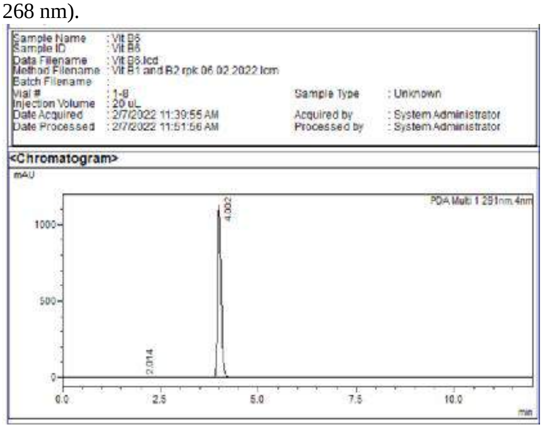


Fig. 7 HPLC peak of $VitB_6$ (RT 4.00 mins, PDA PDA detector at 283 nm).

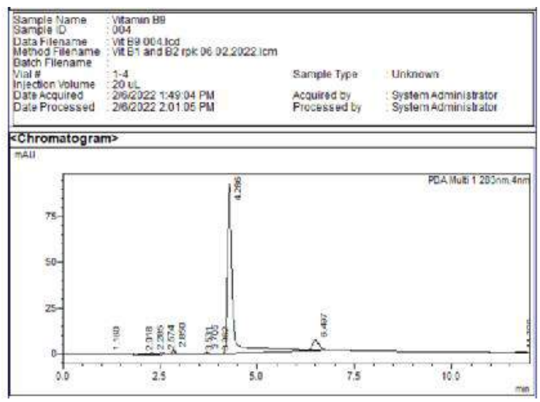


Fig. 8. HPLC peak of $VitB_9$ (RT 4.28 mins, detector at 291 nm).

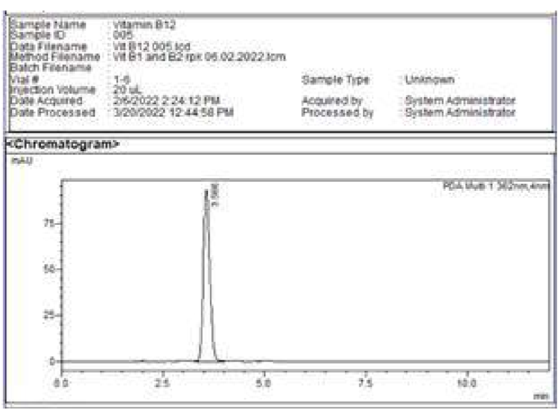
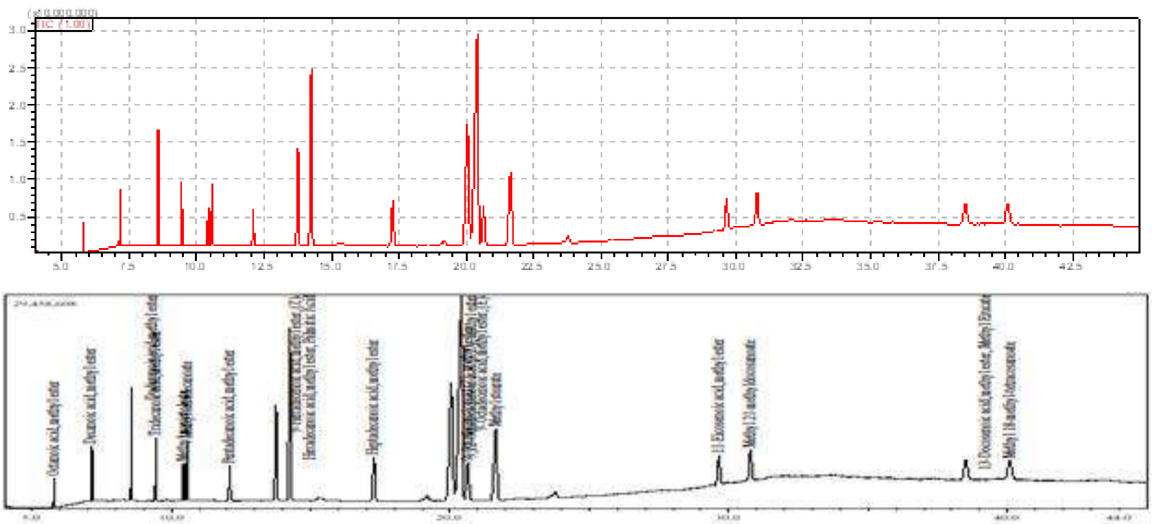


Fig. 9. HPLC peak of $VitB_{12}$ (RT 3.56 mins, PDA detector at 362 nm).

Fatty acids need to be converted into fatty acid methyl esters (FAME) for GCMS analysis. For the purpose, 15 g of each oil sample was poured into a test tube and 2 ml 5M KOH was added. The solution was heated at 85°C for 10 min. The resulting solution was then neutralized with 0.7M HCL. The resulted solution was further heated at same temperature for 10 minutes and methylated oil was extracted with petroleum ether. The fatty acid methyl esters were then separated and subjected to GC2030 equipped with MS-QP2020NX SH-Rxi-5Sil MS (30 m, 0.25 mm ID, 0.25 µm columns) and OPTIC-4. Helium was the carrier gas at the flow rate of 50 psi and SCAN acquisition speed was 1.666 and m/z was between 50 to 500. Interface Temperature was 250°C. The temperature was programmed at holding temperature at 50°C for 1 minute then increased temperature at 200°C at a rate of 25°C per minutes and then hold for 15 mins. Later on increased temperature at 230°C ant rate of 3°C per mins and finally hold at 230°C for 13 mins. In total run time of sample was 45 mins.

Identification and quantification of the methyl esters were made by comparison of retention time with standard fatty acid methyl esters Certified reference materials of Grain FAME Mix CRM47801 Supelco were used in the analysis as reference (Fig. 10). NIST20M1 GCMS library was used for detection and confirmation of fatty acid methyl esters. Data were expressed in percentage format.

2-Acetyl-l-Pyrroline (2AP), volatile aromatic compound was screened and measured in GC2030 equipped with MS-QP2020NX SH-Rxi-5Sil MS (30 m, 0.25 mm ID, 0.25 µm columns) and OPTIC-4. Helium was the carrier gas at the flow rate of 50 psi and SIM acquisition mode was selected for 41, 43, 69, 83 and 111 m/z. Interface temperature was 250°C. The temperature was programmed at holding temperature at 50°C for five minutes then increased temperature at 100°C at a rate of 10°C per minutes. Total run time of sample was 10 minutes. The standard of 2-Acetyl-1-Pyrroline (2AP, 95% purity, Toronto Research Chemicals (TRC) Catalog no.4187225) was used. Four points calibration curve was found linear (y=7569.8x-481224, R^2 :0.997) and standards are ranging from 100 ppb to 500 ppb. Retention time (RT) of 2AP is 6.7 mins and m/z is 43. NIST20M1 GCMS library was used for detection and confirmation of 2AP (Fig. 11).



Quantitative Result Table

ID#	Name	R.Time	m/z	Area	Conc.	Conc.Unit
1	Octanoic acid, methyl ester	5.790	74.00	1845602	1.466	%
2	Decanoic acid, methyl ester	7.156	74.00	3557205	2.825	%
3	Lauric Acid	8.568	74.00	8087145	6.422	%
4	Tridecanoic acid, methyl ester	9.446	74.00	4805808	3.816	%
5	Methyl myristoleate	10.435	55.00	1455737	1.156	%
6	Methyl tetradecanoate/Myristoleate	10.573	74.00	5452136	4.330	%
7	Pentadecanoic acid, methyl ester	12.101	74.00	3808878	3.025	%
8	-Hexadecenoic acid, methyl Palmitat	13.757	55.00	4803076	3.814	%
9	Methyl Palmitoleate	14.257	74.00	23696062	18.818	%
10	Heptadecanoic acid, methyl ester	17.274	74.00	7536716	5.985	%
11	Stearic Acid	20.039	67.00	12501161	9.928	%
12	Elaidic Acid	20.414	55.00	16333050	12.971	%
13	Oleic Acid	20.644	55.00	2510117	1.993	%
14	Linoleic Acid	21.646	74.00	15705063	12.472	%
15	11-Eicosenoic acid, methyl ester	29.656	55.00	2195927	1.744	%
16	Linolenic Acid	30.794	74.00	4909810	3.899	%
17	Behenic Acid	38.500	55.00	2093654	1.663	%
18	Erucic Acid	40.093	74.00	4625327	3.673	%

Fig. 10. Chromatogram view of fatty acid methyl ester (FAME) at GCMS.

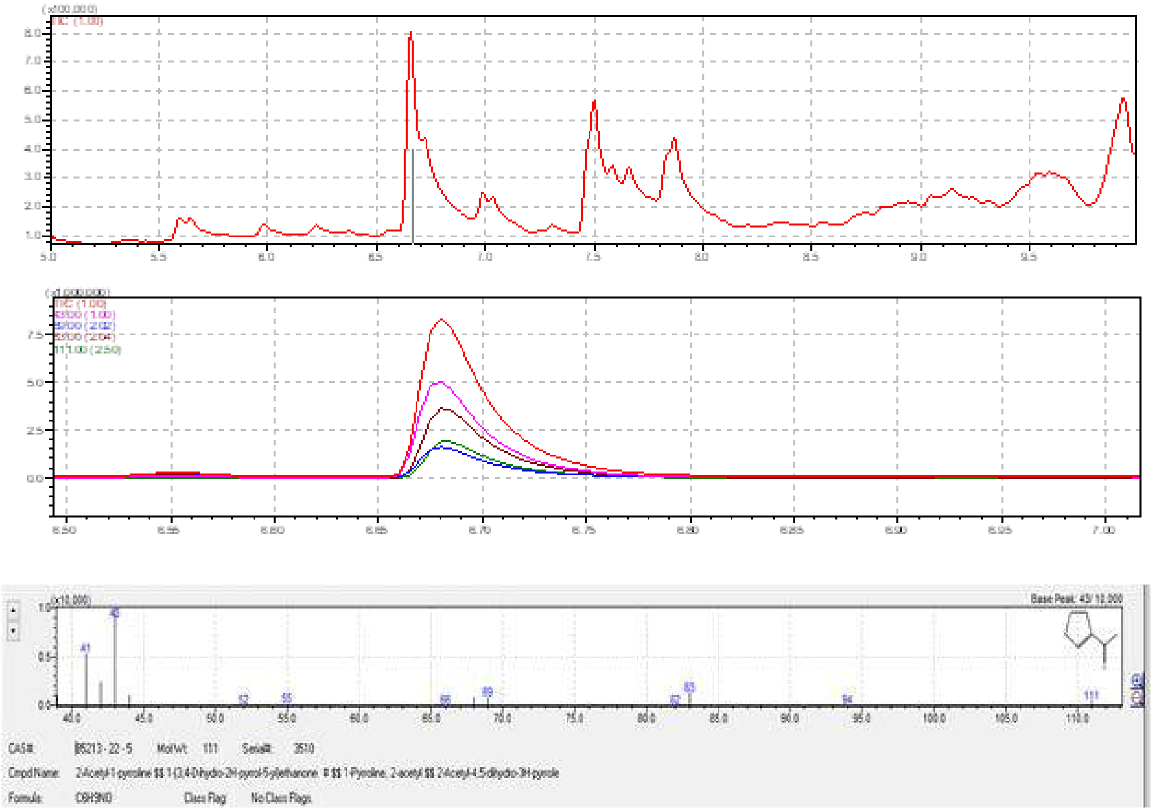


Fig. 11. Chromatogram view of aromatic volatile compound 2-Acetyl-l-Pyrroline (2AP) at GCMS.

COMMERCIAL RICE BASED PRODUCTS

Determination of physicochemical properties and quality of puffed, popped and flattened rice from newly released BRRI varieties

PI: MAH; **CI:** NF, TKS, HBS and MAS

Physical properties viz length, breadth, thickness, increased length and breadth, volume of rice products such as puffed, popped and flattened rice were determined. This study aims to screen out the BRRI released varieties that are suitable for popular snack food products: puffed, popped and flattened rice for instances. BR16 is used as standard for all the products of puffed, popped and flattened rice. Comparing with the standard variety, it is ascertained from the results that BRRI dhan99 and Bangabandhu dhan100 are better in producing fully puffed rice 47.8% and 61.9% respectively followed by BRRI dhan97 (40.7%) and BRRI dhan9 (41.4%) in terms of weight of fully puffed rice. Considering overall parameters, BRRI dhan99 and Bangabandhu dhan100 yielded better results: puffed rice length =11.95 mm and 10.41 mm; increased percentage of puffed rice length= 100.1% and 94.2%; and 50 g puffed rice volume = 530 ml and 550 ml followed BRRI dhan97, (puffed rice length =11.45 mm, increased percentage of length =97.7%, volume =481.7 ml) and BRRI dhan98 (puffed rice length =11.47 mm, increased percentage of length =71.5%, volume =423.3 ml) respectively (Table 15). Results of correlation matrix for relationships ascertained that 1000 puffed rice weight is significant and positively correlated with milled rice length ($r=0.668$, $p<0.05$) and only positively correlated with milled rice breadth. Volume of 50 g puffed rice is highly significant and positively correlated with puffed rice length increased percent ($r=0.832$, $p<0.01$), significant and positively correlated with puffed rice breadth increased percent ($r=0.720$, p<0.05) but highly significant and negatively correlated with 1000 puffed rice weight (r=0.773, p<0.05) (Table 16).

In the case of popped rice, BRRI dhan99 and Bangabandhu dhan100 show excellent performance followed by BRRI dhan96 and BRRI dhan98 considering total popped rice percent, fully popped rice percent, partial and broken popped rice percent. On the other hand, in terms of increased popped rice length and volume of 50 g popped rice, Bangabandhu dhan100 (139.27% and 1050.00 ml) performed better than BRRI dhan99 (112.40% and 816.70 ml). However, BRRI dhan99 (149.66%) and Bangabandhu dhan100 (148.37%) showed the highest potential in increasing breadth percent and fully popped percent (80.01% and 82.28%) respectively after being popped (Table 17). Results of correlation matrix for relationships ascertained that brown rice breadth is significant and positively correlated with total waste (r=0.779, p<0.05). Fully popped rice weight is highly significant and positively correlated with popped rice length (r=0.856, p<0.01). It is also significant and positively correlated with popped rice length percent (r=0.676, p<0.05) increased. Popped rice breadth increased percent is significant and positively correlated with total popped rice weight (r=0.720, p<0.05) and popped rice length increased percent (r=0.769, p<0.05). Weight of 1000 popped rice is significant and positively correlated with total waste (r=0.725, p<0.05), brown rice length (r=0.715, p<0.05) and brown rice breadth (r=0.790, p<0.05). Volume of 50 g popped rice is highly significant and positively correlated with popped rice length increased percent (r=0.876, p<0.01) and popped rice breadth increased (r=0.861, p<0.01) percent. It is also significant and positively correlated with total popped rice weight (r=0.738, p<0.05) and fully popped rice weight (r=0.771, p<0.05) (Table 18).

Similarly, physical properties such as whole, partial and broken flattened rice were considered. Comparing with the standard variety (BR16), it is revealed from the results that in terms of weight of whole, partial and broken flattened rice BRRI dhan98 showed the best performance followed by BRRI dhan96. Moreover, the results demonstrated that BRRI dhan96 showed higher potential in producing flattened rice considering flattened rice length increased percent, thickness of flattened rice and volume of 50 g sample (li=125.40%, t=0.57 mm, vol=170.0 ml) which is better than the standard as of BR16 (li=104.38%, t=0.53 mm, vol=158.3 ml) and other varieties considered for this study (Table 19). It is ascertained from the study that brown rice length and breadth are not insignificantly correlated with the flattened rice length and breadth. Results of correlation matrix for relationships ascertained that flattened rice breadth increased is significant and positively correlated with broken flattened rice wt. (r=0.733, p<0.05). Similarly, 1000 Flattened rice weight is significant and positively correlated with flattened rice breadth (r=0.827, p<0.05) and flattened rice breadth increased (r=0.765, p<0.05) (Table 20) percent.

Table 15. Physical properties of puffed rice of BRRI modern varieties.

Variety name	**Fully puffed rice wt. (%)**	**Partial puffed rice wt. (%)**	**Milled rice length (mm)**	**Milled rice breadth (mm)**	**Puffed rice length (mm)**	**Puffed rice length increased (%)**	**Puffed rice breadth (mm)**	**Puffed rice breadth increased (%)**	**1000 Puffed rice wt. (g)**	**50 gm Puffed rice volume (ml)**
BR16	74.0A	25.9F	6.62	2.23	11.90A	79.8D	4.18C	87.3BC	17.50D	423.3E
BRRI dhan96	17.8EF	82.2AB	5.60	2.09	11.15C	99.0A	4.16C	99.0A	11.78H	530.3B
BRRI dhan97	40.7D	59.2C	5.79	2.53	11.45B	97.7A	4.75A	87.7BC	11.81H	481.7C
BRRI dhan98	41.4	58.6C	6.69	2.07	11.47B	71.5F	3.83E	85.0CD	15.17E	423.3E
BRRI dhan99	47.8C	50.9D	5.97	2.09	11.95A	100.1A	3.99D	91.1B	13.66F	530.0B
Bangaban	61.9B	38.1E	5.36	2.02	10.41D	94.2B	3.67F	81.5D	12.36G	555.0A

dhu dhan100										
BRRI hybrid dhan3	13.2F	86.7A	5.75	2.67	10.04E	74.6E	4.08CD	52.9G	17.83C	366.0G
BRRI hybrid dhan5	21.5E	78.2B	6.92	2.53	11.60B	67.7G	4.12C	62.7F	21.68A	416.0F
Hybrid hera	13.4F	86.5A	5.86	2.54	11.18C	90.7C	4.34B	71.0E	18.15B	440.0D
Range	13.2-74.0	25.9-86.7	5.4-6.9	2.0-2.7	10.04-11.95	67.7-100.1	3.67-4.75	52.9-87.3	11.78-21.68	366.0-555.0
Mean±SD	36.8±22.0	62.9±22.1	6.1±0.54	2.3±0.26	11.238±0.64	86.14±12.8	4.1244±0.31	79.815±17.74	15.549±3.45	462.85±64.35
SE	2.918	2.924	0.0	0.0	0.078	1.388	0.047	2.0	0.1	3.0
CV%	9.7	5.7	0.0	0.0	0.9	2.0	1.4	3.0	0.7	0.8

Table 16. Correlation among the physical properties of puffed rice of BRRI modern varieties

Correlations

Parameter	Fully puffed rice wt. (%)	Partial puffed rice wt. (%)	Milled rice length (mm)	Milled rice breadth (mm)	Puffed rice length (mm)	Puffed rice length increased (%)	Puffed rice breadth (mm)	Puffed rice breadth increased (%)	1000 Puffed rice wt. (g)
Partial puffed rice wt. (%)	-1.000**								
Milled rice length (mm)	.122	-.122							
Milled rice breadth (mm)	-.577	.580	.090						
Puffed rice length (mm)	.348	-.355	.611	-.246					
Puffed rice length increased (%)	.133	-.139	-.753*	-.338	.059				
Puffed rice breadth (mm)	-.265	.267	-.032	.620	.264	.244			
Puffed rice breadth increased (%)	.477	-.480	-.161	-.754*	.518	.645	.044		
1000 Puffed rice wt. (g)	-.298	.300	.668*	.573	.077	-.787*	-.014	-.750*	
50 gm Puffed rice volume (ml)	.329	-.335	-.569	-.683*	.105	.832**	-.175	.720*	-.773*

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 17. Physical properties of popped rice of BRRI modern varieties.

Variety name	Total popped rice wt. (%)	Total waste (%)	Fully popped rice wt. (%)	Partial popped rice wt. (%)	Broken popped rice wt. (%)	Brown rice length (mm)	Brown rice breadth (mm)	Popped rice length (mm)	Popped rice length increased (%)	Popped rice breadth (mm)	Popped rice breadth increased (%)	1000 Popped rice wt. (g)	50 gm Popped rice volume (ml)
BR16	51.79A	33.55D	82.75A	16.21E	1.16EF	6.83	2.08	13.69A	100.44C	4.86C	133.65B	19.72E	780.0C
BRRI dhan96	44.95D	41.26BC	43.45C	49.59B	6.87A	5.8	1.93	10.62F	83.16H	3.93E	103.80C	13.13I	586.0E

BRRI dhan97	32.37 E	46.63 B	40.47 C	59.32 A	0G	6.07	2.55	11.30E	86.21 G	4.96 ABC	94.38 D	20.18D	525.0G
BRRI dhan98	45.82 C	38.62 CD	78.51 A	20.56 E	0.80 FG	6.59	2.02	12.82C	94.54 E	3.95 E	95.38 D	17.29F	690.0D
BRRI dhan99	45.99 C	38.67 CD	80.01 A	17.76 E	2.06 DE	6.34	2.02	13.47B	112.40 B	5.04 AB	149.66 A	16.16G	816.7B
Bangabandhu dhan100	47.33 B	37.45 CD	82.28 A	14.78 E	2.84 CD	5.61	1.95	13.42B	139.27 A	4.84 C	148.37 A	13.25H	1050.0 A
BRRI hybrid dhan3	30.99F	54.67 A	56.62 B	40.99 C	2.23 D	6.22	2.47	12.28D	97.48 D	5.07 A	105.26 C	21.55B	555.7F
BRRI hybrid dhan5	24.36 H	60.09 A	63.33 B	31.06 D	5.41 B	7.26	2.35	13.82A	90.31F	4.097 D	74.33 E	24.86A	529.3G
Hybrid hera	25.97 G	58.19 A	59.17 B	37.23 CD	3.45 C	6.06	2.45	12.29D	102.8 C	4.90 BC	100.14 CD	20.51C	533.3G
Range	24.36-51.79	33.55-60.09	40.47-82.75	14.78-59.32	0.80-6.87	5.61-7.26	1.93-2.55	10.62-13.82	83.16-139.27	3.93-5.07	74.33-149.66	13.13-24.86	525.0-1050.0
Mean±SD	38.8±10.34	45.5±9.87	65.2±16.56	32.0±15.98	2.8±2.21	6.3±0.52	2.2±0.25	12.6±1.1	100.7±17.0	4.6±0.48	111.7±26.1	18.5±3.9	674.0±179.5
SE	0.1675	2.6445	3.4155	3.2718	0.4651	0	0	0.0858	1.3389	0.0677	3.208	0.0385	9.0117
CV%	0.53	7.12	6.42	12.54	20.67	0	0	0.83	1.63	1.79	3.52	0.25	1.64

Table 18. Correlation among the physical properties of popped rice of BRRI modern varieties.

Correlations

Parameter	Total popped rice wt. (%)	Total waste (%)	Fully popped rice wt. (%)	Partial popped rice wt. (%)	Broken popped rice wt. (%)	Brown rice length (mm)	Brown rice breadth (mm)	Popped rice length (mm)	Popped rice length increased (%)	Popped rice breadth (mm)	Popped rice breadth increased (%)	1000 Popped rice wt. (g)
Total waste (%)	-.980**											
Fully popped rice wt. (%)	.562	-.503										
Partial popped rice wt. (%)	-.549	.471	-.991**									
Broken popped rice wt. (%)	-.213	.337	-.303	.175								
Brown rice length (mm)	-.198	.222	.276	-.278	-.054							
Brown rice breadth (mm)	-.857**	.779*	-.556	.605	-.226	.162						
Popped rice length (mm)	.152	-.105	.856**	-.857**	-.207	.579	-.196					
Popped rice length increased (%)	.356	-.330	.676*	-.677*	-.164	-.374	-.381	.539				
Popped rice breadth (mm)	-.066	.012	.114	-.045	-.528	-.273	.391	.166	.447			
Popped rice breadth increased (%)	.720*	-.699*	.621	-.606	-.249	-.385	-.574	.351	.769*	.527		
1000 popped rice wt. (g)	-.743*	.725*	-.182	.204	-.122	.715*	.790*	.268	-.425	.120	-.616	
50 gm popped rice volume (ml)	.738*	-.717*	.771*	-.769*	-.201	-.284	-.707*	.515	.876**	.218	.861**	-.633

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Table 19. Physical properties of flattened rice of BRRI modern varieties

Variety name	Fully flattened rice wt. (%)	Partial flattened rice wt. (%)	Broken flattened rice wt. (%)	Brown rice length (mm)	Brown rice breadth (mm)	Flattened rice length (mm)	Flattened rice length increased (%)	Flattened rice breadth (mm)	Flattened rice breadth increased (%)	Flattened rice thickness (mm)	1000 Flattened rice wt. (g)	50 gm Flattened rice volume (ml)
BR16	75.61 B	2.08D	22.21D	6.77	2.18	13.84 A	104.38 D	4.38D	101.1C	0.53C	18.37 E	158.33 C
BRRI dhan96	73.35 B	4.26B C	22.24D	5.76	2.11	12.98 C	125.4A	4.22E	100.0C	0.57B C	16.30 F	170B
BRRI dhan97	34.09 F	6.25A	59.57A	6.62	2.08	12.94 C	95.42E	4.78B	129.97 A	0.63B	22.28 B	140E
BRRI dhan98	92.43 A	1.28D	6.25E	6.17	2.66	11.73 F	90.06F	3.72F	39.97E	0.58B C	13.78 H	150D
BRRI dhan99	62.81 C	3.76C	33.34C	6.41	2.18	13.35 B	108.22 C	4.87B	123.24 B	0.71A	27.19 A	140E
Bangabandhu dhan100	55.93 DE	6.07A	37.91B	5.59	2	12.03 E	115.27 B	3.82F	90.83D	0.61B	15.62 G	120F
BRRI hybrid dhan3	55.57 E	5.49A B	38.87B	6.39	2.66	12.29 D	92.33F	5.04A	89.77D	0.62B	20.06 C	181.67 A
BRRI hybrid dhan5	59.57 CD	1.2D	39.12B	7.28	2.45	12.29 D	68.77G	4.64C	89.25D	0.56B C	19.93 D	160C
Range	34.09-92.43	1.2-6.25	6.25-59.57	5.59-7.28	2.0-2.66	11.73-13.84	68.77-125.4	3.72-5.04	39.97-129.97	0.53-0.71	13.78-27.19	120-181.67
Mean±SD	63.669±17.3	3.7975±2.1	32.439±15.8	6.3738±0.6	2.2900±0.3	12.680±0.8	99.981±17.4	4.4338±0.5	95.514±27.2	0.6000±0.1	19.191±4.3	152.50±19.4
SE	1.8465	0.7638	1.8028			0.0924	1.4091	0.0509	2.2912	0.0325	0.041	1.1785
CV%	3.55	24.63	6.81	0	0	0.89	1.73	1.41	2.94	6.64	0.26	0.95

Table 20. Correlation among the physical properties of flattened rice of BRRI modern varieties.

Correlation

Parameter	Fully flattened rice wt. (%)	Partial flattened rice wt. (%)	Broken flattened rice wt. (%)	Brown rice length (mm)	Brown rice breadth (mm)	Flattened rice length (mm)	Flattened rice length increased (%)	Flattened rice breadth (mm)	Flattened rice breadth increased (%)	Flattened rice thickness (mm)	1000 Flattened rice wt. (g)
Partial flattened rice wt. (%)	-.724*										
Broken flattened rice wt. (%)	-.996**	.658									
Brown rice length (mm)	-.185	-.498	.268								
Brown rice breadth (mm)	.393	-.465	-.367	.314							
Flattened rice length (mm)	-.105	.004	.113	.257	-.518						
Flattened rice length increased (%)	.101	.475	-.174	-.800*	-.654	.367					
Flattened rice breadth (mm)	-.593	.243	.615	.559	.107	.418	-.288				

Flattened rice breadth increased (%)	-.737*	.534	.733*	.175	-.679	.704	.280	.653			
Flattened rice thickness (mm)	-.322	.491	.272	-.418	-.135	-.013	.396	.356	.560		
1000 flattened rice wt. (g)	-.536	.201	.558	.439	-.185	.525	-.108	.827*	.765*	.725	
50 gm flattened rice volume (ml)	.228	-.247	-.216	.289	.581	.099	-.214	.414	-.160	-.303	-.058

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Hybrid Rice Division

SUMMARY

In T. Aman season 2021, a total of 76 test crosses and 611 (A × R) crosses were made from source nursery. Two hundred seven test crosses (F_1s) were evaluated for their pollen fertility status of which one entry has been found heterotic over check varieties. Pollen parent of this combination was regarded as suspected restorer and selected for fertility restoration ability with other CMS lines in the next season. One entry was found completely sterile and their corresponding male parent was regarded as suspected maintainer line. Four backcross entries were advanced as new CMS lines. Other backcross generations were advanced to the next generations except three BC_1 generations which were found unstable in terms of pollen sterility and hence discarded. Ninety CMS lines along with their respective maintainer lines were maintained by hand crossing.

A total of 134 test crosses and 410 (A × R) crosses were made using 13 CMS lines in Boro season 2021-22. One hundred twenty-seven test crosses (F_1s) were evaluated for their pollen fertility status. Among them thirteen entries showed complete sterility and immediately backcrossed with their corresponding male parents for conversion. On the other hand, four entries have been selected for their high yielding ability compared with check varieties. All the backcross entries were advanced for next generations except for three entries. One hundred eighteen CMS lines along with their respective maintainer lines were maintained by hand crossing in CMS maintenance and evaluation nursery for their genetic purity.

In T. Aman, out of 271 test hybrids under observational trials nine (9) hybrid combinations were selected based on yield, duration and grain type and expressed more than 15-30% yield advantage over check variety BRRI hybrid dhan6, 10-25% over AZ7006 and 4-18 % over Dhanny Gold. The heritability obtained from growth duration, spikelet fertility and grain yield were 78%, 81% and 69% respectively, indicating high level of precision in this experiment. In Boro, out of 429 test hybrids 14 hybrid combinations were selected based on yield, duration and grain type. The selected hybrid combinations expressed 7-30% yield advantage over BRRI hybrid dhan5, 14-38% over SL8H and 24-51% over Suborno. The heritability obtained from growth duration and grain yield was 88% and 80% respectively, indicating high level of precision in this experiment.

Under parental line improvement programme (B × B and R × R) 15 B × B and 11 R × R crosses were confirmed based on different cyto-sources and amylose content in T. Aman, 21 and 10 BxB and 12 R×R crosses were made based on different cyto-sources, grain type and amylose content in Boro 2021-22. Under field rapid generation advancement program 16,819 F_2 and F_3 progenies of B×B, R×R and A×R were advanced in T Aman and 54,163 progenies of F_2, F_3 and F_4 generations of B×B, R×R and A×R crosses were advanced in Boro 2021-22.

In T. Aman, preliminary yield trials, three hybrids were selected out of 14 and showed yield advantage 12-14 % over BRRI hybrid dhan6, 21-24 % over AZ7006 and 6-8 % over Dhanny Gold. In T. Aman under multi-location trials three hybrids out of 18 gave 11-18% yield advantage over BRRI hybrid dhan6, 11-17% over AZ7006 and 20-27% over Dhanny Gold. In Boro, Twenty-seven hybrids were evaluated under two sets along with three hybrids as check variety. In the first set, none of the hybrids showed superiority over BRRI hybrid dhan5 but two hybrids were found promising in second set and expressed yield advantage 12-14% over BRRI hybrid dhan5, 27-29% over Suborno-3 and 22-24% over Teea check variety.

Adaptability under saline condition of BRRI released and popular company hybrids along with popular saline tolerant inbred check BRRI dhan67 and BINA dhan10 along with locally adapted inbred IT was done at three coastal locations of Satkhira. The highest water salinity was found in Assasuni (7.65 dS/m) followed by Kaliganj (7.36 ds/m) and Debhata (6.81 ds/m). We found that the top three highest yielding genotypes were BRRI hybrid dhan3 (7.00 t ha-1), BRRI hybrid dhan5 (6.93 t ha-1) and BRRI hybrid dhan4 (6.88 t ha-1) followed by BRRI99A/EL254R (6.49), BRRI hybrid dhan6 (6.37 t ha-1), IT (6.35 t ha-1), BRRI hybrid dhan7 (6. 28 t ha-1), BRRI99A/BRRI31R (6.11 t ha-1), Binadhan-10 (5.85 t ha-1), BRRI hybrid dhan2 (5.75 t ha-1), BRRI dhan67 (5.75 t ha-1), Janokraj (5.60 t ha-1),

SL-8 (5.47 t ha-1), Gold (Lal teer) (5.45 t ha-1), Heera (Supreme) (5.34 t ha-1). Therefore, we can conclude that BRRI hybrid dhan3, BRRI hybrid dhan5 and BRRI hybrid dhan4 can be cultivated profitably in areas where water salinity level of the paddy field remains 3 dS/m to 6 dS/m.

Fifteen CMS lines including promising and released hybrids were multiplied during Boro 2021-22 and got seed yield ranging from 5.2 kg to 1300 kg/plot equivalent to 0.74 to 1.91 t/ha. Experimental F_1 seed production was made using fifteen CMS with six different restorer lines and seed yield was ranging from 0.8 to 40 kg/plot out of selected promising hybrid combinations during T. Aman 2021 which was equivalent to 0.02 to 1.14 t/ha. Eighty Experimental hybrids were evaluated in augmented design during Boro 2021-22 and selected four hybrids expressed more than 10% yield advantages over check varieties. In Boro 2021-22, a total of 960 kg (2.4 t/ha) from BRRI hybrid dhan5 and 1,246 kg (2.6 t/ha) from BRRI hybrid dhan6, 2,800 kg (2.7 t/ha) from BRRI hybrid dhan7 and 88 kg (2.2 t/ha) from BRRI hybrid dhan8 were obtained. From production side (Ishwardi, Mymensingh and Barishal) 1430 kg (1.8 t/ha) from BRRI hybrid dhan2, 10400 kg (2.4 t/ha) from BRRI hybrid dhna3, 2,460 kg (2.05 t/ha) from BRRI hybrid dhan4, 10,210 kg (2.04 t/ha) from BRRI hybrid dhan5, 6,000 kg (2.5 t/ha) from BRRI hybrid dhan6 and 6,060 (3.03 t/ha) from BRRI hybrid dhan7 was obtained.

In T. Aman 2021, hybrid rice division supplied 6,750 kg of parental lines and F_1 seeds to 90 farmers, 10 seed companies, scientists, extension people, project people and staffs of BRRI. In Boro 2021-22, hybrid rice division supplied 15,000 kg of parental lines and F_1 seeds to 130 farmers, 24 seed companies, scientists, extension people, projects and staffs of BRRI. In T Aus 2022, 4,357 kg F_1 seeds of BRRI hybrid dhan7 was distributed free of cost among farmers through different regional stations of BRRI and department of agricultural extension. Twenty-six stake holders produced more than 325 MT F_1 seeds using BRRI developed hybrid rice parental lines during Boro 2021-22.

DEVELOPMENT OF PARENTAL MATERIALS

Source nursery

Seventy-six test crosses and 611 (A x R) crosses were made during T. Aman season 2021. Ninety-five test crosses and 410 (A × R) crosses were made using 13 CMS lines during Boro season 2021-22.

Test cross nursery

In. Aman 2021, two hundred and seven test crosses (F_1s) were evaluated for their pollen fertility status of which one entry have been found heterotic over check varieties. Pollen parent of this combination was regarded as suspected restorer and selected for fertility restoration ability with other CMS lines in the next season. One entry was found completely sterile and its corresponding male parent was regarded as suspected maintainer line.

In Boro 2021-22, One hundred and twenty-seven test crosses (F_1s) were evaluated for their pollen fertility status. Among them 13 entries showed complete sterility and immediately backcrossed with their corresponding male parents for conversion. On the other hand, four entries have been selected for their high yielding ability compared with the check varieties.

Back cross nursery

In T. Aman 2021, four backcross entries were advanced as new CMS lines. Other backcross generations were advanced to next generations except three BC_1 generations which were found unstable in terms of pollen sterility and hence discarded.

In Boro 2021-22, all entries advanced for next generation except three for their pollen sterility fluctuation.

CMS maintenance and evaluation nursery

Ninety CMS lines were maintained by hand crossing for seed increase and genetic purity in T. Aman 2021 and in Boro 2020-21, 118 CMS lines were maintained through hand crossing for seed increase and genetic purity.

EVALUATION OF PARENTAL LINES AND HYBRIDS

In T Aman 2021, out of 271 test hybrids under observational trials nine hybrid combinations were selected based on yield, duration and grain type and expressed more than 15-30% yield advantage over check variety BRRI hybrid dhan6, 10-25% over AZ7006 and 4-18 % over Dhanny Gold. The heritability obtained from growth duration, spikelet fertility and grain yield were 78%, 81% and 69% respectively, indicating high level of precision in this experiment (Table 1). Upon commercial seed production feasibility of these selected hybrid combinations and grain quality assessment it will be tested under preliminary yield trial (PYT) and multi-location yield trials (MLT). Upon satisfactory yield advantage over check variety it is subjected to registration under National Hybrid Rice Yield Trial (NHRYT) for releasing as new hybrid rice of BRRI. In Boro, out of 429 test hybrids 14 hybrid combinations were selected based on yield, duration and grain type. The selected hybrid combinations expressed 7-30% yield advantage over BRRI hybrid dhan5, 14-38% over SL8H and 24-51% over Suborno-3. The heritability obtained from growth duration and grain yield was 88%% and 80% respectively, indicating high level of precision in this experiment (Table 2).

Table 1. List of experimental hybrids found heterotic over check variety during T. Aman, 2021.

Designation	DTM	SF%	GT	PY(kg) 2m^2	Yield (t/h)	Heterosis (%)		
						Ck-1	Ck-2	Ck-3
BRRI99A/IR86411-2-1-1-1-2-1R	109	89.5	MS	1.54	7.7	17	12	5
BRRI97A/IR85551-9-1-1-1-2-1-1-1R	112	92.3	MS	1.7	8.5	29	23	16
BRRI109A/BRRI37R	113	90.2	LS	1.52	7.6	15	10	4
BRRI110A/BRRI42R	110	88.2	MS	1.72	8.6	30	25	18
BRRI109A/BRRI41R	114	85.2	MS	1.66	8.3	26	20	14
IR79125A/BRRI39R	116	87.4	MS	1.58	7.9	20	14	8
IR78369A/BRRI43R	112	84.2	LS	1.54	7.7	17	12	5
IR102758A/BRRI46R	117	87.3	LS	1.64	8.2	24	19	12
IR79156A/BRRI46R	113	89.4	LS	1.56	7.8	18	13	7
BRRI hybrid dhan6 (ck-1)	111	84.2		1.32	6.6			
AZ7006 (ck-2)	114	79.1		1.38	6.9			
Dhanny Gold (ck-3)	116	82.4		1.46	7.3			
Heritability	0.78	0.81		0.69	0.69			
LSD$_{(0.05)}$	4.9	4.1		2.3	0.8			

Yield data counted from 30 hills per entry, spacing was 20 cm×15 cm (R × P)
DS: 11 Jul 2021; DT: 1 Aug 2021
Legend: DTM = Days to maturity; SF (%) =Spikelet fertility; GT= Grain type

Table 2. List of the hybrid combinations found heterotic from observational nursery during Boro season 2021-22.

Entry	Designation	DTM	PY (kg) 2m^2	Yield (t/h)	Heterosis (%)		
					Ck-1	Ck-2	Ck-3
OT-68	BRRI50A/SyngentaR (Slender)	147	2.48	12.41	29	37	49
OT-127	BRRI99A/727R	148	2.50	12.49	29	38	50
OT-132	BRRI109A/BRRI41R	147	2.20	11.02	14	21	32
OT-139	BRRI99A/EL86R	146	2.07	10.33	7	14	24
OT-144	IR105688A/WinR New	148	2.47	12.35	28	36	48
OT-145	BRRI99A/ZYB-1	147	2.49	12.45	29	37	49
OT-148	BRRI99A/ SyngentaR (Slender)	146	2.38	11.91	23	31	43
OT-155	BRRI99A/IR85503-3-3-A-1-1-1-1-1R	147	2.26	11.29	17	24	36
OT-164	IR105687A/PR585R	149	2.06	10.32	7	14	24
OT-191	IR105687A/IR85503-3-3-A-1-1-1-1-1R	142	2.10	10.50	9	16	26
OT-213	IR105688A/EL108R	146	2.17	10.84	12	19	30

OT-247	IR79125A/CHH56R	150	2.51	12.56	30	38	51
OT-288	IR79156A/BRRI38R	151	2.13	10.67	11	18	28
OT-290	IR79156A/CHH32R	148	2.47	12.33	28	36	48
ck-1	BRRI hybrid dhan5	152	1.93	9.65			
ck-2	SL8H	151	1.82	9.08			
ck-3	Shuborno-3	138	1.67	8.33			
Heritability		0.88	0.80	0.80			
$LSD_{(0.05)}$		5.79	4.21				

DS: 12 Dec 2021; DT: 12 Jan 2022; Plot size: 2 m^2

Preliminary yield trials of promising hybrids

Under preliminary yield trials three hybrids were selected out of 14 and showed yield advantage 4-14 % over BRRI hybrid dhan6, 4-24 % over AZ7006 and 2-8 % over Dhanny Gold in T. Aman 2021 (Table 3). In Boro, fifteen hybrids were evaluated along with three hybrids as check variety. Three hybrids were selected based on yield, grain quality and amylose content. All the selected hybrids showed yield advantage ranging from 5-7 % over BRRI hybrid dhan5, 32-34 % over Suborno-3 and 22-25 % over Tej Gold (Table 4).

Table 3. Results of preliminary yield trials in T. Aman 2021.

Genotype	PHT	Tiller	D50%F	DM	SF (%)	Yield		Heterosis (%)		
						BLUP	BLUE	Ck-1	Ck-2	Ck-3
IR79125A/BRRI31R	118	8	91	117	83.82	5.58	5.79	14.13	23.63	8.22
BRRI97A/BRRI31R	118	8	95	121	87.56	5.11	5.09	0.33	8.68	
BRRI35A/BRRI31R	103	8	95	121	85.45	5.23	5.27	3.94	12.60	
IR79125A/IR86526-11-6-2-1-1-1-1-1R	109	8	91	117	87.25	4.87	4.71		0.64	
IR79156A/IR86526-11-6-2-1-1-1-1R	104	7	91	117	87.25	5.23	5.26	3.75	12.38	
IR58025A/IR86526-11-6-2-1-1-1-1R	103	8	91	117	88.35	5.07	5.03		7.40	
BRRI11A/BRRI44R	105	7	95	121	89.2	5.22	5.25	3.48	12.10	
BRRI97A/BRRI44R	103	8	95	121	88.32	5.05	5.00		6.8	
BRRI99A/BRRI44R	119	7	95	121	89.32	5.53	5.72	12.7	22.1	6.85
IR79125A/IR77498-45-1-2-2R	103	7	92	118	88.34	5.07	5.03		7.4	
IR79156A/IR77498-45-1-2-2R	105	8	91	117	89.34	5.48	5.65	11.4	20.6	5.61
IR102758A/IR77498-45-1-2-2R	103	7	91	117	90.32	4.73	4.50			
IR78369A/IR77498-45-1-2-2R	102	8	91	117	88.23	5.35	5.45	7.4	16.4	1.87
IR58025A/IR77498-45-1-2-2R	104	7	92	117	89.2	4.96	4.86		3.7	
BRRI hybrid dhan6 (Ck-1)	110	8	95	121	87.36	5.10	5.07			
AZ7006 (Ck-2)	119	7	95	121	88.23	4.85	4.68			
Dhanny Gold (Ck-3)	118	7	91	117	89.5	5.29	5.35			
LSD	2.27	0.80	1.21	1.28		0.35	0.61			
CV	1.25	6.38	0.78	0.65		7.12	7.12			
Heritability	0.99	0.36	0.96	0.95		0.66				

DS: 12 Jul 2021; DT: 06 Aug 2021; Plot size=10 m^2; PHT (cm) = Plant height (cm); DM = Days to maturity; SF (%) = Spikelet fertility

4. Result of preliminary yield trial (PYT) during Boro 2021-22.

Designation	PHT (cm)	GD (days)	GT	Yield (t/h)	AC (%)	Heterosis (%)		
						Ck-1	Ck-2	Ck-3
BRRI7A/IR77498-45-1-2-2R	105	146	MS	9.93	22.4	-	25.7	16.8

IR79125A/IR77498-45-1-2-2R	97	145	MS	10.06	23.3	1.6	27.3	18.4
IR105687A/IR77498-45-1-2-2R	108	146	MS	9.70	23.4	-	22.8	14.1
IR102758A/IR77498-45-1-2-2R	105	147	S	10.5	22.7	6.1	32.9	23.5
BRRI99A/IR86526-11-6-2-1-1-1-1R	103	147	S	10.16	23.0	2.6	28.6	19.5
IR105687A/IR86526-11-6-2-1-1-1-1R	107	143	S	9.2	22.7	-	16.5	8.23
IR79156A/IR86526-11-6-2-1-1-1-1R	111	146	S	10.23	22.4	3.3	29.5	20.4
IR58025A/IR86526-11-6-2-1-1-1-1R	106	144	S	9.13	23.6	-	15.6	7.4
IR79125A/BRRI44R	109	152	S	10.6	23.0	7.0	34.2	24.7
BRRI48A/BRRI38R	109	151	S	10.06	24.2	1.6	27.3	18.4
BRRI11A/BRRI49R	110	148	S	10.33	20.0	4.3	30.8	21.5
BRRI97A/BRRI53R	89	148	S	10.4	21.3	5.0	31.6	22.4
BRRI99A/BRRI53R	104	149	S	9.8	23.1	-	24.0	15.3
BRRI109A/BRRI53R	107	153	S	9.6	24.0	-	21.5	12.9
BRRI109A/BRRI42R	108	149	S	9.7	23.0	-	22.8	14.1
BRRI hybrid dhan5(ck-1)	103	145	LB	9.9				
Shuborno-3(ck-2)	105	141	S	7.9				
Tej Gold(ck-3)	112	146	S	8.5				
Mean	105.4	147.0		9.8				
CV (%)	6.1	2.2		8.9				
Lsd (0.05%)	3.3	1.9		0.4				

DS: 4 Dec 2021; DT: 17 Jan 2022; Plot size: 10 m^2

PH=Plant height (cm), GD= Growth duration (days), AC (%) = Amylose content, GT= Grain type, MS= Medium slender, S = Slender, LB= Long bold

Multi-location yield trials of promising hybrids

In T. Aman 2021, under multi-location trials three hybrids out of eighteen produced 11-18% yield advantage over BRRI hybrid dhan6, 11-17% over AZ7006 and 20-27% over Dhanny Gold (Table 5). In Boro 2021-22, twenty-seven hybrids were evaluated along three check varieties under two sets. None of the tested entries performed well than BRRI hybrid dhan5 in set-I. In setr-II, two hybrids were selected based on stable yield performance and advantage over check across location. The selected hybrids showed yield advantage ranging from 12-14 % over BRRI hybrid dhan5, 26-29 % over Suborno-3 and 22-24 % over Teea (Table 6).

Table 5. Results of multi-location yield trials during T. Aman 2021.

Hybrids	PH (cm)	DTM (days)	Yield (t/ha)					SF (%)	GT	Amy (%)	Aver yield Advantage over Ck (%)			Remarks
			Gaz	Ish	Bari	Mym	Av				Ck-1	Ck-2	Ck-3	
BRRI97A/BRRI46R	105	107	6.3	6.5	5.8	4.3*	5.73	76.7	MS	24.0	-	-	4.6	*Rat damage and some entries submerged
BRRI99A/BRRI46R	110	110	6.5	6.7	6.0	4.2*	5.85	79.2	MS	23.4	-	-	6.8	
IR105688A/BRRI46R	107	108	5.9	6.0	5.8	3.7*	5.35	75.0	S	23.4	-	-	-	
IR79156A/BRRI46R	110	114	7.2	7.5	6.3	6.7	6.93	81.7	S	23.5	17.9	16.9	26.5	
IR78369A/BRRI46R	112	117	6.2	6.8	5.8	3.3*	5.53	78.6	M	23.6			0.9	
IR58025A/BRRI46R	115	115	6.8	7.2	7.4	3.4*	6.20	73.2	S	24.2	5.4	4.6	13.1	
BRRI35A/BRRI45R	109	110	6.0	7.3	5.8	4.0*	5.78	74.7	M	23.4			5.5	
IR79156A/BRRI45R	111	117	6.5	7.1	6.4	6.2	6.55	80.2	MS	23.4	11.4	10.5	19.5	
BRRI35A/BRRI50R	111	113	6.1	6.3	5.9	6.4	6.18	80.1	M	24.0	5.1	4.2	12.8	
IR79156A/BRRI50R	112.0	114	6.4	7.3	6.5	5.8	6.50	79.3	S	23.7	10.5	9.6	18.6	
BRRI11A/BRRI38R	108.0	116	7.4	6.8	6.7	3.2*	6.03	78.7	MS	23.6	2.6	1.7	10.0	
IR105688A/BRRI38R	112.0	110	5.8	6.1	5.76	3.8*	5.37	76.5	MS	23.5	-	-	-	
BRRI11A/BRRI37R	110.0	116	6.8	7.7	6.5	6.1	6.78	80.3	M	24.0	15.3	14.3	23.7	
IR79125A/BRRI44R	113.0	118	6.0	5.8	5.7	6.4	5.98	80.0	M	22.8	1.7	0.8	9.1	
IR79156A/BRRI44R	116.0	117	5.8	5.5	5.9	4.9*	5.53	77.4	MS	23.6	-	-	0.9	
IR102758A/BRRI44R	111.0	119	5.9	6.2	5.5	4.8*	5.60	75.7	M	23.4	-	-	2.2	
IR78369A/BRRI44R	115.0	121	6.8	7.3	6.7	4.2*	6.25	79.4	M	23.5	6.3	5.4	14	

	IR58025A/BRRI44R	120.0	122	5.5	5.4	5.8	4.5*	5.30	77.6	MS	23.0	-	-	-
Ck-1	BRRI hybrid dhan6	112.0	115	5.8	6.2	5.7	5.8	5.88	78.5	S	24.0			
Ck-2	AZ-7006	113.0	132	5.8	5.8	6.1	6.0	5.93	79.3	S				
Ck-3	Dhanny Gold	110.0	126	6.0	5.5	5.3	5.1	5.48	77.8	MS				
Mean		112	116	6.3	6.5	6.1	6.1	5.9	78.1					
CV (%)		2.9	5.1	8.1	11.0	8.1	7.7	7.9	2.8					
LSD (0.05%)		1.84	3.34	0.28	0.40	0.28	0.26	0.26	1.21					

DS: 7 Jul 2021; DT: 26 Jul 2021; Unit plot size: 30 m^2

Table 6. Results of multi-location yield trials during Boro 2021-22.

	Hybrids	PH	DTM	Yield (t/h)					Yield advantage over check (%)		
				Gaz	Ishw	Bar	Rang	Mean	Ck-1	Ck-2	Ck-3
	BRRI97A/BRRI46R	105	148	9.3	9.0	8.5	7.92	8.7	-	3.6	-
	BRRI99A/BRRI46R	107	145	10.8	11.8	11.6	8.88	10.8	13.7	28.6	24.1
	BRRI109A/BRRI46R	109	150	9.1	9.5	9.3	7.83	8.9	-	5.6	2.3
	IR105687A/BRRI46R	89	149	9.2	10.3	9.1	7.80	9.1	-	8.3	4.6
	IR79156A/BRRI46R	110	152	8.9	8.7	8.8	7.34	8.4	-	-	-
	IR58025A/BRRI46R	108	149	9.3	9.5	7.9	8.04	8.7	-	3.6	-
	BRRI97A/BRRI37R	102	145	10.7	11.3	11.5	8.90	10.6	11.6	26.2	21.8
	BRRI109A/BRRI37R	114	151	9.9	9.6	9.2	8.84	9.4	-	11.9	8.0
	BRRI110A/BRRI37R	110	149	8.8	9.7	8.7	8.22	8.9	-	5.6	2.3
	BRRI97A/BRRI36R	103	145	8.8	9.3	8.9	7.63	8.7	-	3.6	-
	BRRI99A/BRRI36R	105	145	8.7	9.6	9.3	7.93	8.9	-	5.6	2.3
	BRRI109A/BRRI36R	110	146	9.3	9.5	9.0	7.81	8.9	-	5.6	2.3
	BRRI110A/BRRI36R	113	151	9.8	9.3	8.8	7.86	8.9	-	5.6	2.3
Ck-1	BRRI hybrid dhan5	107	145	9.7	9.9	9.7	8.51	9.5			
Ck-2	Suborno-3	111	141	8.7	8.5	8.2	8.29	8.4			
Ck-3	Teea	110	146	9.3	8.4	8.7	8.49	8.7			
Mean		107.1	147.3					9.1			
CV (%)		5.5	2.0					7.6			
$LSD_{(0.05)}$		3.8	1.9	0.4	0.6	0.7	0.3	0.4			

Gazipur: DS: 8 Dec 2021; DT: 17 Jan 2022; Barishal: DS: 15 Dec 2021; DT: 20 Jan 2022
Ishwardi: DS: 10 Dec 2021; DT: 15 Jan 2022; Rangpur: DS: 17 Dec 2021; DT: 25 Jan 2022; PH (cm) = Plant height; DTM = Days to maturity; Unit plot =20 m^2

Development of maintainer and restorer lines through (B×B) and (R×R) crosses

Fifteen B×B and 11 R×R crosses were confirmed based on different cyto-sources and amylose content in T. Aman season 2021. In Boro, ten B×B and twelve R×R crosses were made. 54,163 progenies from 74 crosses (23 R × R, 17 A × R and 34 B × B) were advanced to F_2 to F_4 generations using field rapid generation advance (FRGA) technique (Table 7).

Table 7. Progenies selected through field RGA, during Boro 2021-22.

	B x B		R x R		A x R	
	Cross	Population	Cross	Population	Cross	Population
F_2	14	15210	7	5655	14	4772
F_3	15	13883	6	3874	-	-
F_4	5	3763	10	5831	3	1175
Sub-total	34	32856	23	15360	17	5947
Total crosses		74				
Total population		54163				

Evaluation of Fatema dhan

Twenty-one Fatema dhan derived fixed lines were evaluated in T. Aman 2021 and four lines were found having yield potentiality > 5.5 t/ha. In Boro 2021-22, Twenty-one separate lines were selected based on red stigma, white stigma, awn less, with awn, plant type, panicle size, yield and other agronomic performances.

Generation Advancement of Parental Lines having multi stress genes (HRDC materials) at Restorer (R) and Maintainer (M) background

Genotyping of parental lines against diagnostic SNP markers (34 F_7 generations) and Progenies were selected based on their genotypic value (Table 8).

Table 8. Genotyping of parental lines against diagnostic SNP markers during T. Aman 2021.

Pedigree	Identified Trait Marker
IR126044-76-2-2-B	xa5 + Waxy + Chalk5
IR126044-76-2-1-B	xa13 + Waxy + Chalk5
IR126044-15-5-1-B	xa13 + Waxy + Chalk5
IR126055-82-2-2-B	qPi33 + Chalk5 + Gn1a
IR126055-46-3-2-B	qPi33
IR126055-30-5-1-B	Chalk5
IR126055-22-4-1-B	Waxy + Chalk5 + Gn1a
IR126066-15-1-2-B	-
IR126066-21-2-2-B	-
IR126066-85-5-2-B	Pita
IR126069-100-3-2-B	-
IR126069-83-2-2-B	-
IR126069-56-1-2-B	Gn1a
IR126069-48-3-2-B	Pita + Gn1a
IR126069-3-1-1-B	Pita + Gn1a
IR126072-257-1-3-B	Gn1a
IR126072-115-6-1-B	Gn1a
IR126072-91-1-2-B	Gn1a + qNa1L + Saltol
IR126072-83-3-3-B	Chalk5 + qNa1L+ Saltol
IR126072-83-3-1-B	Chalk5 + Gn1a+ qNa1L+ Saltol
IR126076-122-1-1-B	Gn1a + Saltol
IR126076-67-3-2-B	Pita + qPi33
IR127275-36-5-2-B	Chalk5 + Gn1a
IR127275-14-2-2-B	qPi33 + Gn1a
IR127275-9-1-2-B	qPi33 + Chalk5 + Gn1a
IR127278-152-1-3-B	xa5 + xa13 + Gn1a + qNa1L
IR127278-114-3-3-B	waxy + Gn1a + qNa1L
IR127278-55-2-2-B	waxy + Gn1a + qNa1L
IR127278-102-3-1-B	Pita + Gn1a + qNa1L
IR127270-80-2-1-B	Gn1a
IR127270-65-2-4-B	waxy + Gn1a
IR127270-40-6-2-B	Pi9 + waxy + Gn1a
IR126037-59-3-2-B	Pita + waxy + Gn1a
IR126037-20-1-1-B	waxy + Gn1a

Legend: Blast (Pb1, Pi9, Pita and qPi33); Bacterial leaf blight (Xa21, xa13 and xa5); Amylose (waxy); Chalkiness (Chalk5); Grain number (Gn1a); Salinity seedling (qNa1L and Saltol)

Blast tolerant parental line development

Six blast tolerant test crosses were evaluated in T. Aman 2021 and isolated two suspected restorer and two suspected maintainer lines based on microscopic pollen analysis using Iodine potassium iodide solution. Seed multiplication was done and ample amount of pure seed was harvested during Boro 2021-22.

Hybrid rice parental lines development for deep water ecosystem

Deep water donor parent derived test crosses were evaluated in T. Aman 2021 and one test cross was confirmed presence of Rf4 gene from dry lab analysis of 3K rice genome project. In Boro 2021-22, one restorer line was isolated based on microscopic pollen analysis using Iodine potassium iodide solution and dry lab analysis. The hybrid plant showed 10 cm internode elongation during 16 days of submerged condition in deep water tank. After removal of water hybrid plant also showed kneeing ability which is special feature of deep water rice.

Assessment of specific and general adaptability for selection of suitable rice hybrids under saline prone areas for Boro season

Adaptability under saline condition of BRRI developed and popular company hybrids along with popular saline tolerant inbred checks BRRI dhan67, Bina dhan-10 and locally cultivated rice IT was done at three coastal locations of Satkhira. Top three highest yielding genotypes were BRRI hybrid dhan3 (7.00 t ha-1), BRRI hybrid dhan5 (6.93 t ha-1) and BRRI hybrid dhan4 (6.88 t ha-1) followed by BRRI99A/EL254R (6.49), BRRI hybrid dhan6(6.37 t ha-1), IT (6.35 t ha-1), BRRI hybrid dhan7 (6. 28 t ha-1), BRRI99A/BRRI31R (6.11 t ha-1), Binadhan-10 (5.85 t ha-1), BRRI hybrid dhan2 (5.75 t ha-1), BRRI dhan67 (5.75 t ha-1), Janokraj (5.60 t ha-1), SL-8 (5.47 t ha-1), Gold (Lal teer) (5.45 t ha-1), Heera (Supreme) (5.34 t ha-1). Therefore, we can conclude that BRRI hybrid dhan3, BRRI hybrid dhan5 and BRRI hybrid dhan4 can be cultivated profitably in areas where water salinity level of the paddy field remains 3 dS/m to 6 dS/m (Table 9 and Fig. 1).

Table 8. Yield and agronomic performance of sixteen genotypes from adaptive trial in Boro 2021-22.

Genotype	BLUP			Yield (t/ha) BLUE			Combined Yield (t/ha)	
	D50% F	GD	PH	Assasuni	Debhata	Kaliganj	BLUP	BLUE
BRRI hybrid dhan2	113	139	109	6.39	5.52	5.34	5.78	5.75
BRRI hybrid dhan3	114	139	99	7.21	6.91	6.90	6.94	7.01
BRRI hybrid dhan4	117	140	105	7.06	6.80	6.79	6.82	6.88
BRRI hybrid dhan5	114	139	101	7.40	6.59	6.80	6.87	6.93
BRRI hybrid dhan6	113	138	103	6.38	6.25	6.48	6.35	6.37
BRRI hybrid dhan7	115	140	101	6.32	5.87	6.64	6.26	6.28
BRRI99A/BRRI31R	113	138	101	6.55	5.62	6.18	6.11	6.11
Gold (Lal teer)	117	140	94	5.51	5.30	5.55	5.50	5.45
Heera (Supreme)	117	138	111	5.47	5.22	5.34	5.40	5.34
SL-8 (BADC)	118	141	110	5.59	5.40	5.42	5.52	5.47
BRRI dhan67	115	138	87	5.75	5.96	5.52	5.77	5.75
Binadhan-10	120	142	90	5.93	5.80	5.84	5.87	5.85
IT	115	141	120	6.25	6.83	5.98	6.34	6.35
Janokraj	113	137	101	5.79	5.70	5.33	5.64	5.60
BRRI99A/EL254R	115	138	103	6.89	6.11	6.48	6.46	6.49
Heritability	0.98	0.99	0.99				0.92	
LSD (0.05%)	0.48	0.22	0.81	0.35	0.40	0.35	0.30	0.45
CV (%)	0.47	0.21	1.16	3.40	4.06	3.51	3.63	3.63

GD=Growth duration (day), PH=Plant height (cm), D50%F=Days to 50% flowering.

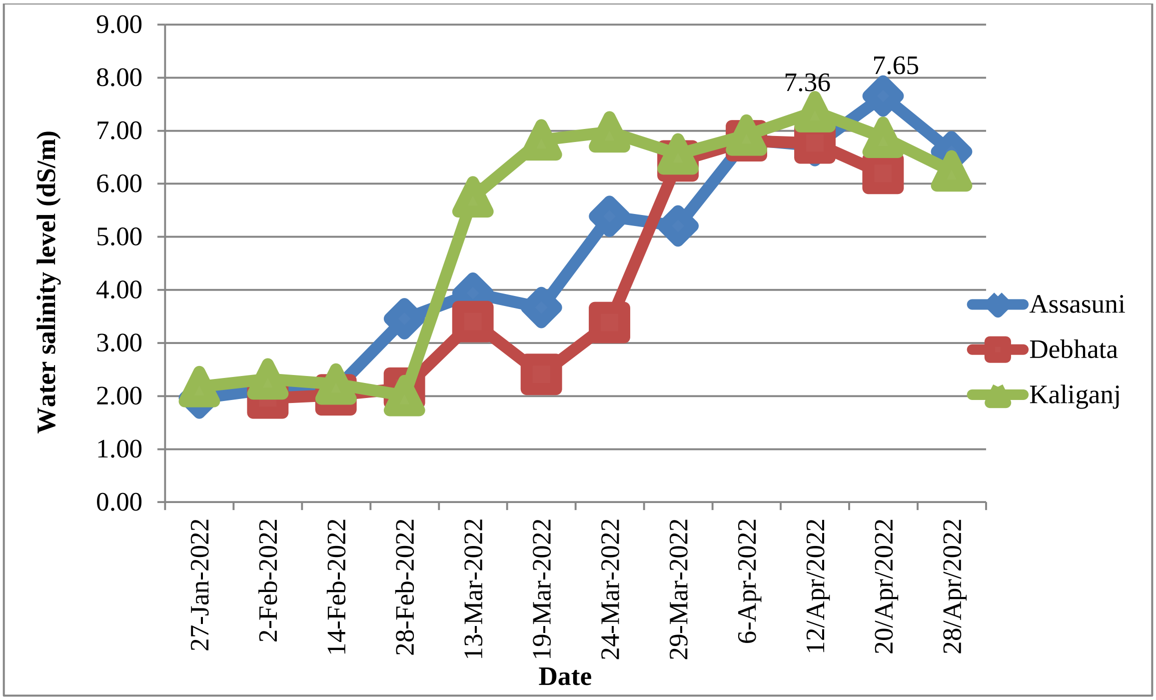


Fig. 1. Water salinity levels (dS/m) of the experimental field during Boro 2021-22.

SEED PRODUCTION OF PARENTAL LINES AND HYBRIDS

CMS line multiplication of released hybrids

Fifteen CMS (Released hybrids CMS and promising CMS lines) were used to multiply using standard CMS multiplication protocol during Boro 2021-22 and seed yield obtained ranging from 5.2 kg/plot (0.74 t/ha) to 1300 kg/plot (1.91 t/ha) depending on plot size and total CMS seeds achieved 4759 kg (Table 9).

Table 9. CMS lines multiplication of released and promising hybrids during Boro 2021-22.

Designation	Plot yield (Kg)	Yield (t/ha)	Out cross potential (%)	Remarks
BRRI7A/B	426	1.33	40	CMS line of BHD5
BRRI10A/B	191	1.36	41	CMS line of BHD2
BRRI11A/B	892	1.38	42	CMS line of BHD3
BRRI48A/B	192	1.92	46	
BRRI99A/B	371	1.86	45	
BRRI109A/B	56	0.93	30	Rainfall during pollination hamper seed yield
BRRI110A/B	96	1.37	41	
BRRI110A/B	12.1	1.73	43	Nucleus seed
BRRI125A/B	5.2	0.74	27	Nucleus seed
IR102758A/B	326	1.36	41	
IR105687A/B	227	1.89	45	
IR105688A/B	172	1.43	43	
IR79156A/B	1300	1.91	47	CMS line of BHD6
IR79125A/B	100	1.0	33	
IR78369A/B	60	0.6	20	Rainfall during pollination hamper

16	IR58025A/B	333	1.33	40	seed yield CMS line of BHD4
Total CMS seeds achieved		4,759			

Experimental F_1 seed production of promising hybrids during T. Aman, 2021

Fifteen CMS lines were used along with six restorer lines. Individual R lines were isolated with cloth barrier during flowering time. Standard seed production protocol was maintained

Seed yield ranging 0.8 to 40 kg/plot from selected promising hybrid combinations. Some combinations did not produce sufficient seeds due to lack of flowering synchronization and frequent raining during flowering time (Table 10).

Table 10. Experimental F_1 seed obtained from different hybrid combinations during T Aman 2021.

Designation	PH (cm)		D50% F		PER (%)	OCR (%)	Plot area (m^2)	Yield (kg/plot)	Seed yield (kg/ha)
	A Line	R line	A line	R line					
IR58025A/ BRRI36R	110	112	87	95	68	11	450	9.50	211
IR78369A/BRRI36R	111	115	88	99	65	9	450	6.22	138
IR79125A/BRRI36R	112	116	86	96	64	6	450	4.14	92
IR102758A/BRRI36R	110	114	86	94	70	13	450	12.47	277
IR105687A/BRRI36R	92	109	84	91	72	15	300	8.88	296
IR105688A/BRRI36R	101	110	87	93	73	17	300	9.77	326
IR79156A/BRRI36R	112	116	86	92	75	22	550	28.72	522
BRRI99A/BRRI36R	102	109	85	91	70	18	550	19.36	352
BRRI 11A/BRRI36R	102	110	86	91	84	7	550	5.42	99
BRRI97A/BRRI36R	103	108	86	89	82	10	550	7.90	144
BRRI50A/BRRI36R	106	110	87	83	80	07	500	1.67	33
BRRI109A/BRRI36R	102	109	79	85	85	13	500	10.59	212
BRRI7A/BRRI36R	87	108	76	87	67	06	250	1.44	58
BRRI110A/BRRI36R	97	108	79	86	69	17	150	4.76	320
BRRI97A/BRRI46R	102	108	87	95	72	14	450	16.8	373
BRRI99A/BRRI46R	110	113	88	99	82	30	350	33.8	966
BRRI109A/BRRI46R	122	116	86	96	69	13	400	12.4	310
BRRI110A/BRRI46R	113	114	86	94	67	3	350	1.20	34
IR105687A/BRRI46R	100	109	84	91	69	11	370	10.4	281
IR105688A/BRRI46R	101	110	87	93	72	17	400	18.0	450
IR79156A/BRRI46R	112	118	89	98	73	20	400	25.8	645
IR102758A/BRRI46R	110	116	84	93	70	15	350	13.5	386
IR79125A/BRRI46R	115	118	96	105	70	16	350	14.9	426
IR78369A/BRRI46R	112	116	90	99	68	13	400	12.2	305
IR58025A/BRRI46R	110	115	86	97	69	15	400	15.4	385
BRRI97A/BRRI53R	102	112	87	95	70	12	450	13.1	291
BRRI99A/BRRI53R	110	115	88	99	68	15	350	8.5	243
BRRI109A/BRRI53R	116	120	86	96	72	16	400	13.1	328
BRRI110A/BRRI53R	113	114	86	94	67	5	350	1.1	31
IR79156A/BRRI53R	112	116	84	91	73	28	470	38.8	826
IR105687A/BRRI53R	101	114	87	93	65	3	400	0.8	20
IR105688A/BRRI53R	102	114	89	98	71	17	400	14.6	365
IR102758A/BRRI53R	110	116	84	93	70	22	350	21.4	611
IR79125A/BRRI53R	115	118	96	105	69	17	350	15.0	429
IR58025A/BRRI53R	112	116	90	99	68	6	400	4.6	115
IR78369A/BRRI53R	110	115	86	97	70	19	400	16.8	420

BRRI48A/BRRI42R	99	110	87	95	70	12	350	11.0	314
BRRI50A/BRRI42R	100	110	88	99	65	4	350	1.8	51
BRRI97A/BRRI42R	102	112	86	96	68	10	350	8.7	249
BRRI99A/BRRI42R	110	116	86	94	67	10	350	8.4	240
BRRI109A/BRRI42R	112	118	84	91	71	15	350	13.5	386
BRRI110A/BRRI42R	108	114	87	93	67	8	350	6.6	189
IR79156A/BRRI42R	112	118	89	98	74	32	350	40.0	1143
IR102758A/BRRI42R	110	116	84	93	67	9	350	8.7	249
IR79125A/BRRI42R	115	120	96	105	67	7	350	5.9	169
IR78369A/BRRI42R	112	118	90	99	72	20	350	15.0	429
IR105687A/BRRI42R	101	115	86	97	65	3	350	1.2	34
IR58025A/BRRI42R	110	116	87	95	66	10	350	7.8	223
BRRI7A/BRRI37R	99	110	87	95	73	29	350	28.0	800
BRRI11A/BRRI37R	100	110	88	99	69	15	350	13.5	386
BRRI48A/BRRI37R	102	112	86	96	65	5	350	5.5	157
BRRI50A/BRRI37R	110	116	86	94	69	13	350	12.0	343
BRRI97A/BRRI37R	112	118	84	91	71	27	350	26.0	743
BRRI99A/BRRI37R	108	114	87	93	72	29	350	28.0	800
BRRI109A/BRRI37R	112	118	89	98	70	21	350	19.8	566
BRRI110A/BRRI37R	110	116	84	93	64	2	350	3.8	109
IR105687A/BRRI37R	115	120	96	105	63	2	350	3.1	89
IR105688A/BRRI37R	112	118	90	99	70	15	350	13.5	386
IR79156A/BRRI37R	101	115	86	97	70	17	350	16.2	463
IR102758A/BRRI37R	110	116	87	95	69	15	350	13.0	371
IR79125A/BRRI37R	114	118	95	103	65	5	350	5.8	166
IR78369A/BRRI37R	115	120	96	105	68	14	350	12.5	357
IR58025A/BRRI37R	112	117	87	96	68	12	350	11.0	314
BRRI11A/BRRI43R	111	117	87	95	68	11	300	10.0	333
BRRI50A/BRRI43R	100	110	88	99	65	2	300	2.0	67
BRRI97A/BRRI43R	102	112	86	96	68	11	300	10.0	333
BRRI99A/BRRI43R	110	116	86	94	67	10	300	9.50	317
IR79156A/BRRI43R	112	118	84	91	74	34	300	38.4	1280
IR105687A/BRRI43R	102	114	87	93	68	4	300	4.5	150
IR105688A/BRRI43R	104	118	89	98	71	30	300	28.1	937
IR102758A/BRRI43R	110	116	84	93	69	16	300	13.4	447
IR79125A/BRRI43R	115	120	96	105	68	15	300	12.50	417
IR78369A/BRRI43R	112	118	90	99	70	28	300	24.2	807
IR58025A/BRRI43R	110	115	86	97	70	15	300	11.5	383

DS: 15 Jul 2021; DT: 4 Aug 2021

F_1 seed production of BRRI hybrid dhan5, BRRI hybrid dhan6, BRRI hybrid dhan7 and BRRI hybrid dhan8 in Boro 2021-22

Seed yield 960 kg (2.4 t/ha), 1,246 kg (2.59 t/ha), 2,800 kg (2.69 t/ha) and 88 kg (2.2 t/ha) was obtained from BRRI hybrid dhan5, BRRI hybrid dhan6, BRRI hybrid dhan7 and BRRI hybrid dhan8, respectively (Table 11).

Table 11. F_1 seed production of BRRI hybrid dhan5, BRRI hybrid dhan6, BRRI hybrid dhan7 and BRRI hybrid dhan8 during Boro 2021-22 (Gazipur).

Hybrid	PHT (cm)		D50%F		PER (%)	OCR (%)	Yield	
	A line	R line	A line	R line			kg/plot	t/ha
BRRI hybrid dhan5	88	97	124	140	82	43	960	2.4
BRRI hybrid dhan6	85	94	126	129	89	47	1246	2.59

BRRI hybrid dhan7	89	98	125	133	88	50	2800	2.69
BRRI hybrid dhan8	87	96	126	134	83	42	88	2.20

DS: R_1 = 15 Nov 2021; R_2 = 22 Nov 2021; A = 11 Dec 2021; DT: R = 20 Dec 2021; A = 11 Jan 2022;
DS: R_1 = 1 Dec 2021; R_2 = 05 Dec 2021; A = 14 Dec 2021; DT: R and A = 19 Jan 2022. PER (%) = panicle exertion rate, OCR (%) = Out crossing rate

F_1 seed production at Ishwardi, Barishal and Mymensingh during Boro 2021-22

We had F_1 seed production programme in Ishwardi, Barishal and Mymensingh during Boro 2021-22 with our strict supervision. 1,430 kg (1.8 t/ha), 12,205 kg (2.4 t/ha), 2,460 kg (2.05 t/ha), 10,210 kg (2.04 t/ha), 6000 kg (2.5 t/ha) and 6,060 kg (3.03 t/ha) seed yield was obtained from BRRI hybrid dhan2, BRRI hybrid dhan3, BRRI hybrid dhan4, BRRI hybrid dhan5, BRRI hybrid dhan6 and BRRI hybrid dhan7, respectively (Table 12).

Table 12. F_1 seed production of BRRI released hybrids during Boro 2021-22 at different locations.

Variety	Area (Acre)	Seed yield (kg)	Yield t/ha)	Remark
BRRI hybrid dhan2	2.0	1430	1.80	Ishwardi
BRRI hybrid dhan3	5.0	4550	2.28	Ishwardi
BRRI hybrid dhan3	5.0	5655	2.83	Mymensingh
BRRI hybrid dhan3	2.5	2000	2.00	Barishal
BRRI hybrid dhan4	3.0	2460	2.05	Ishwardi
BRRI hybrid dhan5	7.0	5460	1.95	Ishwardi
BRRI hybrid dhan5	3.5	3250	2.32	Mymensingh
BRRI hybrid dhan5	2.0	1500	1.86	Barishal
BRRI hybrid dhan6	6.0	6000	2.50	Ishwardi
BRRI hybrid dhan7	5.0	6060	3.03	Ishwardi
Total=	41	38365		

Dissemination of hybrid rice technology

In the reporting year, under T. Aman season HRRI Hybrid Rice Division supplied 6,750 kg of parental lines and F_1 seeds to 90 farmers, 10 seed companies, scientists, extension people, projects and staffs of BRRI (Table 13), 15000 kg of parental lines and F_1 seeds to 130 farmers, 24 seed companies, scientists, extension people, project people and staffs of BRRI during 2021-22 (Table 14) and 4,357 kg F_1 seeds of BRRI hybrid dhan7 was distributed among different stake holders during T. Aus 2022 (Table 15). Around 4 MT parental seeds (A & R line) distributed among different stake holders during Boro 2021-22 (Table 16).

Table 13. Amount of parental line and hybrid seeds supplied to different organization during T Aman 2021.

Recipient	Nos.	F_1 (kg)	A line (kg)	B line (kg)	R line (kg)
Seed Companies	10	550	170	-	64
Farmers	90	1216	-	-	-
BRRI Scientists + staffs	45	1200	-	-	-
BRRI, RS (5)+DAE	21	3550	-	-	-
Total	166	6516	170	0.00	64.00
Grand total		6750 Kg			

Investigator: All staff of BRRI Hybrid Rice Division.

Table 14. Amount of parental line and hybrid seeds supplied to different organization during Boro 2021-22.

Recipient	Nos.	F_1 (kg)	A line (kg)	B line (kg)	R line (kg)
Seed Companies	24	1650	2869	-	959
Farmers	130	1350	-	-	-
BRRI Scientists + staffs +DAE	85	3672	-	-	-
BRRI, RS	11	4500	-	-	-
Total	250	11172	2869	0.00	959
Grand Total		15000			

Investigators. All staff of hybrid rice division.

Table 15. Amount of BRRI released Aus hybrid seeds distributed during T. Aus 2022.

Variety	Institute/ Organization/ Farmers	Seed amount supplied (Kg)	Area covered with supplied seeds	Remark
BRRI hybrid dhan7	BRRI R/S	2945	196	
BRRI hybrid dhan7	DAE	950	63	
BRRI hybrid dhan7	Farmers	462	31	
Total=		4357	290	

Investigators. All staff of BRRI Hybrid Rice Division.

Table 16. Amount of parental lines seed distribution during Boro 2021-22.

Variety	CMS(A) line (kg)	R line (Kg)	Area covered (Acre)
BRRI hybrid dhan1	30	09	3.0
BRRI hybrid dhan2	49	16	5.0
BRRI hybrid dhan3	1050	350	105.0
BRRI hybrid dhan4	123	43	15.0
BRRI hybrid dhan5	387	130	43.0
BRRI hybrid dhan6	947	316	118.0
BRRI hybrid dhan7	283	95	35.0
Total=	**2869**	**959**	**324**

Agronomy Division

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SUMMARY

To achieve higher yield, medium and long duration T. Aman rice varieties should preferably be transplanted on 1st week of August (5th to 10th). BRCC266-5-1-1-1 produced lower grain yield than the check entries and matured 5-6 days earlier irrespective of planting time. From 10 to 25 July transplanting BRRI dhan93 and BRRIdhan94 displayed similar grain yield and growth duration. In case of BRRI dhan95, the growth duration and grain yield decreased from 10 August to 10 September transplanting. BRRI dhan91 was found neither suitable for ratoon crop nor suitable to grown in Boro season might be due to its photosensitivity and long growth duration (182 days). However, among the supplied advanced lines, BRH11-9-11-4-5B yielded the highest grain yield (5.46 t/ha) in Boro season as the main crop without having the ratooning ability. Both BRRI dhan93 and BRRI dhan95 produced higher grain yield in STB (Soil test based) treatment than BRRI dhan87 with 16% less Nitrogen compared to BRRI recommended fertilizer dose. Growth stage-based fertilizer application on BRRI dhan92 produced the highest grain yield (6.23 t $ha^{=1}$) on STB + 10% additional dose. On the other hand, BRRI dhan96 produced the highest grain yield (5.53 t ha^{-1}) on STB treatment. Both BRRI dhan73 and BRRI dhan87 could not tolerate 50 mM NaCl (Approximately 5.25 ds m^{-1}) salinity level. The economic N rate appeared as 56 and 55 kg for BRRI dhan34 and BRRI dhan90, respectively where initial soil N was 0.10% and organic matter was 1.47%. The application of 50 % RDF (recommended doses of fertilizer) along with cowdung @5 t ha^{-1} or poultry manure @3 t ha^{-1} is recommended for getting higher grain yield of BRRI dhan87 in Sirajganj farm. In saline condition, 250 ppm of chitosan enhanced the chlorophyll content and photosynthetic activity of both BRRI dhan28 and BRRI dhan67 produced 35% higher grain yield than without spray. Mungbean (BARI Mung-6)-T. Aus (BRRI dhan48)-T. Aman (BRRI dhan62)-Potato (BARI Alu41) four crops pattern was economic, profitable and not harmful in terms of soil fertility when proper agronomic management was given. New molecule herbicide showed better weed control efficiency (>80%) in both T. Aman and Boro season. Weeding cost is higher in hand weeding compared to herbicide and BRRI weeder and late weeding also reduced grain yield in the farmer's field. The degradation of a widely used insecticide (virtako) by the two PGPR strains *Proteus sp* and *Bacillus sp* showed a reduction of concentration by 20.96% and 70.69%, respectively over the control. Among the two bacterial strains, *Bacillus tequilensis* was identified as a potential strain for virtako degradation under laboratory conditions.

SCIENTIFIC INFORMATION

Planting Practices

Influence of transplanting dates on the yields of rice in north, central and south region of Bangladesh.

The experiment was conducted at BRRI R/S Rangpur, Cumilla and Barishal farms aimed to identify a suitable planting window of short, medium and long duration T. Aman rice cultivars to maximize grain yield. The selected cultivars were transplanted from 5 July to 5 September Twenty-five-day-old seedlings were transplanted following split-plot design with three replications. At Rangpur region, early transplanting of BRRI dhan75 (10 to 20th of July) produced higher grain yield than the delayed transplanting. BRRI dhan87 and BRRI dhan93 transplanted on 10 August produced higher grain yield (Table 1). The tested varieties transplanted on 30 of July were found to have less grain yield. This happened due to the continuous rainfall with wind (depression) at flowering stage in the 1st week of October that hampered pollination and seed setting. At BRRI R/S Cumilla farm, all the varieties produced higher yield transplanted on 5 August. After 20th August, the yield of all tested varieties decreased sharply (Table 2). At BRRI R/S Barisal farm, from 5-20 August transplanting, BRRI dhan23 produced the highest grain yield followed by BRRI dhan72 and BRRI dhan76 with 121-135 days growth duration (Table 3). However, considering the grain yield and growth duration, early transplanting on 5 August was found suitable with BRRI dhan72 (5.49 t/ha) and late transplanting on 20 August was found suitable with BRRI dhan23 (5.59 t/ha). In conclusion, to achieve appreciable better yield, medium and long duration aman rice varieties should preferably be transplanted on 1st week of August (5 to 10).

Table 1. Effect of planting time on the GDD accumulation and rice yield in T. Aman, 2021 season at BRRI R/S Rangpur.

Variety	Date of transplanting									
	10 Jul		20 Jul		30 Jul		10 Aug		20 Aug	
	Yield ($t\ ha^{-1}$)	**GDD (ºC)**	**Yield ($t\ ha^{-1}$)**	**GDD (ºC)**	Yield ($t\ ha^{-1}$)	GDD (ºC)	Yield ($t\ ha^{-1}$)	GDD (ºC)	Yield ($t\ ha^{-1}$)	GDD (ºC)
BRRI dhan75	5.30	2051	5.46	2090	3.76	2116	4.90	2174	4.84	1962
BRRI dhan87	3.68	2284	5.19	2281	4.01	2199	5.92	2098	5.71	2028
BRRI dhan93	4.48	2510	6.17	2441	5.43	2324	7.05	2232	6.76	2119
$LSD_{(0.05)}$	0.81	52	1.13	17	1.23	54	1.43	139	0.81	45
CV (%)	8.1	1.00	8.9	0.30	12.3	1.10	10.4	2.80	5.9	1.00

Table 2. Effect of planting time on yield and growth duration of T. Aman rice varieties, 2021, BRRI RS Cumilla.

	Transplanting date				
Variety	5 Jul	20 Jul	5 Aug	20 Aug	5 Sep
BRRI dhan75	3.42 (121)	4.02 (119)	4.82 (119)	4.46 (123)	3.96 (117)
BRRI dhan87	3.52 (130)	3.97 (128)	5.43 (131)	4.97 (132)	4.37 (129)
BRRI dhan90	2.98 (121)	3.57 (121)	4.54 (119)	3.91 (121)	3.49 (119)
BRRI dha95	3.90 (137)	4.65 (136)	5.18 (132)	4.95 (124)	4.40 (123)
BR22	3.59 (163)	4.03 (154)	4.67 (144)	4.37 (133)	3.91 (131)
	LSD	CV(a)%	CV(b)%		
	0.18 (4.69)	3.01 (1.72)	3.96 (2.22)		

- Data on parenthesis indicates growth duration

Table 3. Effect of planting time of newly released transplanted Aman varieties on yield in T. Aman 2021 at BRRI RS Barishal farm.

		Transplanting date		
Variety	20 Jul	5 Aug	20 Aug	5 Sep
BRRI dhan72	4.82 (124)	5.49 (121)	5.22 (118)	4.91 (116)
BRRI dhan76	5.02 (130)	5.32 (128)	4.67 (125)	3.82 (123)
BRRI dhan77	4.37 (143)	5.07 (139)	4.82 (132)	3.54 (126)
BRRI dhan78	4.59 (125)	4.78 (123)	4.22 (118)	3.94 (122)
BRRI dhan87	4.79 (127)	5.29 (126)	4.70 (124)	4.22 (130)
BR23	4.94 (150)	5.36 (143)	5.59 (135)	5.12 (132)
$LSD_{(0.05)}$	0.42 (1.20)			
CV%	9.64 (1.5)			

- Data on parenthesis indicates growth duration

Effect of time planting on grain yield and growth duration of ALART, low glycemic index rice line in Boro, 2021-22 season at BRRI HQ farm Gazipur

The experiment was conducted to determine the suitable planting time and potential yield of ALART line BRCC266-5-1-1-1 with check BR16 and BRRI dhan58 at BRRI HQ farm, Gazipur during Boro 2021-22. Forty days old seedlings were transplanted on 20 December, 5 Jany, 20 January and 5 February. The treatments were distributed in a split-plot design with three replications when planting time was in the main plot and variety was in the subplot.

Results indicated that from 5-20 January transplanting, BR16 produced the highest grain yield followed by BRRI dhan58 and BRCC266-5-1-1-1 with 162-148 days growth duration (Table 4). Advanced line BRCC266-5-1-1-1 mature 5-6 days earlier than BRRI dhan58 and 7-8 days earlier than BR16.

Table 4. Effect of planting time on grain yield and growth duration of ALART, Low glycemic index rice line in Boro, 2020-21 season at BRRI farm Gazipur.

Variety/lines	20 Dec	5 Jan	20 Jan	5 Feb	20 Feb
BRCC266-5-1-1-1	5.20 (161)	6.04 (156)	5.57 (149)	5.44 (145)	5.11 (142)
BR16 (Ck)	6.51 (168)	6.59 (163)	6.86 (157)	6.12 (153)	5.50 (149)
BRRI dhan58 (Ck)	5.70 (163)	6.23 (159)	5.99 (155)	5.72 (151)	5.18 (147)
LSD $_{(0.05)}$			NS (0.87)		
CV (%)			8.02 (0.33)		

Enhancing rice yield by optimizing planting time of newly released T. Aman varieties.

The experiment was conducted at the BRRI HQ farm, Gazipur, during Aman, 2021 to determine the effect of variable planting time on the growth and yield of newly released transplanted Aman varieties. The treatments were A: Time of planting: i) 10 July, 25 July, 10 August, 25 August and10 September t B. Varieties: BRRI dhan93, BRRI dhan94 and BRRI dhan95. The treatments were distributed in split plot design with three replications (Planting time in main plot and variety in sub plot). Twenty-five days-old seedlings were transplanted at 20 × 20 cm spacing. Results indicated that 10 to 25 July transplanting of BRRI dhan93 and BRRIdhan94 produced similar grain yield and growth duration (Table 5). After 25 July grain yield was decreased but growth duration increased gradually. In case of BRRI dhan95 growth duration as well as grain yield were decreased from 10 July to 10 September transplanting. BRRI dhan95 produced flowering in October at all transplanting dates. It may due to the variety is weakly photosensitive.

Table 5. Effect of planting time of newly released transplanted Aman varieties on yield, T. Aman 2021 at BRRI HQ farm, Gazipur.

Variety	Grain yield (t ha^{-1})				
	10 Jul	25 Jul	10 Aug	25 Aug	10 Sep
BRRI dhan93	5.14 (142)	5.24 (140)	4.54 (145)	4.08 (148)	2.91 (153)
BRRI dhan94	4.97 (141)	5.10 (140)	4.41 (144)	3.87 (148)	2.90 (152)
BRRI dhan95	5.09 (140)	5.08 (135)	4.28 (127)	3.12 (121)	2.56 (113)
LSD $_{(0.05)}$			0.37		
CV%			7.1		

* Growth duration (day) (in the parenthesis)

Evaluation of the ratooning performance of selected rice genotypes in Boro season, 2021-22 at BRRI HQ farm Gazipur.

The experiment was conducted to observe the ratooning ability of advanced breeding lines including some released varieties at BRRI HQ farm, Gazipur during Boro 2021-22. The treatments were distributed in a randomized complete block design with three replications. Forty day old seedlings were transplanted on 20 January. All agronomic management was done per BRRI recommendation when necessary. The main crop was harvested at 20-30 cm height from the ground soil surface. Top dress of urea and MoP fertilizer was applied at 35 kg/ha and 30 kg/ha, respectively at 3-5 days after harvesting and fertilizer was properly mixed along with hand weeding. Irrigation was assured till to the hard dough stage of the ratoon crop.

In the main crops stage, BRRI dhan88 produced the highest grain yield (5.48 t ha^{-1}) followed by BRH11-9-11-4-5B (5.46 t ha^{-1}) and BRRI dhan100 (5.45) with 140-148 days growth duration (Table 6). Consequently, BRRI dhan88 produced the highest tiller and panicles among other entries. In the ratoon crop's stage, BRRI dhan100 produced the highest grain yield (1.00 t/ha) followed by BRRI dhan28 (0.91 t/ha) and BRRI dhan49 (0.83 t ha^{-1}) within 54-59 days of growth duration. BRRI dhan91 was found neither suitable for ratoon crop nor suitable to grown in Boro season might be due to its photosensitivity and long growth duration (182 days).

Table 6. Evaluation of ratooning ability of selected rice genotypes in Boro season, 2021-22 at BRRI HQ farm Gazipur.

Variety/Entry	Grain yield main crop ($t\ ha^{-1}$)	Tiller no. m^{-2}	Panicle no. m^{-2}	Growth duration of main crop (day)	Grain yield ratoon crop ($t\ ha^{-1}$)	Duration of ratoon crop (day)
BRRI dhan91	1.33	261	245	182	-	-
BR9377-2-1-3B	4.72	227	214	133	-	-
BR9390-6-2-1B	1.09	237	227	192	-	-
BR9392-6-2-3B	5.05	256	248	138	0.76	55
BR9396-6-2-2B	5.25	247	240	143	-	-
BRH11-9-11-4-5B	5.46	220	208	148	-	-
BRRI dhan28	5.19	240	233	141	0.91	57
BRRI dhan49	4.85	251	240	145	0.83	59
BRRI dhan88	5.48	275	261	140	0.80	59
BRRI dhan100	5.45	235	229	144	1.00	54
LSD $_{(0.05)}$	0.64	NS	NS	0.99	0.08	0.87
CV%	8.47	9.89	10.62	0.51	11.09	1.79

FERTILIZER MANAGEMENT

Effect of Nitrogen management to maximize grain yield of Swarna type varieties in T. Aman season.

The experiment was conducted at the Bangladesh Rice Research Institute BRRI farm, Gazipur, during Aman 2021 to find out optimum nitrogen management for BRRI dhan93 and BRRI dhan95. The treatments were: A: N rate: i) N_1 = STB (N-P-K-S= 77-13-47-6 kg ha^{-1}), ii) N_2= STB + 10%, iii) N_3 = STB - 10%, iv) N_4= BRRI Recommended dose (N-P-K-S= 92-12.5-42-10 kg ha^{-1}) and v) N_5= Control (0 N); and B. Varieties: i) V_1: BRRI dhan93, ii) V_2: BRRI dhan95 and iii) V_3: BRRI dhan87. The treatments were distributed in split plot design with three replications (Nitrogen management in the main plot and variety in the sub plot). Twenty-five days-old seedlings were transplanted at 20 × 20 cm spacing.

Table 7. Effect of nitrogen management of Swarna type varieties on yield during T. Aman 2021 at BRRI HQ farm, Gazipur

Treatment	Grain yield ($t\ ha^{-1}$)		
Nitrogen level (kg ha^{-1})	BRRI dhan93	BRRI dhan95	BRRI dhan87
N_1: STB	5.33	5.25	4.38
N_2: STB + 10%	5.29	5.10	4.75
N_3: STB - 10%	4.86	4.72	4.23
N_4: BRRI recommended	5.22	5.29	5.42
N_5: Control (N_0)	3.486	3.87	2.84
LSD $_{(0.05)}$		0.43	
CV (%)		6.9	

Result indicates that BRRI dhan93 and BRRI dhan95 produced higher grain yield in STB treatment which is similar with STB + 10% and BRRI recommended dose (Table 7). Grain yield was significantly higher in N_1, N_2 & N_4 treatments than STB – 10% and control. On the other hand, BRRI dhan87 produced higher yield in BRRI recommended dose, which was also similar to the STB + 10% treatment. BRRI dhan93 and BRRI dhan95 produced higher grain yield in STB treatment than BRRI dhan87 by using 16% less nitrogen than BRRI recommended fertilizer dose.

Effect of N levels and growth stage-based N application on growth, yield and nitrogen use efficiency of BRRI dhan92 and BRRI dhan96.

The experiment was conducted at the Bangladesh Rice Research Institute (BRRI) farm, Gazipur, during Boro,2021-22 to find out the influence of growth stage-based nitrogen application on growth and yield of rice. The treatments were: A: Nitrogen level (kg ha^{-1}): i) N_1: STB (V_1=147, V_2=118), ii) N_2: BRRI recommended (V_1=138, V_2=120), iii) N_3: STB + 10% (V_1=161, V_2=130), iv) N_4: STB + 20% (V_1=176, V_2=141), v) T_5: Control (0 N); and B. Varieties: i) V_1: BRRI dhan92 and ii) V_2:

BRRI dhan96. The treatments were distributed in RCB two factor design with three replications. Thirty-five day-old seedlings were transplanted at 20 × 20 cm spacing. Result indicates that BRRI dhan92 and BRRI dhan96 produced highest grain yield on STB + 10% and STB treatment, respectively (Table 8) and consequently panicle m^{-2}, grains/panicle also higher in these treatments. So, more Nitrogen is required than BRRI recommended dose in case of BRRI dhan92.

Effect of different N levels on growth, yield, nitrogen use efficiencies (NUEs) and grain quality of aromatic rice varieties.

Therefore it is necessary to know the best N application rate for each variety, as well as its influence on components of yield and other agronomic paramet

The experiment was conducted at BRRI farm Gazipur during T. Aman 2021 with two factors. The different N rates N_0, N_{30}, N_{60}, N_{90}, N_{120} and USG (1.8 g 4 $hill^{-1}$) were applied in BRRI dhan34 and in BRRI dhan90. The experiment followed factorial RCB design with three replications. Twenty-five-old seedlings were transplanted on 10 August 2021 having 20 × 20 cm spacing with two seedlings $hill^{-1}$. The variation of grain yield of BRRI dhan34 and BRRI dhan90 at different nitrogen rates was determined through regression equation (Fig 1). Differentiating the quadratic equation of yield response with respect to applied different N doses the optimum N rate and economic N rate appeared as 57 and 56 kg ha^{-1} and 56 and 55 kg for BRRI dhan34 and BRRI dhan90, respectively. After calculation of regression model the economic N rate appeared as 56 and 55 kg for BRRI dhan34 and BRRI dhan90, respectively where initial soil N was 0.14% and organic matter was 1.47%.

Table 8. Effect of nitrogen levels on yield of BRRI dhan92 and BRRI dhan96 during Boro 2021-22 at BRRI HQ farm, Gazipur.

Treatment	Panicle number m^{-2}	Grain $panicle^{-1}$	1000 grain weight (g)	Grain yield (t ha^{-1})
V_1N_1	252	117	23.43	5.90
V_1N_2	246	115	24.10	5.74
V_1N_3	270	117	24.03	6.52
V_1N_4	241	115	23.60	5.55
V_1N_5	193	106	23.53	3.50
V_2N_1	275	118	20.06	6.01
V_2N_2	257	116	86.73	5.46
V_2N_3	263	116	20.30	5.65
V_2N_4	246	113	19.86	5.31
V_2N_5	191	105	19.83	3.13
$LSD_{(0.05)}$	13.73	4.12	0.70	0.47
CV (%)	3.29	2.11	1.88	6.85

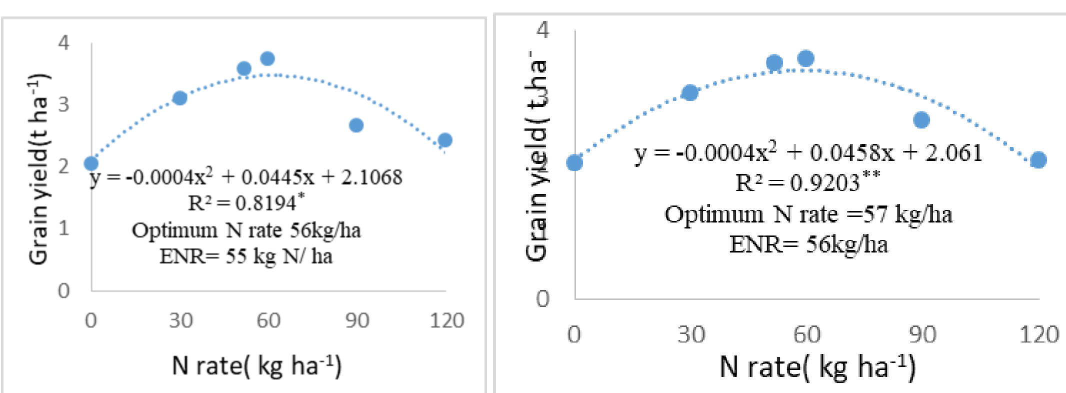


Fig 1. Determination of optimum and economic nitrogen rate of BRRI dhan34 and BRRI dhan90 .

4. Growth and yield improvement of T. Aman rice in Sirajganj farm through integrated nutrient management. It was conducted at BRRI R/S, Sirajganj farm during T. Aman season, 2021. The experiment was carried out following RCB design with three replications. The treatment was included inorganic and organic combinations of nutrient management and varieties. The nutrient management treatments were: T_1 = Control (No fertilizer), T_2 = BRRI Recommended dose of fertilizer (RDF) (N-P-K-S @ 69-10.4-41-10.8 kg ha^{-1}) , T_3 = Vermicompost (1 t ha^{-1}) + 50% of RDF , T_4 = Cowdung (5 t ha^{-1}) + 50% of RDF , T_5 = AEZ Based fertilizer dose (N-P-K-S-Zn @ 76-15-42.5-8.1-1.8 kg ha^{-1}), T_6 = Tricho-compost (2 t ha^{-1}) + 50% of RDF, T_7 = Poultry Manure (3 t ha^{-1}) + 50% of RDF.). Initial soil nutrient status of the experimental field was pH = 6.7, Total N (%) = 0.13, OC (%) = 1.35, P = 10.34 ppm, K = 0.16 meq/100g, S = 28.4 ppm and Zn = 8.5 ppm. Grain yield variation was significant due to higher number of panicles and higher number of grains $panicle^{-1}$. Significantly higher grain yield (6.14 and 5.78 t ha^{-1}) was observed in BRRI dhan87 with treatment T_4 (cow dung @ 5 t ha^{-1}) + 50% of RDF) followed by treatment T_7 (Poultry manure @ 3 t ha^{-1} + 50% of RDF). The lowest yield (4.02 t ha^{-1}) was found in control (Table 9). All the yield attributes were higher with the substitution of cow-dung or poultry manure in combination with 50% RDF due to slow release and continuous supply of nutrients in balanced quantity throughout the various growth stages, resulted in the production of increased panicles with higher number of fertile grains, lowest sterility (%) and grain yield. About 15-22% higher grain yield was obtained in 50% RDF along with cow-dung or poultry manure applied plots compared to BRRI recommended practices.

Table 9. Yield and yield components of BRRI dhan87 as influenced by integrated nutrient management at BRRI R/S, Sirajganj farm 2021.

Treatment	Panicles m^{-2}	Grain $panicle^{-1}$	1000 grain wt. (g)	Grain yield (t ha^{-1})	Sterility%
Nutrient management					
T_1	171	101	23.1	4.02	31.0
T_2	180	120	23.4	5.02	21.1
T_3	198	114	23.4	5.44	16.1
T_4	213	125	23.6	6.14	12.3
T_5	195	115	23.0	5.07	24.1
T_6	178	114	23.2	4.71	22.1
T_7	208	124	23.5	5.78	14.1
$LSD_{(0.05)}$	24.9	9.07	NS	0.85	7.90
CV (%)	7.3	4.39	2.03	9.3	21.1

T_1 = Control (No fertilizer), T_2 = Recom. dose of fertilizer (RDF) (N-P-K-S @ 69-10.4-41-10.8 kg ha^{-1}) , T_3 = Vermicompost (1 t ha^{-1}) + 50% of RDF , T_4 = Cowdung (5 t ha^{-1}) + 50% of RDF, T_5 = AEZ based fertilizer Dose (N-P-K-S-Zn@ 76-15-42.5-8.1-1.8 kg ha^{-1}), T_6 = Tricho-compost (2 t ha^{-1}) + 50% of RDF, T_7 = Poultry Manure (3 t ha^{-1}) + 50% of RDF.

Application of chitosan to improve salt tolerance in rice in reproductive stage.

A pot experiment was conducted at rain-out shelter of Agronomy Division, BRRI HQ Gazipur in Boro 2021-22 to find out the effect of chitosan on growth and yield of rice in saline condition. The pots were set as split-split design with three replications. The main plots represented two salinity levels of 0 mM NaCl and 65 mM NaCl (Approximately 6.5 dS m^{-1}). Sub-plots represented two concentrations of chitosan;0 ppm and 250 ppm. Sub-sub-plots represented two varieties of rice; i. BRRI dhan28 (salt sensitive), ii. BRRI dhan67 (salt tolerant). The highest chlorophyll content; chlorophyll a (35.6 mg g^{-1} FW) was measured in BRRI dhan67. Salt stress (65 mM) caused a drastic reduction in Chl 'a', Chl 'b' content compared to non-stress condition in the BRRI dhan28, whereas salt tolerant cultivar BRRI dhan67 showed a slight reduction. On contrary, supplementation of CS the showed significant alleviation of Chl 'a', Chl 'b' content and photosynthetic activity in both the varieties. Photosynthetic rate was significantly higher in BRRI dhan67 (22.1 µmol CO^2 m^{-2} s^{-1}) supplemented with chitosan with non-saline condition and salt stress reduced the photosynthetic rate in BRRI dhan28 and BRRI dhan67 (13.1 and 15.4 µmol CO_2 m^{-2} s^{-1}).

(Table 10). Grains panicle^{-1} were significantly influenced by different treatments in BRRI dhan28 compared to BRRI dhan67. In saline condition, yield reduction was found from both the varieties and chitosan spray could slightly mitigate the saline stress in BRRI dhan28. In BRRI dhan67, grains panicle^{-1} and yield reduced in saline condition but with 250 ppm chitosan spray affected grains panicle^{-1} and yield increased in both saline and non-saline condition (Table 11). In 65 mM salinity level BRRI dhan67 produced 35% higher yield with 250 ppm chitosan spray than without spray. In control condition, BRRI dhan67 gave 12% higher yield with 250 ppm chitosan spray than without spray (Table 11).

Table 10. Effect of salinity and chitosan spray on chlorophyll content and photosynthetic activity of BRRI dhan28 and BRRI dhan67 in Boro 2021-22, BRRI HQ Gazipur.

Salinity level	Chitosan spray	Variety	Chlorophyll a (mg g^{-1} FW)	Chlorophyll b (mg g^{-1} FW)	Photosynthesis rate (μmol CO_2 m^{-2} s^{-1})
0 mM	0 ppm	BRRI dhan28	2.66	0.70	17.1
		BRRI dhan67	3.02	1.05	19.7
	250 ppm	BRRI dhan28	3.11	0.94	21.1
		BRRI dhan67	3.56	1.42	22.1
65 mM	0 ppm	BRRI dhan28	1.87	0.50	13.1
		BRRI dhan67	2.34	0.68	15.4
	250 ppm	BRRI dhan28	2.84	0.94	17.5
		BRRI dhan67	3.49	1.27	18.0
LSD $_{(0.05)}$			0.48	0.30	2.07
CV%			9.6	18.2	6.5

Table 11. Effect of salinity and Chitosan spray on growth and yield components of BRRI dhan28 and BRRI dhan67 in Boro 2021-22, BRRI HQ Gazipur

Salinity level	Chitosan spray	Variety	Panicle hill^{-1}	Grains panicle^{-1}	1000 GW (g)	Yield (g pot^{-1})	Sterility%
0 mM	0 ppm	BRRI dhan28	21	79	18.21	37.1	15.1
		BRRI dhan67	22	107	16.84	47.4	7.5
	250 ppm	BRRI dhan28	20	92	18.51	41.1	14.5
		BRRI dhan67	23	120	17.34	53.3	5.7
65 mM	0 ppm	BRRI dhan28	13	44	15.10	8.6	18.1
		BRRI dhan67	18	79	14.16	24.6	10.6
	250 ppm	BRRI dhan28	20	55	16.15	12.5	15.0
		BRRI dhan67	22	92	14.50	34.2	7.0
LSD $_{(0.05)}$			4.76	20.7	1.76	6.98	5.44
CV%			13.4	13.7	6.1	12.2	26.1

Improvement of soil health in four crops pattern through agronomic management.

A study was under taken in 2021-22 at BRRI farm Gazipur to improve the soil health and to increase the cropping intensity and productivity HQ. Cropping pattern was the Mungbean (BARI Mung-6)-T. Aus (BRRI dhan48)-T. Aman (BRRI dhan62)-Potato (BARI Alu41); besides agronomic management was 1. Incorporation of mungbean stubble with soil before T. Aus 2. Incorporation of compost @ 2.0 t ha^{-1} with soil before potato sowing and 3. Recommended dose of chemical fertilizers was applied for all crops as per schedule.

Results indicated that potato yield was not so satisfactory because soil is newly developed and not yet suitable for potato. It was not possible to harvest mungbean because of poor germination. The rice equivalent yield was 29.5 t ha^{-1} (23.0 t ha^{-1} potato = 20.7 t ha^{-1} rice, Rice = Tk 20/kg, Potato = Tk 18/kg)

(Table 12). Initial soil of each crop was collected before starting sowing/ transplanting. The results showed that there was increasing trend in soil OM, total N, P, K and S with few exceptions (Table 13). However, despite cultivation of four crops in same land, are not harmful in terms of soil fertility if the proper management is given.

Table 12. Yield of different crops in four crops systems BRRI HQ farm, Gazipur, 2021-22

Crop	Field duration	Variety	Yield (t ha^{-1})	Remark
T. Aus	10 May to 6 Aug 2021	BRRI dhan48	4.55	-
T. Aman	11 Aug to 5 Nov 2021	BRRI dhan62	4.25	-
Potato	16 Nov 19 to 19 Feb 2022	BARI Alu41	23.00	-
Mungbean	1 Mar 2022 (Sowing)	BARI mung6	-	Poor germination

Table 13. Initial Soil status of experimental plots in four crops system, BRRI HQ Gazipur, 2021-22.

Crop	pH	OM	Total N	P (ppm)	K (meq/100 g)	S (ppm)	Zn (ppm)
T. Aus	7.41	2.15	0.13	8.90	0.136	11.77	-
T. Aman	7.25	2.03	0.12	9.55	0.152	9.68	-
Potato	7.22	2.22	0.14	11.90	0.203	6.73	-
Mungbean	7.02	2.12	0.13	15.28	0.210	13.33	-

YIELD MAXIMIZATION

Maximizing yield of BRRI developed new varieties through influencing some agronomic critical factors in different seasons

A study of the individual agronomic critical factor together with their possible combinations has been taken to find out the effect of agronomic critical factors for yield maximization of newly BRRI developed varieties. Split plot design was followed where management in main plot and variety was in sub plot. Different agronomic critical factors based six managements were considered, where M_1 = BRRI Recommended practices, M_2 - M_6 were different agronomic management. The detailed treatment description is as follows:

Critical factor	M_1	M_2	M_3	M_4	M_5	M_6
Transplanting time	Jan 1st week	Dec 2nd week	Dec 3rd week	Dec 4th week	Dec 2nd week	Dec 3rd week
Seedling age	35 days	15 days	20 days	25 days	15 days (tray)	20 days (tray)
Spacing	20 × 20 cm	30 × 30 cm	30 × 25 cm	25 × 25 cm	30 × 30 cm	30 × 25 cm
Seedling/hill	2	1	2	2	1	2
Upper soil Stirring	0	20 DAT & 35 DAT	20 DAT & 35 DAT	20 DAT & 35 DAT	20 DAT & 35 DAT	20 DAT & 35 DAT
Inorganic Fertilizer	BRRI RR	STB +1% MoP solution*	STB +1% MoP solution*	STB +1% MoP solution*	STB +1% MoP solution*	STB +1% MoP solution*

*Sprayed at 35 and 45 DAT

The varieties were: V_1= BRRI dhan88, V_2= BRRI dhan89 and V_3= BRRI dhan29.

Experiment result showed significant yield differences among the treatments (Table 14). The highest grain yield was observed in long duration variety BRRI dhan89 in all management treatments followed by BRRI dhan29 than short duration BRRI dhan88. For obtaining higher yield, it may be recommended that seeding would be done on last week of December, younger seedling (15 to 25-day old) should be transplanted following wider spacing (30 × 25 or 25 × 25 cm) on 3rd week of December. Upper soil stirring should be done on at 20 and 35 DAT. STB fertilizer management would be followed and additionally 1% MoP solution to be sprayed on 30 and 45 DAT.

Table 14. Effect of some agronomic critical factors on yield of different growth duration of Boro varieties at BRRI HQ farm Gazipur, 2021-22.

Management	V1=BRRI dhan88	V2=BRRI dhan89	V3=BRRI dhan29
M_1	6.18	6.72	7.17
M_2	6.26	7.58	7.28
M_3	6.45	7.53	7.03
M_4	6.14	7.65	7.05
M_5	6.38	7.76	6.98
M_6	5.86	7.79	7.00
$LSD_{(0.05)}$ for variety = 0.361373 $LSD_{(0.05)}$ for management = 0.511059 $LSD_{(0.05)}$ for V × M = 0.885180 CV(Rep*Management*Variety) = 7.7			

(Note: The field performance of M_2, M_3, M_4, M_5 and M_6 treatment was very good in both the years up to heading stage, after hard dough stage 30 to 70% lodging was occurred)

Maximizing yield of some local fine aromatic cultivars through influencing some Agronomic management in Aman seasons A study of some agronomic factors together with their possible combinations was undertaken in T. Aman 2021 to find out the effect of agronomic management on yield maximization of some local fine aromatic popular varieties. Seven locally popular fine aromatic rice varieties including one check variety were tested under four different agronomic management practices. The agronomic management were: M_1 = BRRI Recommended practices, M_2 - M_4: Proposed agronomic management treatments. The agronomic management treatments in details are described bellow:

Management	M_1	M_2	M_3	M_4
Seeding time	2nd week of Jul	4th week of Jul	4th week of Jul	1st week of Jun
Transplanting time	2nd week of Aug	1st week of Aug	2nd week of Aug	1st TP: Jun 3rd week 2nd TP: Aug 1st week
Seedling age	30 days	10 days	15 days	1st TP: 20-25, 2nd TP: 35-40 days
Spacing	20 × 20 cm	20 × 25 cm	20 × 25 cm	1st: 15 × 10 cm 2nd: 20 × 20 cm
Seedling/hill	3-4	1-2	1-2	1st TP: 5-6 2nd TP: 3
Soil Stirring	0	25 & 40 DAT	25 & 40 DAT	0
Inorganic Fertilizer	BRRI RR (kg ha^{-1}) N=40 (at 0, 25 and 7 days before PI), P=10, K=30, S=8	70% of RR+ 1% MoP solution spray	70% of RR+ 1% MoP solution spray	1st TP: N @ 30 kg ha^{-1} 2nd TP: BRRI RR ($kgha^{-1}$) N=40 (at 0, 25 and 7 days before PI), P=10, K=30, S=8
Vermicompost	0	1 t ha^{-1}	1 t ha^{-1}	2 t ha^{-1}

The experiment was laid down in Split plot design with three replications where Management was in the main plot and variety was in the sub plot. Results (Table 15) showed that there was management sensitivity among tested local fine rice varieties, but some varieties had not on grain yield. Among the eight tested variety, BRRI dhan34, Tulshi Mala and Kathari Voaug have higher sensitivities to agronomic management and produced higher grain yield in respective to other tested varieties. Kalo Malshira and Gobidha Voaug have les management sensitivity on grain yield production, as a result has produced similar yield at all agronomic managements. Among the four agronomic managements, Management 2 and Management 3 have more effect on grain yield production rather than other two tested agronomic management. So, to obtain the higher yield from local varieties, following agronomic management should be: Seeding and transplanting should be completed within 4th week of July and 2nd week of August, respectively with 15-day-old seedling. Spacing will be line to line 25 cm and plant to plant 20-cm. Upper soil will be needed to stirring on 25 and 40 DAT. Applied organic and inorganic fertilizers will be vermicompost 1 t ha^{-1} and NPKSZn @ 30-10-30-10 kg per ha, respectively. 1% MoP solution need to be applied as foliar spray on 30, 40 and 50 DAT.

Table 15. Effect of some Agronomic management on some local fine aromatic cultivars for maximizing yield in Aman 2020 seasons at BRRI HQ farm Gazipur.

Variety	Management 1	Management 2	Management 3	Management 4
V_1 = Kalo Malshira	2.34	2.49	2.26	2.39
V_2 = Kalo Shailla	2.20	2.45	2.22	2.42
V_3 = Cini Gura	2.38	2.22	2.43	2.21
V_4 = Gobindha Voaug	2.28	2.26	2.27	2.05
V_5 = Kathari Voaug	1.94	1.94	2.23	2.17
V_6 = Tulshi Mala	2.40	2.31	2.77	2.60
V_7 = Kalo Jira	2.34	2.31	2.09	2.17
V_8 = BRRI dhan34 (Ck)	3.43	3.23	4.06	3.44

$LSD_{(0.05)}$ for variety(V) = 0.387273,
$LSD_{(0.05)}$ for management(M) = 0.273844 and $LSD_{(0.05)}$ for V × M = 0.440094
CV (%) = 19.4 CV(Rep*TP*Variety)

Maximizing yield of new rice varieties through influencing agronomic critical factors

A study of agronomic management with possible combinations was undertaken to find out the effect of critical factors for yield maximization of long (BRRI dhan52), medium (BRRI dhan87) and short duration (BRRI dhan71) varieties in T. Aman. The treatment combinations of agronomic management were as follows: M_1 = BRRI recommended practices and M_2 -M_5= Proposed Agronomic management treatments. The description of the treatment is details is as follows:

Agro. factors	**M_1**	**M_2**	**M_3**	**M_4**	**M_5**
Transplanting time	V_1= August 15 V_2= August 10 V_3= July 29	V_1= July 30 V_2= July 25 V_3= July 14	V_1= August 05 V_2= July 30 V_3= July 20	V_1= August 01 V_2= August 05 V_3= July 24	V_1= August 10 V_2= August 15 V_3= August 04
Seedling age	30 days	15 days	20 days	25 days	35 days
Spacing (cm × cm)	20 × 20	25 × 25	25 × 20	25 × 15	25 × 10
Seedling/hill	2-3	2	2	2	3-4
Upper soil Stirring	0	20 & 35 DAT	20 & 35 DAT	20 & 35 DAT	20 & 35 DAT
Inorganic Fertilizer	BRRI RR	STB + 1% MoP solution*	STB 1% MoP solution*	STB + 1%MoP solution*	STB + 1%MoP solution*

*Sprayed at 30 and 45 DAT, Manure was applied in M_2-M_5

Split plot design was followed where management in the main plot and variety was in the sub plot. The result (Table 16) shows that BRRI dhan71, BRRI dhan87 and BRRI dhan52 varieties obtained the highest yield by M_4 and M_5 agronomic management combinations than the other tested agronomic management practices.

Table 16. Effect of Agronomic factors for maximizing grain yield of BRRI developed new varieties in T. Aman seasons at BRRI HQ farm Gazipur.

Management	V1=BRRI dhan71	V2=BRRI dhan87	V3=BRRI dhan52
M_1	5.12	4.56	4.68
M_2	4.16	4.03	3.80
M_3	4.85	4.19	4.24

M_4	5.61	5.72	5.62
M_5	5.63	5.63	6.24
LSD $_{(0.05)}$ for Variety = 0.658575			
LSD $_{(0.05)}$ for Management = 0.850216			
LSD $_{(0.05)}$ for V × M = 1.47262			
CV% = 17.88			

WEED MANAGEMENT

Evaluation of candidate herbicides for transplanted rice

During the reporting year (T. Aman 2021 and Boro 2021-22), forty herbicides of 12 different groups were evaluated at field level to evaluate the weed control efficiency of candidate herbicide in transplanted rice. Field-trials were conducted at the BRRI HQ farm, Gazipur during T. Aman 2021 and Boro 2021-22 seasons to evaluate the efficacy of candidate herbicides according to standard protocol. Pre emergence herbicides were applied at 4 DAT and post emergence herbicides at 1-2-leaf-stage of weed. Weed sampling was done at 40 DAT for T. Aman and 45 DAT for Boro season. Weed control efficiency was calculated on weed dry weight basis. Most of the herbicide performed more than 80% weed control efficiency in different weed populations observed in the field (Table 17). Only *Cynodon dactylon* cannot be controled >80% by some herbicide in most cases. Among the herbicides, three herbicides did not control weed effectively and their weed control efficiency were less than 80%. Some herbicides were found highly phytotoxic which were treated not satisfactory. Table 17 showed that post emergence herbicide coming to dominant and most of the herbicide contains combination chemicals which indicates to be more effective where the weed control efficiency of these herbicide was more than 80%.

Table 17. Herbicide chemical name, dose and weed control efficiency of different herbicides evaluated during T. Aman 2021 and Boro 2021-22 at BRRI farm Gazipur.

Chemical name	Dose ha^{-1}	Season	Weed Control Efficiency (%)					Remarks
			Cynodon dactylon	*Echinochloa crus-galli*	*Monochoria vaginalis*	*Scirpus maritimus*	*Cyperus difformis*	
Bispyribac sodium 4% + Metamifop 10% SE	100 g	Aman	86.50	84.50	84.50	88.88	80.90	Pre-emergence satisfactory
		Boro	65.50	82.00	82.85	85.55	79.78	
Pyrazosulfuron ethyl 10% + Bispyribac 20% WP	150 g	Aman	74.50	82.0	84.80	86.28	86.75	Post-emergence Satisfactory
		Boro	72.10	83.65	80.44	80.20	80.50	
Qunichlorac 34% + Bensulfuron methyl 6%	600 g	Aman	87.52	85.50	80.45	70.20	50.50	Post-emergence very sensitive to over dose
		Boro	84.54	85.00	82.30	80.50	80.84	
Sulfentrazone 48% SC	200ml	Aman	65.70	85.00	80.00	82.60	82.70	Pre-plant and pre-emergence Satisfactory
		Boro	78.86	84.50	83.70	81.75	76..47	
Bispyribac sodium 40% SC	150ml	Aman	80.70	82.88	85.00	80.25	83.88	Post-emergence Satisfactory
		Boro	83.00	80.28	86.00	84.50	81.22	
Pyraclonil 2%	152 g	Aman	75.40	83.80	88.4	83.77	80.44	Pre to early Post-emergence Satisfactory
		Boro	70.60	85.77	82.55	84.60	84.20	
Bensulfuron metlyl 4% + Bispyribac sodium	150 g	Aman	70.50	88.65	88.00	84.33	87.00	Post-emergence Satisfactory
		Boro	77.50	83.55	83.00	86.80	84.75	

Cost effective weed management in transplanted rice

The trial was conducted at the Sadar upzilla, Gazipur during Aus 2021 and Tahirpur, Sunamganj and Paba, Rajshahi during Boro 2021-22 seasons to evaluate the method of weed suppression and to find out an appropriate way to reduce weed infestation in farmers' field. The trial was carried out with three treatments viz weed management by pre/post emergence herbicide + 1 HW, Weed management by BRRI weeder just after 1st and 2nd top dress of urea and weed management by farmers' practice. Twenty-five-day-old seedlings of BRRI dhan48, BRRI dhan98 and BRRI hybrid dhan7 were transplanted at 20 × 20 cm spacing with two seedlings hill^{-1} in Aus and forty-day-old seedlings of BRRI dhan67, BRRI dhan75, BRRI dhan81 in Aman and forty-six days old seedlings of BRRI dhan89 were transplanted at Boro season. Fertilizer was applied by following BRRI recommended dose Aus: N:P:K= 62:11:41 kg ha^{-1} and Boro: N:P:K:S:Zn=120:19:60:20:4 kg ha^{-1}. Pre-emergence (Bensulfuran methyl + acetachlor) herbicide was sprayed at five days after transplanting and post-emergence (Penoxulam) herbicide was sprayed at eight days after transplanting with the help of a knapsack sprayer. Weeding was done by BRRI weeder during 1st and 2nd top dress of urea. Results indicated that applying BRRI weeder just after 1st and 2nd top dress of urea showed the highest grain because just after urea top dressing BRRI weeder incorporate in the soil properly and yield reduce the weed infestation. Weed management by pre-emergence herbicide also produce similar grain yield. Farmers have done hand weeding in their plots. So weeding cost is higher for farmers and due to late weeding their yields were also reduced than BRRI treatments.

SOIL MICROBIOLOGY AND MANAGEMENT

Study on biodegradation of pesticides in soil using selected microbial strain

The experiment was conducted in the Agronomy and Entomology division, BRRI to estimate the rate of pesticide degradation by the beneficial soil microbes. The bacterial strains were collected from the soil microbiology laboratory, Soil science division, BRRI. The two PGPR strains *Proteus sp* and *Bacillus sp* and a widely used insecticide, popularly known as virtako (Chlorantraniliprole + thiamethoxam) (CTP) were used in this study. Initially, the bacterial strain was cultured in Tryptic Soy Broth (TSB) medium. The recommended dose of the insecticide was inoculated in each of the bacteria inoculated flask. The flask was allowed for shaking in a rotary shaker until a period of 21 days. The aliquot was collected at 1, 3, 7, 10, 15, and 21 days after pesticide inoculation. The pesticide residue was extracted from the collected samples through centrifugation using acetonitrile (ACN). The extracted liquid was transferred into autosampler vials for analysis using LC-MS. The concentration of insecticide in non-inoculated media was almost consistent over the period. However, inoculation of bacterial strains *Proteus mirabilis* showed a steady fall in concentration from 7 DAI onwards. The concentration of CTP in *Proteus mirabilis* inoculated media at 21 DAI was reduced by 20.96% over the control. Besides, the concentration of CTP in *Bacillus tequilensis* inoculated media reduced drastically at 7 DAI following a gradual decrease thereafter. It showed a 70.69% of decrease at 21 DAI over the control (Fig 2). Among the two bacterial strains, *Bacillus tequilensis was* highly performed to degrade CTP in TSB media.

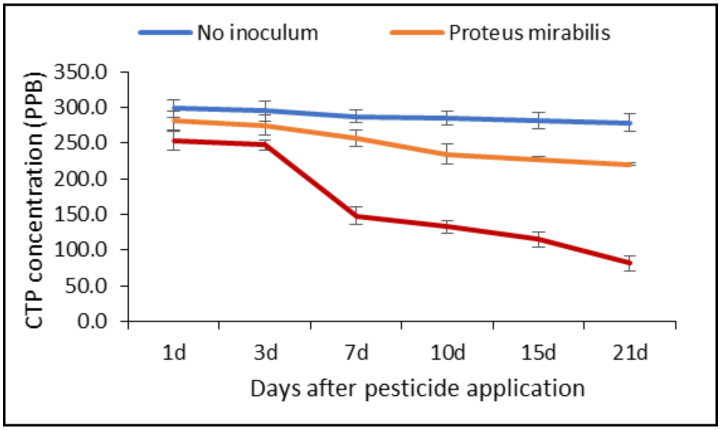


Fig 2. The degradation of CTP inoculated with bacterial strains in TSB media.

Residue analysis of widely used herbicides in the irrigated rice eco-system in 2020-21 season at BRRI HQ farm Gazipur.

Good Agricultural Practices (GAP) were ensured based on a quick, easy, cheap, rugged, safe (QuEChERS) method coupled with LCMS-MS. The experiment was conducted to determine the residue of four popular herbicides, 1) Bensulfuron-methyl + Acetochlor (Pre-emergence), 2) Pyrazosulfuron-ethyl (Post-emergence), 3) Pendimethalin (Pre-emergence), 4) Ethoxysulfuron-ethyl (Post-emergence) compared with the weed-free plot (No chemical) at BRRI HQ farm, Gazipur during Boro 2021-22. The treatments were distributed in an RCB design with three replications. Fortyday-old seedlings of BRRI dhan28 were transplanted on 22 January. All agronomic management was done per BRRI recommendation and when necessary. For the determination of the residue effect, a calibration curve was generated using 11 points in the range of 0.1 to 100ppb with a regression of 0.999. Both of the herbicides, Bensulfuron-methyl and Pendimethalin were dissolved in Acetonitrile LCMS grade (Sigma Aldrich) and passed through a Shim-pack Scepter column (C-18, 2.1 x 150 mm). The limit of detection (LOD) for Bensulfuron-methyl and Pendimethalin was found 0.10 µg/Kg and 0.12 µg/Kg, respectively. The limit of quantification (LOQ) of the two herbicides was observed at 0.35 µg/Kg and 0.31 µg/Kg, respectively (Fig. 3). The maximum residue limit (MRL) of both Bensulfuron-methyl and Pendimethalin is 100 ppb in rice (Brown). Such a method could be used to determine the assessment as well as scientific guidance on the proper and safe application of herbicides in paddy fields.

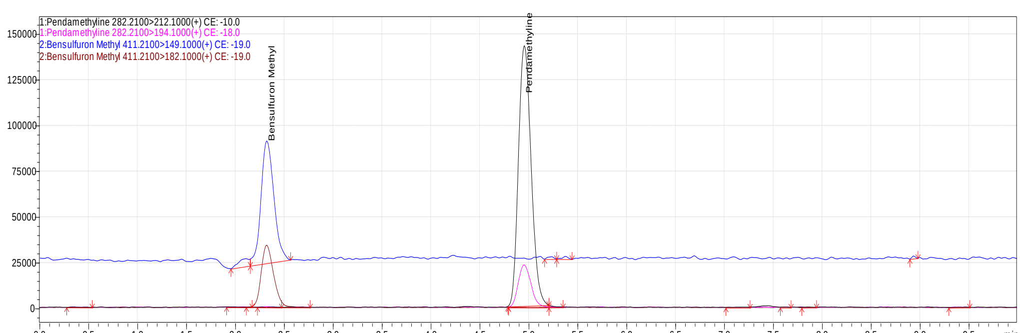


Fig. 3. Herbicides measures and standardized in LCMS-MS.

Soil Science Division

SUMMARY

In T. Aman season, the ZER line BR 9674-1-1-5-2-P4 produced comparatively lower grain yield (5.24 t ha^{-1}) than the check varieties BRRI dhan49, BRRI dhan72 and BRRI dhan87. The economic optimum doses of N for ZER advanced line BR 9674-1-1-5-2-P4 was 64 kg N ha^{-1}, and for the check varieties BRRI dhan49, BRRI dhan72, and BRRI dhan87 were 70, 54 and 64 kg N ha^{-1}, respectively. In Boro season, the PQR-ALART materials BR9930-2-3-2-2 (6.72 t ha^{-1}) and BR9930-2-3-3-1 (6.75 t ha^{-1}) produced higher grain yield than the three PQR check varieties of BRRI dhan50 (6.52 t ha^{-1}), BRRI dhan63 (6.58 t ha^{-1}) and BRRI dhan81 (6.43 t ha^{-1}) in the same dose of N (120 kg N ha^{-1}). The economic optimum N dose for PQR advanced lines BR9930-2-3-2-2 and BR9930-2-3-3-1 were 122 kg and 121 kg N ha^{-1}, respectively. The calculated economic optimum N dose for BRRI dhan95 in T. Aman season was 88 kg N ha^{-1} and in Boro season for BRRI dhan92 it was 180 kg N ha^{-1}.

Urea-HA nanohybrid saves up to 50% urea use providing comparable N use efficiency with widely applied prilled urea. In P deficient soil, the economic optimum dose of P for BRRI dhan87 was 27.5 kg ha^{-1} in T. Aman season and in Boro season of BRRI dhan89 and BRRI dhan96 the P doses were 27 kg and 26.8 kg ha^{-1}, respectively. The optimum N and K rates were 98 and 106 kg ha^{-1}, respectively for BRRI hybrid dhan6 during T. Aman, while for BRRI dhan89 in Boro season, the rates were 128 kg N and 100 kg K ha^{-1}. Result of the pot experiment in T. Aman season showed that application of Cu, Ni, Se and Si along with full dose of chemical fertilizer had positive impact on yield and yield contributing characters of BRRI dhan87. In Gazipur, after 6th crop cycles, it was revealed that AEZ or STB based chemical fertilizers (CF) seemed sufficient to obtain potential yield of each crop in Mustard-Boro-T. Aus-T. Aman (CP-1) or Mustard-Mungbean-T. Aus-T. Aman (CP-2) cropping pattern. Considering rice equivalent yield (REY), CP-1 performed better than CP-2.

Besides N, P and K, omission of S and Zn from balanced complete fertilizer reduced grain yield greatly in both T. Aman and Boro seasons. The annual yield of organic fertilizers with IPNS based chemical fertilizer showed an increasing trend compared to balanced complete fertilizer application. In the continuous wetland, additional application of Zn and Cu once in a year with NPKS increased annual grain yield by more than 1.0 t ha^{-1} than NPKS alone. In T. Aman BRRI dhan87 and BRH11-2-4-7B produced comparatively higher grain yield than the other tested rice genotypes and IIMP performed better than BRRI management.

Application of 100% STB dose or 50% STB + mixed manure showed similar yield trend and increased soil fertility in long-term double and triple rice cropping pattern in HQ, BRRI Gazipur farm soil. Some positive effect on yield increment was observed due to application of vermicompost @ 1 or 2 t ha^{-1} in coastal belt of Borguna and Khulna district. No additional yield advancement was observed in application of vermi-compost (2.5, 5 and 10 tha^{-1}) incombination with silicon (100, 200 and 400 kg ha^{-1}) in both T. Aman and Boro seasons at BRRI HQ, Gazipur.

Soil test-based fertilizer recommendation performed good in both BRRI RS farmers, Cumilla and Sonagazi soil for maximizing rice yield although some organic matter (2 t ha^{-1}) would be need for sustained soil fertility in the long run. Increased grain yield observed in residue management and AEZ based chemical fertilizer (100%) application but crop establishment methods have no positive effect on grain yield.

In considering yield, N use efficiencies and NH_3-N loss, N applied @ 105 kg ha^{-1} from UDP and PU + BRRI-organic fertilizer in Boro season and N applied @ 83 kg ha^{-1} from UDP in T. Aman season could be the most suitable N management interventions to sustain rice production and reduce environmental pollution. In charland, application of biochar @ 4 t ha^{-1} along with chemical fertilizer maximized the grain yield in Boro season. Whereas, some residual effect of biochar in grain yield was observed in the succeeding T. Aman season. Reduced N dose (78 kg N ha^{-1}) with mixed manure (cowdung 2 ton + ash 1 ton) produced the highest yield than the other N management

packages in coastal rice ecosystems of BRRI RS, Satkhira farm.

BRRI-organic fertilizer (2 t ha^{-1}) has potential to supplement 30% N and 100% P requirement for HYV rice without sacrificing yield. Microbial characterization of eight different AEZs soils have been done. Soil bio-physico-chemical properties of different AEZ's, biomolecular characteristics of the isolated strains and formulation of biofertilizer for acid and saline soil were evaluated.

SOIL FERTILITY AND PLANT NUTRITION

Determining N requirement of ZER and PQR ALART materials. N is the most limiting nutrients for rice production. Separate field trials were conducted for ZER (zinc enrich rice) and PQR (premium quality rice) genotypes at BRRI HQ farm, Gazipur (AEZ 28; Modhupur Tract) during T. Aman 2021 and Boro 2021-22 following split-plot design with three replications, where fertilizer doses were assigned in main-plot and rice genotypes in sub-plot. In T. Aman, one ZER line BR 9674-1-1-5-2-P4 was compared with three check varieties viz BRRI dhan49, BRRI dhan72 and BRRI dhan87 and in Boro season, two PQR lines BR9930-2-3-2-2 and BR9930-2-3-3-1 and three rice varieties viz. BRRI dhan50, BRRI dhan63 and BRRI dhan81 as check were evaluated. Six urea-N doses (kg ha^{-1}): N_0, N_{20}, N_{40}, N_{60}, N_{80} and N_{100} with standard doses (soil test based) of P, K, S were applied for T. Aman and in Boro the N doses (kg ha^{-1}): N_0, N_{30}, N_{60}, N_{90}, N_{120} and N_{150} with standard doses of P, K, S and Zn were applied. A quadratic regression model was used to determine the optimum N requirement.

Grain yield and N requirements. In T. Aman, grain yield increased with increasing the N doses up to 80 kg ha^{-1} in most genotypes than decreased. The ZER line BR 9674-1-1-5-2-P4 produced a comparatively lower grain yield (5.24 t ha^{-1}) than the three check varieties. The economic optimum doses of N for ZER advanced line BR 9674-1-1-5-2-P4 was 64 kg N ha^{-1}, and for the check varieties BRRI dhan49, BRRI dhan72, and BRRI dhan87 were 70, 54 and 64 kg N ha^{-1}, respectively. In Boro season, the highest grain yield was obtained in T_5 (120 kg N ha^{-1}) treatment in all the tested genotypes but the result was insignificant compared with T_4 (90 kg N ha^{-1}) and T_6 (150 kg N ha^{-1}) treatments. Comparatively higher grain yield was obtained with two PQR-ALART materials BR9930-2-3-2-2 (6.72 t ha^{-1}) and BR9930-2-3-3-1 (6.75 t ha^{-1}) than the three PQR check varieties BRRI dhan50 (6.52 t ha^{-1}), BRRI dhan63 (6.58 t ha^{-1}) and BRRI dhan81 (6.43 t ha^{-1}) in the same doses of nitrogen (120 kg N ha^{-1}). The economic optimum N dose for PQR advanced lines BR9930-2-3-2-2 and BR9930-2-3-3-1 were 122 kg and 121 kg N ha^{-1}, respectively and for the check varieties BRRI dhan50, BRRI dhan63 and BRRI dhan81 were 115,114 and 114 kg N ha^{-1}, respectively

Determining N doses for MV rice varieties. The experiment was conducted at the experimental field of BRRI HQ, Gazipur in T. Aman 2021 and Boro 2021-22 seasons to determine the optimum N requirement of BRRI dhan95 and BRRI dhan92, respectively. The experiment was laid out in a RCB design with three replications. The applied N doses (kg ha^{-1}) for T. Aman was 0, 30, 60, 90, 120, 150 and Boro was 0, 40, 80, 120, 160, 200, respectively, along with flat doses of P, K, S fertilizer. The grain yields of BRRI dhan95 and BRRI dhan92 were significantly influenced by N rates. The calculated economically optimum N dose for BRRI dhan95 was 88 kg/ha in T. Aman season and in Boro season, for BRRI dhan92 it was 180 kg/ha. However, in case of BRRI dhan92 the grain yield was similar with 120, 160 and 200 kg N ha^{-1}. The slow response to higher N rates might be due to the slow mineralization of N because of low temperature during the growing period.

Increasing N use efficiency and determining nutrient requirements of MV rice. A rice growth pot experiment was set up using a terrace paddy soil of BRRI, Gazipur from January to May 2022 covering 6 fertilizer treatments × 3 replicates. The intention was to investigate the N use efficiency of typically synthesized urea-HA (hydroxyapatite) nanohybrid and urea plus purified natural zeolite (71% SiO_2) over prilled urea. Urea-HA nanohybrids was synthesized according to method by Kottegoda *et al*. (2017). Transplanted rice (BRRI dhan89) was grown in the green house under continuous flooding for 114 days. Six treatments viz T_1: PKSZn, T_2: Urea-N_{120} PKSZn, T_3: Nano fert.-N_{120} PKSZn, T_4: Nano fert.-N_{60} PKSZn, T_5: Urea-N_{120} PKSZn + purified natural zeolite (71% SiO_2) @ 2.5 t ha^{-1} and T_6: Urea-N_{60} PKSZn were tested.

Yield and N use efficiency. Among the studied parameters, the number of effective tiller and panicle, filled grain weight and grain yield were significantly greater in all N fertilizer treated pots (T_2, T_3, T_4, T_5 and T_6) than N untreated pot (T_1) (Table 1). All these parameters were statistically identical between the N fertilizers treatments except greater tiller no. recorded in N applied at 60 kg ha^{-1} from urea (T_6). In nano fertilizer, N applied at 60 kg N ha^{-1} i.e. in T_4, the number of panicle, filled grain weight and grain yield were statistically identical with N applied at 60 kg N ha^{-1} from urea (T_6), as well as N applied at 120 kg N ha^{-1} from urea (T_2), nano fertilizer (T_3) and urea + zeolite (T_5). The agronomic N use efficiencies (AE_N) (kg grain kg^{-1} N applied) were greater in T_4 (15), T_2 (14), T_3 (14) and T_6 (13) and lower in (T_5). Therefore, Urea-HA nanohybrid may save up to 50% urea use providing comparable N use efficiency with widely applied prilled urea but requires characterization of synthesized nanofertilizer and further verification via i*n-situ* research certainly with nanofertilizer in more paddy soils.

Table 1. Typical yield attributes, grain and straw yields, and agronomic N use efficiency (AE_N) of the studied greenhouse rice growth pot experiment during Boro season 2021-22.

Treatment	Plant height (cm)	Tiller no. (pot^{-1} $hill^{-1}$)	Panicle no. (pot^{-1} $hill^{-1}$)	Filled grain wt. (g pot^{-1} $hill^{-1}$)	Grain yield (t ha^{-1})	Straw wt. (g pot^{-1} $hill^{-1}$)	Straw yield (t ha^{-1})	AE_N (kg grain kg^{-1} N applied)
T_1: PKSZn	87ab	13d	13c	33b	8.3b	26.8b	6.7b	
T_2: UreaN_{120}-PKSZn	89ab	17b	16ab	40a	10.0a	31.3ab	7.8ab	14
T_3: Nano fert. N_{120}-PKSZn	85ab	15cd	14bc	40a	10.0a	30.6ab	7.6ab	14
T_4: Nano fert. N_{60}-PKSZn	91a	17bc	17ab	37ab	9.2ab	30.2b	7.5b	15
T_5: UreaN_{120}-PKSZn + Zeolite (2.5 t ha^{-1})	86ab	17bc	17ab	36ab	9.0ab	30.5ab	7.6ab	6
T_6: UreaN_{60}-PKSZn	81b	20a	19a	36ab	9.1ab	36.9a	9.2a	13

Different lower-case letters within the column denote significant differences between the treatments according to ANOVA and Duncan's Multiple Range Post-Hoc Test.

Performance of rice varieties under P deficit conditions. Acute P deficiency reduces rice yield depending on internal and/or external mechanisms that allow greater soil P extraction. The experiments were conducted at BRRI farm, Gazipur during T. Aman 2021 and Boro 2021-22 season having deficit soil available P conditions. Six treatments of P doses calculating from soil test value (STB) viz T_1= P control, T_2= 50% of STB P (11 kg ha^{-1}), T_3= 75% of STB P (16.5 kg ha^{-1}), T_4= 100% of STB P (22 kg ha^{-1}), T_5= 125% of STB P (kg ha^{-1}) and T_6= 150% of STB P (27.5 kg ha^{-1}) were applied in both the seasons. BRRI dhan87 in T. Aman and BRRI dhan89 as well as BRRI dhan96 in Boro season were used as tested rice varieties. Each plot received a flat dose of N-K-S-Zn (kg ha^{-1}) @ 90-42-10-1 in T. Aman and 160-60-20-2 in Boro

Grain yield of T. Aman and Boro. In the P deficient soil, P fertilizer had significant effect on grain yield. The grain yield in the P fertilized plot progressively increased with the increasing level of P fertilizer in both the seasons. In T. Aman season, yield increasing trend was observed up to T_6 treatment. Although the highest grain yield was obtained with T_6 treatment (5.55 t/ha), but it was statistically similar with T_4 (5.52 t/ha) and T_5 (5.42 t/ha). The P control plot yielded only 3.13 t/ha. From the response curve, the economic optimum dose of P for BRRI dhan87 in P deficient soil was found 27.5 kg ha^{-1}. In Boro, under control P condition, grain yield was 1.45 t ha^{-1} only and with 50% and, or 75% applying of fertilizer P, grain yield increased sharply and significantly up to T_4 (7.01 t ha^{-1}) for BRRI dhan89 which was significantly higher than T_3 and T_2 treatment. In BRRI dhan96, the P control plot yielded only 1.99 t ha^{-1}, but the application of P fertilizer in T_2 (50% P), T_3 (75% P) and T_4 (100% P) treatment grain yield increased significantly. Both the rice varieties performed best at 100% STB P condition. Among the tested rice genotypes, BRRI dhan96 performed better in the same level of applied P condition than BRRI dhan89. From the response curve, the economic optimum dose of P for BRRI dhan89 and BRRI dhan96 were found 27 and 26.8 kg ha^{-1}, respectively in P deficient soil in Boro season.

Influence of N and K on the performance of modern rice. The study was conducted to observe the effect of nitrogen (N) and potassium (K) on the yield and nutrition of modern rice at BRRI farm, Gazipur during T. Aman 2021 and Boro 2021-22 season. The experiment was laid out in split-plot design with three replications assigning the rates of K in the main plots and that of N in the subplots. Soil test based flat rates of P and S were applied to all the plots. The application rate of K was 0, 50, 100, 150, and 200 kg ha^{-1} both in T. Aman and Boro seasons. Nitrogen was applied @ 0, 50, 75, and 100 kg ha^{-1}, in T. Aman season, while in Boro season, the rate of N was 0, 100, 150 and 200 kg ha^{-1}. The test varieties were BRRI hybrid dhan6 and BRRI dhan89 in T. Aman and Boro seasons, respectively.

Grain and straw yield. The interaction effect of rice yield between N and K was significant in both T. Aman 2021 and Boro 2021-22 (Table 2). The highest grain yield (5.10 t ha^{-1}) was found when N and K fertilizer was used at 75 kg and 100 kg ha^{-1}, respectively in T. Aman 2021. In Boro 2021-22, grain yield of BRRI dhan89 was significantly affected by the interaction of N and K addition (Table 2). The effect of N on rice grain yield was distinctly dominant over K effect during the Boro season. The highest grain yield (7.19 t ha^{-1}) was achieved with 100 kg N and 100 kg K ha^{-1} (Table 2). The optimum N and K rates that produced the maximum grain yield were determined using the quadratic equations of the response curves. Accordingly, the optimum N and K rates estimated from the equations were 98 and 106 kg/ha, respectively for BRRI hybrid dhan6 during T. Aman, while for BRRI dhan89 in Boro season, the rates were 128 kg N and 100 kg K/ha (Table 2).

Table 2. Effect of N and K on the grain yield (t ha^{-1}) of BRRI hybrid dhan6 in T. Aman 2021 and BRRI dhan89 in Boro 2021-22 at BRRI farm, Gazipur.

K rate (kg ha^{-1})	N rate (kg ha^{-1})							
	0	50	75	100	0	100	150	200
	BRRI hybrid dhan87 (T. Aman)				BRRI dhan89 (Boro)			
0	3.85a	4.43b	3.98c	3.54b	3.61a	4.49c	4.07b	4.09d
50	4.07a	4.66ab	4.91ab	4.73a	3.50a	6.37b	6.44a	5.95c
100	4.21a	4.69ab	5.10a	4.88a	3.65a	7.19a	7.07a	6.84a
150	4.27a	4.97a	4.83ab	4.60a	3.92a	6.84ab	6.83a	6.66ab
200	4.19a	4.90ab	4.47bc	4.03b	4.02a	6.66ab	6.77a	6.08bc
Mean	4.12C	4.73A	4.66A	4.36B	3.74B	6.31A	6.24A	5.93A
ANOVA (p values)								
Nitrogen (N)	0.0000				0.0000			
Potassium (K)	0.0127				0.0000			
N × K	0.0038				0.0000			

Values followed by the same letter are not significantly different at the 5% level of probability

Effect of different micro and beneficial nutrients on growth and yield of rice. The study was undertaken with the objective to determine the effect of micronutrients and beneficial nutrients on growth and yield of rice. A pot experiment was set up in the glass house of Soil Science Division, BRRI, Gazipur. The study was laid out in a completely randomized block design with three replications and five treatments: T_1= NPKSZn, T_2= T_1 + CuNiSeSi, T_3= T_1 + CuNiSi, T_4= T_1 + CuSi and T_5= T_1 + Si. All treatments received a blanket dose of chemical fertilizer i.e. N-P-K-S-Zn @ 120-15-60-10-1.5 kg ha^{-1}. The Cu, Ni, Se and Si were applied as a foliar spray with the rate of 1%, 0.2%, 10 ppm and 0.2%, respectively. In T. Aman season, the growth and yield of BRRI dhan87 significantly differed with the applied treatments. The highest plant height (96.11 cm) was recorded in T_2 treatment but there is no significant variation with T_5, for number of panicles per hill (22), panicle length (22.47 cm), number of filled grains per panicle (131), grain (76.34 g pot^{-1}) and straw yield (56.99 g pot^{-1}). From the treatment combination it appeared that the increased growth and yield of BRRI dhan87 was attributed to the application of Si.

Nutrient management for growing four crops in a year. The experiment has been initiated in T. Aus 2016 to grow four crops in a year to sustain soil fertility and increase productivity. Three fertilizer treatments viz soil test based (STB) fertilizer (T_1), crop residues (CR) + STB fertilizer (T_2) and fertilizer control i.e. native soil nutrients (T_3) were tested with Mustard-Boro-T. Aus-T. Aman (CP-1) and Mustard-Mungbean-T. Aus-T. Aman (CP-2) patterns. The experimental design was randomized complete block with three replicates. The first crop Mungbean was incorporated in T_2 treatment. After two crop cycles, T_1 and T_2 treatments produced statistically identical grain yield in each crop. In the 3rd year and 3rd crop cycle, both the cropping patterns were also giving their potential yield with AEZ based chemical fertilizer application (T_1) as well as with crop residue incorporation (T_2). After 4^{th}, 5^{th} and 6^{th} crop cycles, it is revealed that AEZ based or soil test based (STB) chemical fertilizers seemed sufficient to obtain potential yield of each crop under both the patterns except for Mungbean 2021-22 (6^{th} crop cycle) in CP-2 (Table 3). In all the cases, incorporation of crop residue had some positive impact on yield, soil organic C and total N (on average soil OC and total N content increased by 0.1% and 0.01%, respectively; data not shown) chemical fertilizer only (Table 3). Considering rice equivalent yield (REY), CP-1 (Mustard-Boro-T. Aus-T. Aman) performed better than CP-2 (Mustard-Mungbean-T. Aus-T. Aman) (Table 3), but postharvest soil nutrients levels will provide detail insights on soil nutrients buildup or mining/depletion.

Table 3. Grain yield and rice equivalent yield (REY) (t ha^{-1}) of CP-1 and CP-2 at BRRI HQ, Gazipur during 2021-22 (6^{th} crop cycle).

Treatment	T. Aus 2021		T. Aman 2021		Mustard 2021-22		Boro 2021-22	Mungbean 2021-22	REY**	
	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2	CP-1	CP-2
T_1: STB fertilizer dose	3.41a*	3.57a	3.25a	3.29a	0.34a	0.50a	5.02a	0.44	12.6	9.8
T_2: Crop residues (CR) + T_1	3.38a	3.29a	3.54a	3.59a	0.44a	0.66a	5.85a	0.44	14.0	10.3
T_3: Native nutrient	1.43b	2.55b	1.49b	2.18b	0.01b	0.15b	2.53b	0.35	5.5	6.4

*Different lower-case letters within the column denote significant differences of grain yields between the treatments according to ANOVA and DMRT- Post-Hoc Test. **To calculate REY it was assumed that prices of mustard, mungbean and rice are 50, 65 and 18 Tk. kg^{-1}, respectively.

IDENTIFICATION AND MANAGEMENT OF NUTRITION DISORDER

Long-term use of organic and inorganic nutrients in Boro-Fallow-T. Aman rice: A long-term experiment was initiated on a permanent layout at BRRI HQ farm, Gazipur in 1985 Boro season having 12 treatments assigned in RCB design with four replications. The objective of the study was to find out the impact of long-term nutrient management on grain yield and soil health. The treatments were revised according to needs (see BRRI, 2016 and BRRI, 2020). The recent STB doses of NPKSZn were 160-12-80-5-2 kg ha^{-1} and 100-10-80-5-2 kg ha^{-1} for Boro and T. Aman rice, respectively. The tested rice varieties were BRRI dhan87 in T. Aman and BRRI dhan89 in Boro season.

Grain yield of T. Aman and Boro. In the T. Aman and Boro seasons, omission of N, P, K and S decreased grain yield significantly compared to the complete fertilizer treatment **(**Table 4**).** In T. Aman 2021, among the applied organic materials, poultry manure (PM) @ 2 t ha^{-1} as integrated plant nutrient system (IPNS) produced the highest grain yield (5.38 t ha^{-1}) which was statistically similar to complete chemical fertilizer (5.25 t ha^{-1}). Cowdung (CD) @ 3 t ha^{-1}as IPNS (5.0 t ha^{-1}) and vermicompost (VC) @ 2 t ha^{-1}as IPNS (4.85 t ha^{-1}) treated plots produced lower grain yield compared to PM with IPNS treated plots. The omission of N, P and K produced significantly lower grain yield than the complete fertilizer and IPNS treated plots but the omission of S and Zn produced almost similar yield with organic treated plots except PM. In Boro 2021-22, the highest grain yield (7.07 t ha^{-1}) was obtained from PM added IPNS, which was statistically identical with complete fertilizer (6.92 t ha^{-1}) and CD added IPNS (6.70 t ha^{-1}) but VC added IPNS (6.41 t ha^{-1}) produced significantly lower grain yield. In both the seasons, sulfur (4.81 and 6.40 t ha^{-1}) and zinc (4.68 and 6.29 t ha^{-1}) omitted plot produced significantly lower grain yield compared to full dose of chemical fertilizer plot. Moreover, significant yield difference was found among reduced K doses (60 and 40 kg K ha^{-1}) and complete K fertilizer treatment (K 80 kg ha^{-1}) in both the seasons. In case of annual yield, organic with IPNS based chemical fertilizer treatment shows an increasing yield trend compared to complete chemical fertilizer treatment **(**Fig. 1**).**

Table 4. Effect of organic and inorganic amendments on rice grain yield (t ha^{-1}) of BRRI dhan87 and BRRI dhan89 at BRRI HQ, Gazipur, in 2020-21.

Treatment	Grain yield (t ha^{-1})	
	T. Aman 2021	Boro 2021-22
T_1 = NPKSZn@150/100-12/10-80-5-2 $kgha^{-1}$	5.25 ab	6.92 ab
T_2 = NPSZn (-K)	3.59 ef	3.75 e
T_3 = NKSZn (-P)	2.51 g	1.87 g
T_4 = PKSZn (-N)	3.85 e	2.67 f
T_5 = CD (3 t ha^{-1}) + IPNS	5.00 bc	6.70 abc
T_6 = NPKS (-Zn)	4.68 cd	6.29 cd
T_7 = NPKZn (-S)	4.81 cd	6.40 bcd
T_8 = PM (2 t ha^{-1}) + IPNS	5.38 a	7.07 a
T_9 = NPKSZn @150/100-12/10-60-5-2 $kgha^{-1}$	4.55 cd	6.22 cd
T_{10} = VC (2 t ha^{-1}) + IPNS	4.85 c	6.41 bcd
T_{11} = NPKSZn@150/100-12/10-40-5-2 $kgha^{-1}$	4.47 d	6.01 d
T_{12} = Control (native nutrients)	3.37 f	1.85 g
CV (%)	*3.37*	*4.05*

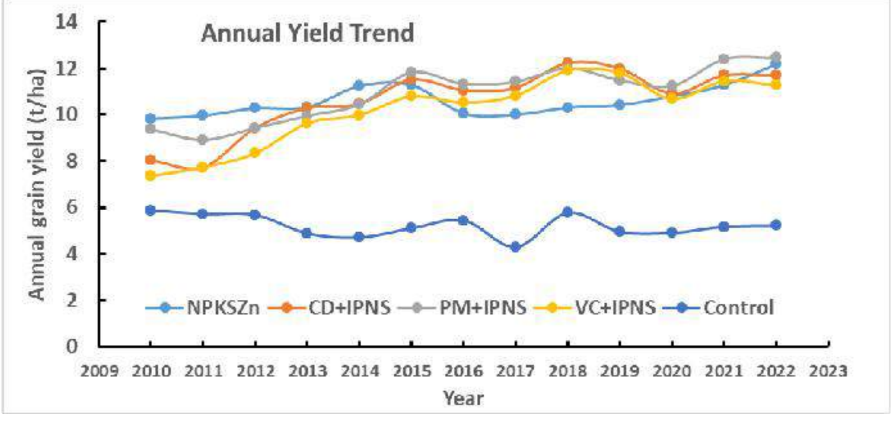


Fig. 1. Annual yield trend of IPNS based treatment compared with complete chemical fertilizer and control treatment, 2021-22, BRRI, Gazipur.

Post-harvest soil pH, %OC and %N.

The post-harvest soil pH, organic carbon and total nitrogen were greatly influenced by long-term (more than ten years) applications of organic and inorganic amendments in both the measures (0-15 cm and 15-30 cm) of depth **(**Table 5**)**. The pH in the upper layer (0-15 cm) slightly acidic than the lower layer (15-30 cm). Slightly increased soil pH was observed in organic amendment plots which was the highest in poultry manure (6.98) treated plot. Soil pH decreased in omission of P, K, S, and Zn in upper layer (0-15 cm depth). Long-term use of balanced and organic fertilizer increased soil organic carbon (SOC) significantly. The highest SOC was found in CD treated plot followed by PM and VC which were significantly higher than complete chemical fertilizer treatment. The omission of other nutrients like P, K, S and Zn showed lower SOC than balanced fertilizer treatment. Like organic carbon, similar trend was observed for total nitrogen in the post-harvest soil.

Table 5. Effect of long-term organic and inorganic amendments on soil pH, organic carbon and total nitrogen in the post-harvest soil of 0-15 cm depth, BRRI, Gazipur, 2021-22.

Treatment	Soil pH		Organic carbon (%)		Total nitrogen (%)	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
T_1 = NPKSZn (complete)	6.72	7.62	2.21	1.37	0.191	0.118
T_2 = NPSZn (-K)	6.64	7.68	1.58	1.11	0.136	0.096
T_3 = NKSZn (-P)	6.66	7.90	1.47	1.09	0.127	0.094
T_4 = PKSZn (-N)	6.65	7.75	1.56	1.08	0.135	0.093
T_5 = CD (3 tha^{-1}) + IPNS	6.74	7.80	3.37	1.60	0.290	0.138
T_6 = NPKS (-Zn)	6.68	7.92	2.01	1.33	0.173	0.115
T_7 = NPKZn (-S)	6.65	7.77	1.87	1.32	0.162	0.113
T_8 = PM (2 tha^{-1}) + IPNS	6.98	7.94	2.80	1.64	0.241	0.141
T_{10} = VC (2 tha^{-1}) + IPNS	6.84	7.85	2.27	1.47	0.195	0.126
T_{12}= Fert. control	6.94	7.93	1.20	1.01	0.103	0.086
$LSD_{0.05}$	*0.17*	*0.21*	*0.38*	*0.25*	*0.032*	*0.022*
CV (%)	*0.88*	*0.90*	*6.43*	*6.66*	*6.42*	*6.74*

Effect of intensive rice cropping on rice yield under continuous wetland conditions. The experiment was designed to harvest three rice crops per year with the evaluation of the consequences of intensive rice cropping under continuous wetland conditions and to monitor soil fertility changes over time. This experiment was initiated in 1971 in a permanent layout with NPK fertilizer application. Since Boro 2000, the experiment was modified to accommodate six treatments viz control (native nutrient), reverse control (NPKSZnCu), NPK, NPKS, NPKSZn and NPKSZnCu after several revision in 1982, 1984 and 1991. In Boro 2020-21, the experiment was revised again with the N and K fertilizers from 140 to 160 and 80 to 100 kg ha^{-1}, respectively. The varieties tested in T. Aus, T. Aman and Boro seasons were BRRI dhan48, BRRI dhan87 and BRRI dhan84, respectively. The NPK doses used were 160-25-100, 60-15-80 and 60-10-60 kg ha^{-1} for Boro, T. Aman and T. Aus, respectively. Sulfur, Zn and Cu were applied at 10, 4 and 1 kg ha^{-1} in Boro season only.

Grain yield and yield trend. The annual rice production trend from 1981 to 2021 was decreasing because of continuous rice cultivation with no fertilizer application treatment. However, from 2001 the reverse control treatment produced grain yield almost similar to complete fertilized treatment (Fig. 2). In 2021, annual rice production in the control plot was only 4.94 t ha^{-1} while its reversed management (addition of NPKSZnCu fertilizer) resulted in 13.35 t $ha^{-1}yr^{-1}$ grain production, which was close to complete fertilizer treatment (14.14 t ha^{-1} yr^{-1}). It indicates that complete fertilization can recuperate soil productivity even after a long period of rice cultivation. Results indicated that additional use of Zn and Cu once in a year with NPKS increased annual grain yield by more than 1.0 t ha^{-1} over the application of NPKS alone (Table 6). A similar increasing trend was observed in complete fertilizer (NPKSZnCu) treatment of grain yield in Boro season, 2020-21.

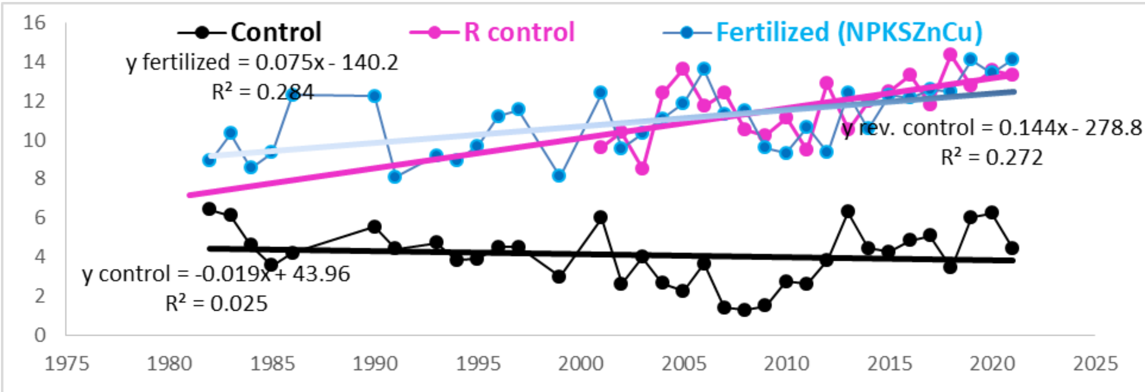


Fig. 2. Annual rice production trend under intensive wetland conditions in BRRI HQ, Gazipur during 1981-2021..

Regional yield maximization trial (RYMT) under recommended management practices. The experiment was conducted at the experimental farm of BRRI, Gazipur in T. Aman 2021 to validate integrated improved management practices (IIMP) compared with BRRI recommended practices (Control) and to maximize proper filling of grains in a panicle under integrated management practices. Five selected genotypes (BRH13-2-4-7-2B, BRH10-1-14-2-7B, BRH11-2-4-7B, Jirasail and BRRI dhan87) were evaluated under integrated improved management practices compared to BRRI recommended practices with split plot design having three replications. Integrated improved management practices were: healthy seedling raising using 60g seeds per square meter seed bed; urea fertilizer application using four splits – basal, 25-30 DAT, 55-60 DAT (before PI) and 75-80 DAT (beginning of heading); harvesting at 90% maturity. BRRI recommended practices were: traditional seedling raising using 100g seeds per square meter seed bed; urea fertilizer application using 3 splits- 10 DAT, 30-35 DAT, 55-60 DAT; harvesting at 80% maturity. Results of T. Aman 2021 showed that BRRI dhan87 (5.4 t/ha) and BRH11-2-4-7B (5.2 t/ha) produced the highest grain yield with sterility 23.3% and 22.1%, respectively. No significant difference between management practices were observed, although IIMP performed better in T. Aman 2021.

INTEGRATED NUTRIENT MANAGEMENT

Integrated nutrient management for double and triple rice cropping. The experiment was initiated in Boro 2008-09 at BRRI HQ, farm Gazipur in a clay loam soil to find the suitable fertilizer management for double and triple rice cropping system and to find out the impact of triple rice cropping on soil health. In Boro-Fallow-T. Aman pattern, BRRI dhan58 and BRRI dhan87 were used. In Boro-T. Aus-T. Aman pattern, BRRI dhan84, BRRI dhan48 and BRRI dhan87 were included as test variety. Fertilizer treatments used were: control, STB dose (NPKS @ 160-25-60-20 kg ha^{-1} for Boro, 70-12-48-10 kg ha^{-1} for T. Aus and 84-21-32-06 kg ha^{-1} for T. Aman), STB (50%) + Mixed manure (MM) (CD @ 2 t ha^{-1} + ash @ 1 t ha^{-1} oven dried), farmers' practice (FP) (NPKS @ 80-10-20-10 kg ha^{-1} for Boro, 70-10-15-0 kg ha^{-1} for T. Aus and 70-10-15-0 kg ha^{-1} for T. Aman). The experiment was laid out in RCB design with three replications.

Grain yield. Figure 3 presents the annual grain yield of double rice cropping pattern from 2008 to 2021. A similar increasing trend of grain yield of 100% STB fertilization and 50% STB with mixed manure were observed from the beginning to till date. But control and farmers practices (FP) showed decreasing trend with the increment of time. Almost similar yield trend was observed in triple rice cropping pattern except FP (Fig. 4). Cumulative yield of triple cropping was always higher than double rice cropping pattern irrespective of treatments. Table 6 shows soil chemical properties changes after certain period of time. Percentage of soil organic carbon, available P and S were increased in 100% STB and 50% STB with mixed manure application plot. Increasing trend was more in 50% STB with mixed manure application plot.

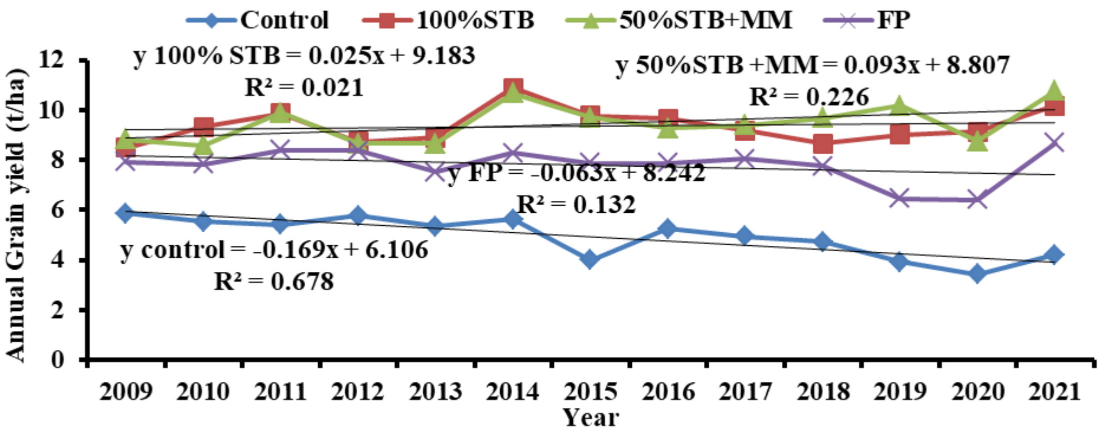


Fig. 3. Annual rice production trend under integrated nutrient management for double rice cropping for maximizing productivity during 2009-2021 in BRRI, Gazipur.

Table 6. Scenario of changes in soil chemical properties after a certain period of time.

Soil parameter	Initial status Boro 2008-09	After Boro 2015-16		After Boro 2020-21	
		STB (100%)	STB (50%) +MM	STB (100%)	STB (50%) +MM
Soil pH (1:2.5)	6.1	7.0	7.1	7.1	7.1
Organic C (%)	1.10	1.11	1.20	1.14	1.25
Total N (%)	0.11	0.11	0.12	0.12	0.12
Available P (ppm)	5.9	5.9	7.4	6.3	9.2
Available K (meq/100g soil)	0.16	0.18	0.18	0.15	0.16
Available S (ppm)	15.3	20.1	17.0	22.5	18.4

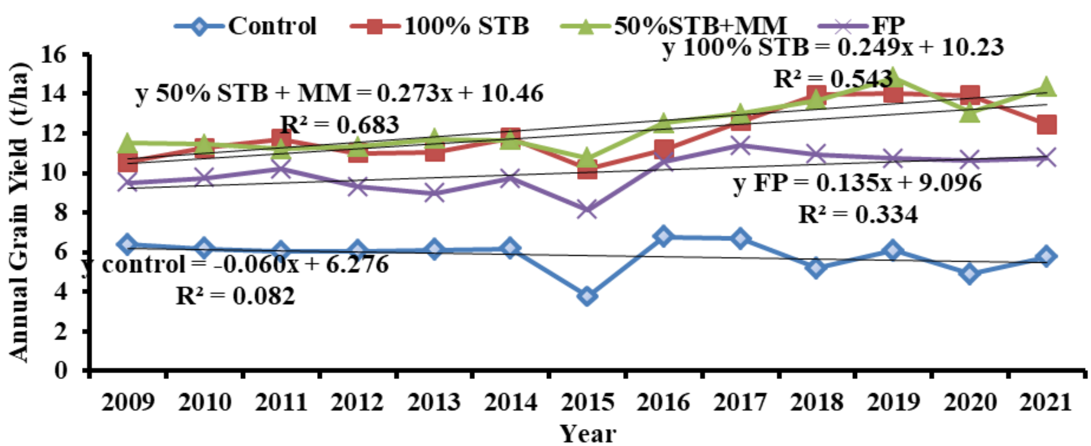


Fig. 4. Annual rice production trend under integrated nutrient management for triple rice cropping for maximizing productivity during 2009-2021 in BRRI, Gazipur.

Increase of rice yield through vermicompost (VC) amendments in coastal land. The experiments were initiated at three farmer's fields each of Dumuria, Khulna and Amtali, Borguna, Bangladesh in T. Aman (wet) season in 2021 to find out the effect of VC on grain yield improvement. Treatments were @ 0, 1, 2 t ha^{-1} (oven dry basis) VC with full dose of chemical fertilizer (FRG, 2018). Grain yield was significantly increasing due to vermicompost added at the rate of 1 and 2 t ha^{-1} in Dumuria, Khulna in T. Aman 2021 but insignificant in Boro 2021-22. In Amtali, Borguna site vermicompost added at the rate of 1 and 2 t/ha with a full dose of chemical fertilizer significantly increased grain yield both in T. Aman 2021 and Boro 2021-22 seasons (Table 7).

Table 7. Yield performance of BRRI rice varieties under vermicompost amendments with recommended chemical fertilizer in coastal land, 2021-22.

Grain yield (t/ha)				
Treatment	Dumuria, Khulna		Amtali, Burguna	
	T. Aman 2021 (BRRI dhan87)	Boro 2021-22 (BRRI dhan28)	T. Aman 2021 (BRRI han87)	Boro 2021-22 (BRRI dhan67)
Vermicompost @ 0 t/ha	6.44b	6.21	6.12b	5.41a
Vermicompost @ 1 t/ha	6.92a	6.57	6.65a	6.41b
Vermicompost @ 2 t/ha	7.14a	6.9	6.60a	6.63b
CV(%)	5.96	7.06	6.60	4.54

Increase rice yield through the organic and inorganic amendment. The experiment was initiated at the experimental field of BRRI, Gazipur in T. Aman 2019 to investigate the effect of vermicompost and silicon on rice grain yield and soil health. Before the initiation of the experiment, soil samples were collected and analyzed. The soil was silty clay loam in texture having pH 7.1, organic carbon 13 g kg^{-1}, total nitrogen 1.2 g kg^{-1}, Olsen available phosphorus 10.1 mg kg^{-1}, exchangeable potassium 44 mg kg^{-1} and available sulfur 31 mg kg^{-1}. The experiment was laid out in a split- plot design with three replications, where main plots comprised of four levels of vermicompost (0, 2.5, 5, 10 t ha^{-1}) and sub-plots had four silicon rates (0, 100, 200, 400 kg ha^{-1}). The variety was BRRI dhan87 in T. Aman and BRRI dhan89 in Boro season. Results of Boro 2020-21 showed that grain yield of BRRI dhan89 with different vermicompost rates did not increased significantly. There was no significant variation on rice yield between two rates (2.5 and 5.0 t/ha) of vermicompost. Among silicon rates, 400 kg ha^{-1} performed better, however, it was statistically similar with all the silicon rates. The highest grain yield (7.42 t ha^{-1}) of BRRI dhan89 was obtained with 10 t ha^{-1} vermicompost and 200 kg ha^{-1} silicon rate. In T. Aman 2021, the highest grain yield (4.57 t ha^{-1}) of BRRI dhan87 was obtained with 10 t ha^{-1} vermicompost application and grain yield was statistically similar with 2.5 and 5 t ha^{-1} vermicompost rates. Silicon application showed insignificant effect on grain yield.

Soil management to maximize the yield of newly released rice varieties. The experiment was initiated in T. Aman 2021 at BRRI RS farms, Cumilla and Sonagazi to find the best soil management to maximize rice yield with organic and inorganic amendment and to maintain soil health. Before the initiation of the experiment, soil samples were collected, analyzed for calculating soil test based fertilizer recommendation in each site. Treatments were T_1= soil test based fertilizer application, T_2= soil test based fertilizer plus 20% more nitrogen T_3= soil test based fertilizer plus 20% more potassium and T_4= soil test based fertilizer with available organic matter (2 t/ha). Vermicompost and cowdung were available in Cumilla and Sonagazi respectively. Soil test based nutrient recommendation in Cumilla and Sonagazi were 96:12:52:10 and 88:15:54:6 kg/ha for T. Aman season 173:18:61:12:1.5 and 178:24:82:10:1.7 kg/ha for Boro season respectively. Annual grain yield was highest in Sonagazi farm irrespective of treatments (Fig. 5). Soil test based fertilizer management was enough for both the locations, although organic matter was required in Cumilla farm along with STB dose.

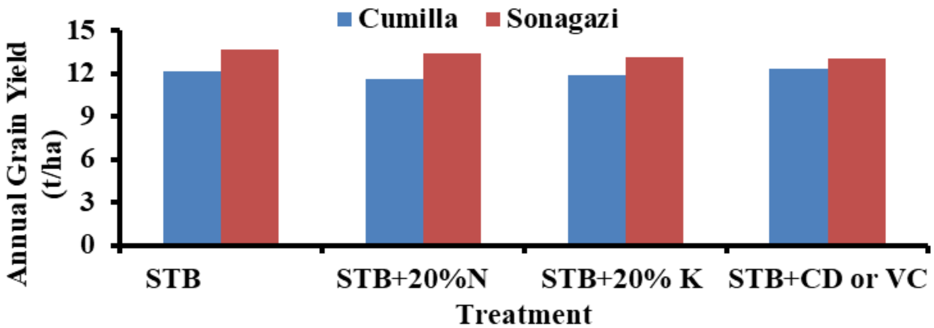


Fig. 5. Annual grain yield under different soil management practices for double rice cropping for maximizing productivity of newly released BRRI rice varieties in BRRI RS farms.

Nutrient management under conservation agriculture (CA) in double rice cropping system. This experiment was initiated at Paba, Rajshahi, in Boro 2018-19 seasons with the objectives to determine the nutrient requirement of rice in Boro-Fallow-T. Aman cropping pattern, and to improve soil health under conservation agriculture practices. Two crop establishment methods (unpuddled and puddled) in the main plot, two residue management practices (straw retained and straw removed) in the sub plot and four fertilizer doses as recommended fertilizer (RD) 100%, 125% of RD, 75% of RD, and 50% of RD were assigned in split-split plot design with three replications.

Grain yield. In Boro 2020-21 and T. Aman 2021, grain yields were insignificant among puddled and unpuddled cultivation, but rice straw incorporation significantly increased the rice yield (Table 8). FRG recommendation (100%) fertilizer application was enough for the grain yield of rice irrespective of residue management and crop establishment method in both the seasons.

Table 8. Effect of crop establishment methods (EM), rice straw incorporation (RS) and fertilizer rates (FR) on grain yield (t ha^{-1}) of Boro and T. Aman rice, Paba, Rajshahi, 2021.

Grain yield (t ha^{-1}								
EM	Boro 2020-21	T. Aman 2021	Rice straw	Boro 2020-21	T. Aman 2021	Fertilizer FRG	Boro 2020-21	T. Aman 2021
Unpuddled	4.28a	4.54a	Yes	4.31a	4.64a	125%	5.14a	4.76b
Puddled	4.22a	4.66a	No	4.18b	4.57b	100%	5.17a	5.50a
						75%	4.38b	4.45c
						50%	2.30c	3.70d

SOIL AND ENVIRONMENTAL PROBLEMS

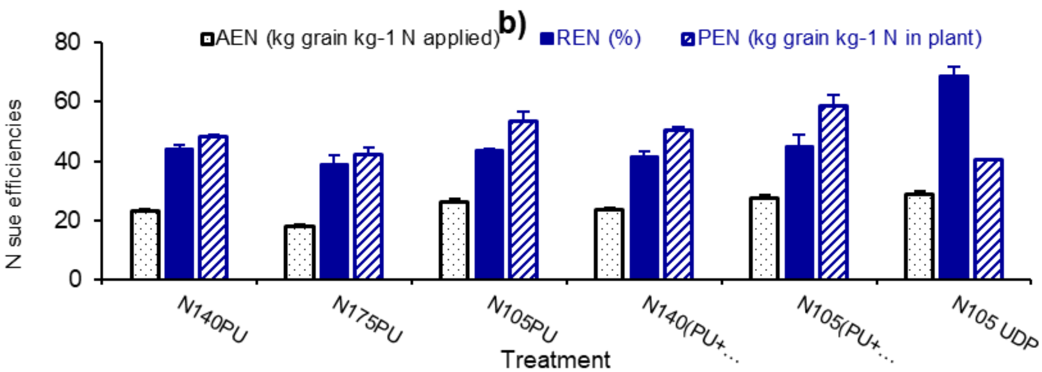
Management interventions to improve NUE and reduce N losses. The field experiment was conducted during T. Aman (July to November 2021) and Boro (January to May 2022) rice seasons at BRRI farm, Gazipur to quantify the fate of N fertiliser (crop, soil and losses) and N fertilizer use efficiency (NUE) under various N management options. The selected rice cultivars were BRRI dhan87 for T. Aman and BRRI dhan89 for Boro season. In both the seasons, overall 28 (7 treatments × 4 replication), 20 m^2 plots were established. The experiment was laid out in a RCB design. The blocks are separated from each other by 1 m irrigation channel and each plot is separated from each other by 40 cm earth bund to prevent exchange of water and fertilizer across the plots. In T. Aman season, the tested seven treatments were: T_1: no N fertilizer (N0), T_2: 110 kg N ha^{-1} from prilled urea (N110PU), T_3: T_2+25% N (N138PU), T_4: T_2-25% N (N83PU), T_5: Cow dung (CD) (2 t ha^{-1}) + IPNS with T_2 (N110 PU+CD), T_6: Bioorganic fertilizer (2 t ha^{-1}) + IPNS with T_4 (N87 PU+ Bioorganic fert.) and T_7: Deep placed urea alike T_4 (N83 UDP). During Boro season, the tested seven treatments were: T_1: no N fertilizer (N0), T_2: 140 kg N ha^{-1} from prilled urea (N140PU), T_3: T_2+25% N (N175PU), T_4: T_2-25% N (N105PU), T_5: Cow dung (CD) (2 t ha^{-1}) + IPNS with T_2 (N140 PU+CD), T_6: Bioorganic fertilizer (2 t ha^{-1}) + IPNS with T_4 (N105 PU+ Bioorganic fert.) and T_7: Deep placed urea (UDP) alike T_4 (N105 UDP). The blanket rates of P-K-S-Zn were 20-60-10-1 kg ha^{-1}, respectively in T. Aman and 25-80-10-1 kg ha^{-1}, respectively in Boro season. The whole amount of P, K, S and Zn fertilizers were broadcasted and mixed with soil on the day of transplanting in all seven treatments with a subtracted amount of P and K from CD and Bioorganic fertilizer in T_5 and T_6, respectively. The sources of P, K, S and Zn were triple super phosphate (TSP), muriate of potash (MoP), gypsum and zinc sulphate monohydrate, respectively. Partially decomposed CD in T_5 and Bioorganic fertilizer in T_6 at the rate of 4 kg $plot^{-1}$ (oven dry basis) (both equals the dose of 2 t ha^{-1}) were applied on 3 (in T. Aman) and 7 (in Boro) days before final land preparation and transplanting. In T_2, T_3, T_4, T_5 and T_6, N fertilizer was applied as urea into three equal splits on 9, 23 and 37DAT (days after transplanting) in T. Aman, and on 15, 35 and 54 DAT in Boro season, respectively. In case of T_7, the full amount of UDP was applied at once on 9 DAT in T. Aman and on 15 DAT in Boro season. In both the seasons, gas samples were collected covering 25 to 26 sampling events to analyze CH_4 and N_2O emission. Locally fabricated lysimeter was installed to analyze NH_4^+-N and NO_3^--N in the collected leachates. Measurement of NH_3 emission (volatilization) was performed by using closed chamber technique and Boric Acid Trap method. At maturity, grain, straw and root yields were recorded. The N concentration in all these samples were analyzed to assess plant N uptake.

Grain yield and N use efficiencies. The grain yield was significantly ($p<0.01$) greater in all N fertilizer applied treatments than no N applied treatment (N0) in dry season (Table 9). In both the seasons, the grain yield was statistically identical between the N fertilizer applied treatments (Table 9). However, in wet season, the grain yield was only significantly ($p<0.05$) greater in N110PU, N138PU, N110 (PU+CD) and N87 (PU+Bio fert.) than no N applied treatment (N0) (Table 9). In T. Aman season, the greater agronomic (AE_N) and recovery (RE_N) N use efficiencies were obtained from the N applied at 83 kg N ha^{-1} from deep placed urea (N83UDP) (Fig. 6a). While in Boro season, the greater agronomic (AE_N) and recovery (RE_N) N use efficiencies were obtained from the N applied at 105 kg N ha^{-1} from deep placed urea (N105UDP) followed by prilled urea plus bioorganic fertilizer (N105 PU+ Biofert.) (Fig. 6b).

Table 9. Grain yield (mean ± SE, n=4) impacted by different N management options in T. Aman and Boro rice season 2021-22.

Treatment	N0	N110PU	N138PU	N83PU	N110 (PU+CD)	N87 (PU+Bio fert.)	N83UDP
T. Aman 2021	4.43b*	4.99a	5.04a	4.72ab	5.17a	5.01a	4.98ab
Treatment	N0	N140PU	N175PU	N105PU	N140(PU+CD)	N105(PU+Biofert)	N105 UDP
Boro 2021-22	2.30b*	6.01a	5.92a	5.47a	6.08a	5.65a	5.78a

*Different lower- case letters within the row denotes significant differences ($p<0.01$ in T. Aman; $p<0.05$ in Boro) between the treatments according to ANOVA and Duncan's Multiple Range Post-Hoc Test.



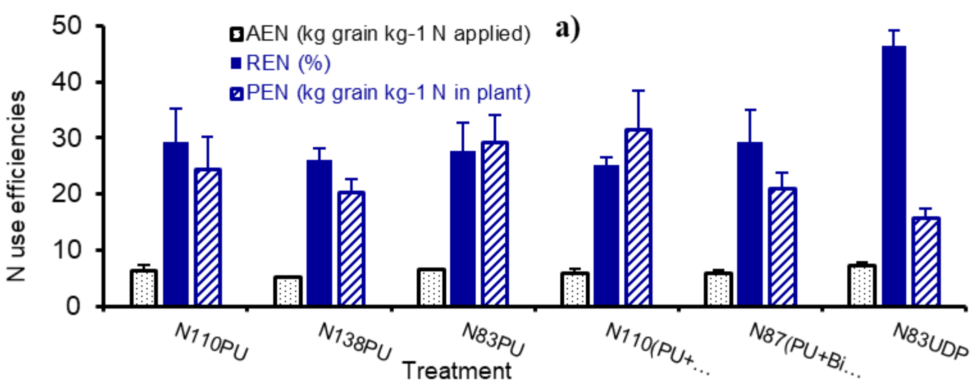


Fig. 6. Agronomic (AE_N), recovery (RE_N) and physiological (PE_N) N use efficiencies (mean ± SE, n=4) impacted by different N management options in T. Aman (a) and Boro (b) rice, 2021-22.

Time course of NH_3 emission fluxes after urea application in T. Aman season. Overall NH_3 emission was only detected from day 1 to day 5 in all N fertilizer applied plots after each split application of urea and no NH_3 emission was observed in the treatment with no N fertilizer application (N0) (Fig. 7). The NH_3 emission peaks were usually observed on day 1 to 3 after all three split applications of urea (Fig. 7a and 7b). The peak NH_3 emissions were greater in the treatment with higher rate of N application i.e. in the N138PU (T_3) after 1st and 2nd splits, while this was the case for N110PU after 3rd split (Fig. 7a). In case of N83UDP, notable NH_3-N emission rates were only recorded on day 2 (4.2 mg $m^{-2}d^{-1}$) and day 3 (5.8 mg $m^{-2}d^{-1}$) after application of the whole amount of UDP at once during 1st split **(**Fig. 7b**)**. Among the N fertilizer applied treatments, the NH_3-N emission rate was lower in N83UDP followed by N110 (CD+ PU) and N87 (PU+Bio fert.) **(**Fig. 7a and 7b**)**.

This one -year experimental results revealed that considering yield, N use efficiencies and NH_3-N loss, N applied at the rate of 105 kg ha^{-1} from deep placed urea and PU + Bio-organic fertilizer in Boro season and N applied at 83 kg ha^{-1} from deep placed urea in T. Aman season could be the most suitable N management interventions to sustain rice production, reduce environmental harm from reactive N (Nr) and sustain soil health.

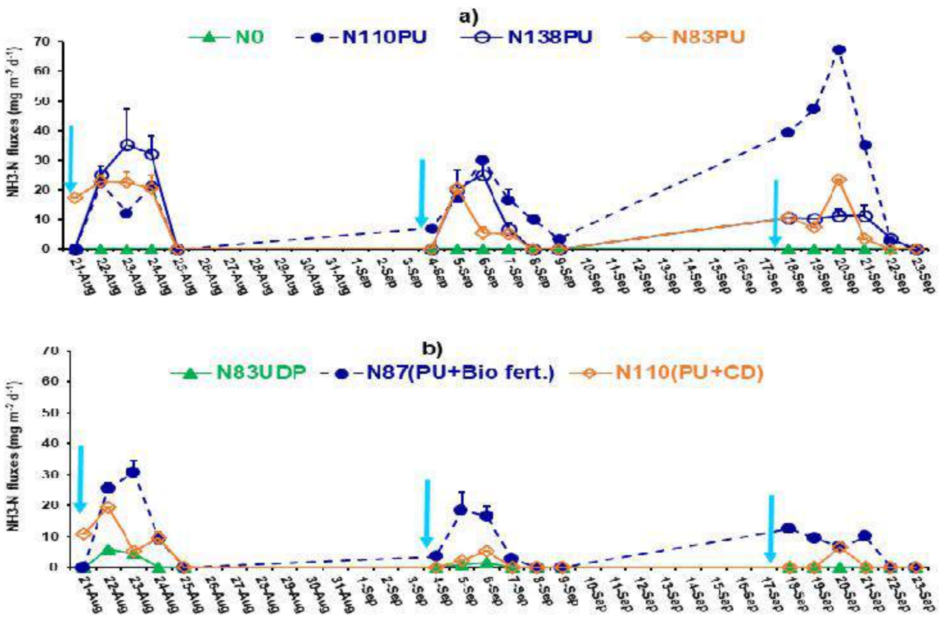


Fig. 7. Daily NH_3 emission fluxes (mean ± SE; n =2 or 3) (a, b) at different N managements in wet season rice, 2021; arrow shows the day of split application of prilled urea or deep placed urea.

Effect of biochar on rice yield in the charland. The study was conducted at BRRI RS, Sirajganj with the objective to determine the effect of biochar on rice growth and yield and soil health in problem soils. The experiment was initiated in Boro 2019-20 and consisted of four treatments: T_1= Control, T_2= recommended fertilizer (RF), T_3= RF + biochar @ 2 t ha^{-1} and T_4= RF + biochar @ 4 t ha^{-1}. The treatments were arranged in RCB design with three replications. The biochar was produced from *chita dhan* (unfilled grain). The recommended dose of N-P-K-S was 100-15-40-10 kg ha^{-1} in T. Aman and 138-21-75-18 kg ha^{-1} in Boro season. Biochar was applied only in Boro season and incorporated with soil before seven days of transplanting. In T. Aman season, 30 % fertilizer was reduced from the recommended dose in the biochar treated plots to observe the residual effect of biochar on rice yield. In T. Aman season, reduction of 30% fertilizer from the recommended dose in the biochar treated plots produced grain yields similar to full dose of recommended fertilizer (6.52 t ha^{-1}) which might be due to the residual effect of biochar. In Boro 2021-22 season, application of biochar @ 4 t/ha with recommended fertilizer resulted in the highest yield (7.30 t ha^{-1}) of BRRI dhan89 than the other treatments.

Effect of variety and fertilizer management on yield and greenhouse gas emissions from rice fields in the south-western coastal ecosystems. The field experiments were conducted in BRRI RS farm, Satkhira. Two rice varieties were tested including BRRI dhan67 (salt tolerant and shorter growth duration; ca. 140 days) and BRRI dhan92 (longer duration; growth duration ca. 160 days). Five fertilizer treatments were tested: (i) N control, broadcast prilled urea (PU) at 78 kg N ha^{-1}, (ii) urea deep placement at 78 kg N ha^{-1}, (iii) BRRI recommended dose at 120 kg N ha^{-1}, and (iv) integrated nutrient management at 78 kg N ha^{-1} with cow dung 2 t/ha and ash 1 t/ha. The experiment was laid out in a split-plot design, distributing the variety to the main plots and treatments to the sub-plots with three replications. Nutrients viz P, K, S and Zn were used as basal at the recommended rate to all plots as per National Fertilizer Recommendation Guide (FRG-2018) and the rates were 20 kg P/ha, 80 kg K/ha, 18 kg S/ha and 1 kg Zn/ha, respectively. Soil amendments (cow dung and ash) were applied three days prior of transplanting. Urea briquettes (UB) were placed at a depth of 10 cm at the center of four rice hills 10 days after transplanting (DAT). PU was applied in three equal splits except for the N control plot. The crop was harvested at full maturity of the crops. Grain yield was adjusted at 14% moisture and expressed in t ha^{-1}. The sundry weight of straw was also recorded plot-wise and expressed as t ha^{-1}. Notable, GHG data were not included in this report due to a lack of calculation and analysis.

Grain and straw yield. Application of N fertilizer significantly increased rice yield compared to the other treatments (Table 10). Integrated nutrient management (INM-N78 kg/ha) with two ton CD and one ton ash produced the highest grain yield of 5.87 t/ha in BRRI dhan67 and 5.15 t /ha in BRRI dha92 and it was statistically similar with UDP-N78 and PU-N120 treatment. Broadcast PU-N78 significantly reduced grain yield compared to other treatments. Similarly, BRRI recommended dose and INM treatment produced higher straw yield compared to broadcast PU. We could not get any additional advantage using a higher dose of N fertilizer (120 kg N ha^{-1}) as broadcast compared to UDP. However, BRRI dhan67 showed similar grain and straw yield with BRRI dhan92 in the Boro season (Table 10).

Table 10. Effects of variety and fertilizer management on grain and straw yield at BRRI farm, Satkhira during Boro season

Treatment	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	BRRI dhan67	BRRI dhan92	Mean of 2 varieties	
N control	2.73c	3.00c	3.39c	
Prilled urea-N78	4.87b	4.18b	5.02b	
Urea deep placement-N78	5.52a	4.79a	5.65ab	
BRRI recommended dose N120	5.49a	4.99a	5.90a	
INM-N78 with 2 ton cow dung and 1 ton ash/ha	5.87a	5.15a	5.98a	
	BRRI dhan67	BRRI dhan92	BRRI dhan67	BRRI dhan92
Treatment mean	4.90A	4.42A	5.15A	5.22A

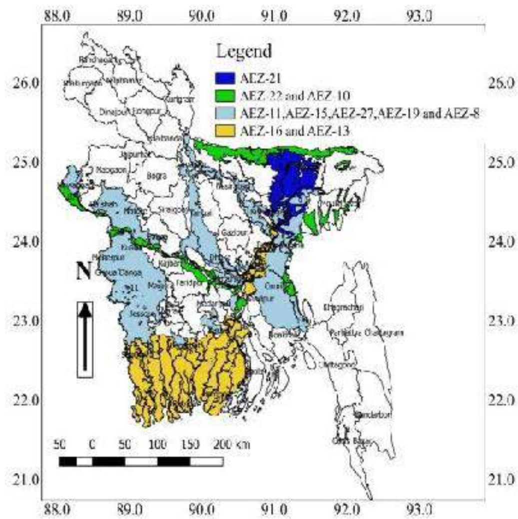
SOIL MICROBIOLOGICAL STUDIES

Field evaluation of BRRI bio-organic fertilizer. BRRI bio-organic fertilizer was developed with the objectives to reduce synthetic N and P fertilizer use in rice cultivation and improve soil health. To evaluate its field performance, one field experiment was conducted at BRRI HQ in both the season of T. Aman 2021, and Boro 2021-22. Bio-organic fertilizer (BoF) was used at 2 t ha^{-1}. The treatment combinations were NPKS (100%), BoF + 70% (N) +100% (KS), BoF +100% NPKS and fertilizer control. Recommendation rates of chemical fertilizers for T. Aman and Boro were (kg ha^{-1}) N-P-K-S @ 67-10-41-10 and 140-20-80-10, respectively. BRRI dhan87 at T. Aman and BRRI dhan89 was grown in the Boro season.

Grain yield. Study result proved bio-organic fertilizer (BoF_1@ 2t ha^{-1}) has potential to supplement 30% N and 100% P requirement for HYV rice without sacrificing yield. In the T. Aman, application of BoF with 70% (N) +100% (KS) produced the highest grain yield of 5.47 t ha^{-1}. Statistically similar grain yield was obtained in 100% NPKS (4.75 t ha^{-1}) and BoF +100% NPKS (4.85) treatment. However, in the Boro season, the highest grain yield was recorded (7.40 t ha^{-1}) in the BoF with 70% (N) +100% (KS) treatment and it was statistical by similar with BoF with 100% NPKS application. Significantly the lowest grain yield was found at the control treatment.

Microbial characterization of different AEZs soil. Soil biology dictates soil health. Studies were conducted with the aim to determine the soil microbial populations from eight AEZ's of Bangladesh and to characterize the potential free-living N_2 fixing, phosphate solubilizing, and indoleacetic acid producing bacteria and finally prepared a climate smart biofertilizer using the potential bacteria for higher rice productivity. Soil samples (0-15 cm depth) were collected using GPS recording from AEZ-10 (Faridpur), AEZ-11 (Jashore- Rajshahi), AEZ-13 (Satkhira), AEZ-15 (Munshiganj), AEZ-16 (Brahmanbaria-Munshiganj), AEZ-19 (Cumilla- Kishoreganj), AEZ-22 (Moulavibazar- Habiganj) and AEZ-27 (Rangpur- Bogura) and tested for microbial properties, texture, soil pH and organic matter.

Soil bio-physico-chemical properties of different AEZs. Microbial populations were enumerated on the selective media following 'total plate count' method. Study report showed that the range of total bacteria populations were significantly high in the Decreerchar union of AEZ-10 (2 x 10^6 to 2 x 10^9 cfu/g soil), Panisara union of AEZ-11 (2 x 10^7 to 2 x 10^9 cfu/g soil), and Deorghachi union of AEZ-22 (7 x 10^6 to 1 x 10^9 cfu/g soil) (Map). The lowest total bacteria range was found in AEZ-13. Total fungus population range was comparatively lower in the AEZ-10, AEZ-13, AEZ-15, AEZ-16 and AEZ-27. On average, Actinomycetes populations were low in all the tested AEZ's. The populations of free-living N_2 fixing bacteria were higher than the Rhizobium populations. However, populations of phosphate solubilizing bacteria were higher than free-living N_2 fixing bacteria. Aside soil microbial properties, soil physico-chemical properties such as soil texture, pH, total nitrogen and organic matter content were determined following standard protocol. Among the tested eight AEZs, the highest organic matter (3.90%) and total N (0.21%) was recorded in the Chadnighat union of Moulovibazar Sadar upazila in AEZ-22. In conclusion, among tested eight AEZs, the populations of beneficial bacteria (free-living N_2 fixing, Rhozobium and phosphate solubilizing bacteria), soil organic matter and total N were lower than any healthy agricultural soil. Application of organic matter and biofertilizer is crucial to replenish soil health and sustainable crop production.



Map showing that highest population found in AEZ-21(10^9 cfu/g soil), AEZ-10 and AEZ-22 (10^8 cfu/g soil), AEZ-11, AEZ-15, AEZ-27, AEZ-19 and AEZ-8 (10^7 cfu/g soil) and AEZ-16 and AEZ-13 (10^6 cfu/g soil)

Biomolecular characteristics of the isolated strains. The dominant potential bacteria from each AEZ were identified and tested for biomolecular characteristics. Among the strains, the highest N_2 fixation (28 ppm) NH_4) was recorded by *Bacillus thuringiensis* (B49) isolated from AEZ-27 and *Pseudomonas geniculata* (B61) isolated from AEZ-15. The highest 3,746 ppm P was solubilized by the *Stentrophomonas maltophilia* (B53), isolated from Shahjahnpur upazila of AEZ-27. The highest amount of indoleacetic acid (144 ppm) was produced by the *Bacillus sp.* (B59) isolated from Shyamshiddhi union of Sreenagar upazila (AEZ-15).

Formulation of biofertilizer for acid and saline soil. Isolated 15 potential strains were coated with TSP and urea fertilizer and named as 'Bio-coated urea' and 'Bio-coated TSP' biofertilizer, respectively. Nutrient mineralization form Bio-coated fertilizer and survival of the bacteria during the incubation study were in satisfactory level (Figs. 8a and b). In the glasshouse, pot experiments were conducted for testing the efficacy of the developed biofertilizer in the soil plant system. Study results showed that about 36% grain yield increased in BRRI dhan28 and saved 50% TSP fertilizer by the application of 'Bio-coated TSP' in acid soil compared to TSP fertilizer only (Table 11). Application of PGPR-coated urea improved grain yield 10.53% of BRRI dhan99 over chemical fertilizer in the saline soil (Table 12).

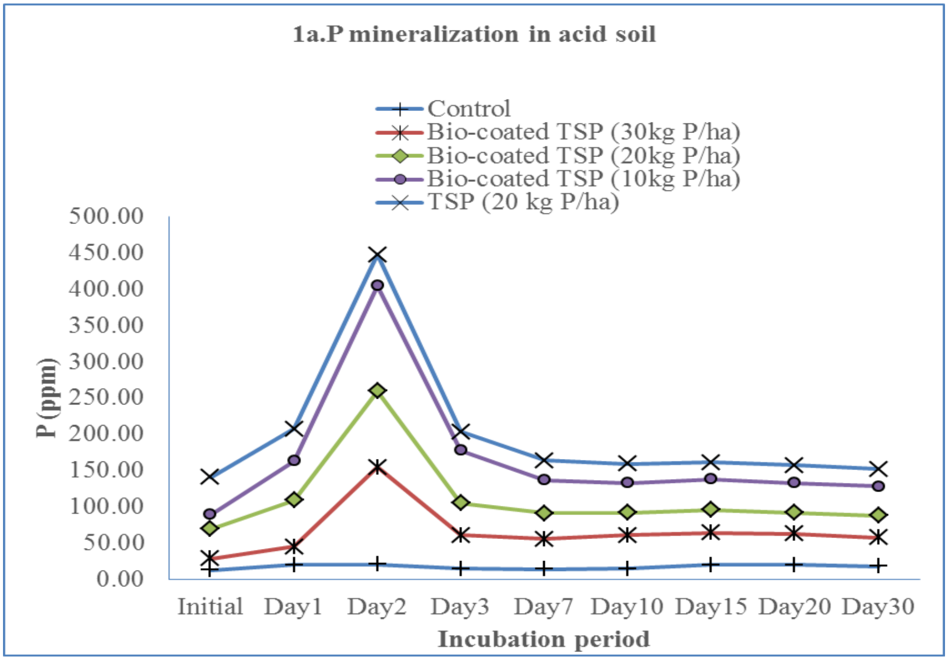


Fig. 8a. Effect of Bio-coated TSP and TSP fertilizer on available P mineralization in Acid soil.

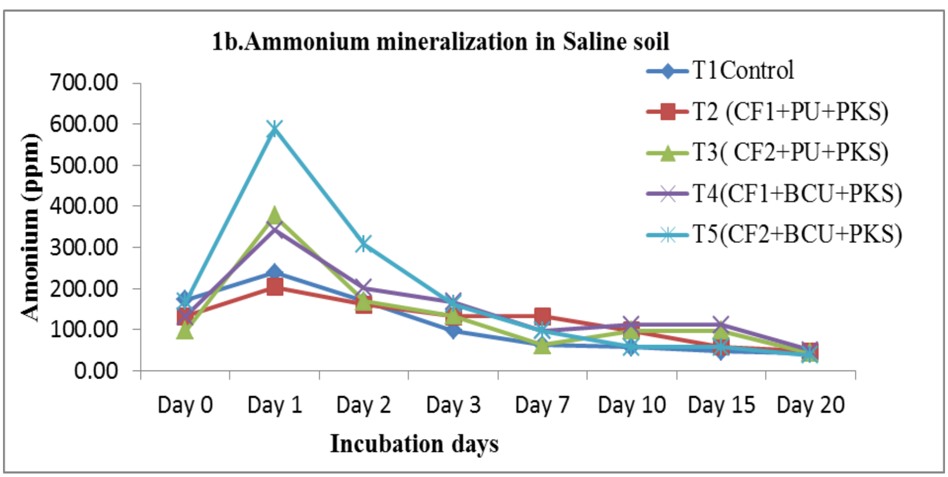


Fig. 8.b. Effect of Bio-coated urea and urea fertilizer on N mineralization in saline soil.

Here, CF1: NPKS (kg/ha) @ 120-20-50-10, and CF2: NPKS (kg/ha) @ 120-20-120-10, PU: Prilled urea and BCU: bio-coated urea.

Table 11. Effect of Bio-coated TSP and TSP fertilizer on growth and yield of BRRI dhan28 and PSB population after harvest.

Treatment	Plant height (cm)	Tiller /hill	Straw weight (g)	Panicle /hill	Yield/ plant (g)	PSB population (cfu/g soil)
Control	67.5 b	6.7	4.9b	5.0c	4.3c	$3x10^3$
Bio-coated-TSP (@30 kgP/ha)	68.3 b	7.2	6.7a	7.2a	7.0ab	$2x10^6$
Bio-coated-TSP (@20 kgP/ha)	73.0 ab	5.8	6.8a	5.8bc	7.0ab	$4x10^6$
Bio-coated-TSP (@10 kg P/ha)	69.0 ab	6.7	7.0a	6.7ab	7.6a	$5x10^6$
TSP (@20 kg P/ha)	75.2 b	5.0	5.3b	5.0 c	5.6bc	$3x10^4$
CV (%)	10.8	32.9	14.9	15.4	21.0	8

PSB; Phosphate solubilizing bacteria. In the colum, means followed by the letter were significant at the 5% level of significance.

Table 12. Effect of Bio-coated urea on growth and yield of BRRI dhan99.

Treatment	Plant height (cm)	Tiller /hill	Straw weight (g)	Yield/ plant (g)
Control	85.7 b	6 b	18.8 b	13.7 d
NPKS (kg/ha) @ 120-20-50-10, N as prilled urea	88.5 ab	10 a	26.8 ab	15.2 bc
NPKS (kg/ha) @ 120-20-120-10, N as prilled urea	92.7 a	11 a	29.6 a	15.0 c
NPKS (kg/ha) @ 120-20-50-10, N as Bio-coated urea	90.7 ab	11 a	31.7 a	16.6 a
NPKS (kg/ha) @ 120-20-120-10, N as Bio-coated urea	92.8 a	10 a	31.2 a	16.25 ab
CV (%)	25	11.8	27	5.97

In the column, means followed by the letter were significant at the 5% level of significance

Irrigation and Water Management

SUMMARY

During 2021-22, Irrigation and Water Management Division reported sixteen programmes of basic and applied research as well as two major programmes of technology validation and adaptation in different agroecological zones with a target to generate and extend water efficient technologies in rice water management for increasing land and water productivity which would lead to sustainable food security and improved livelihood. A soil physical property analysis indicated that at BRRI RS Kushtia farm, the average saturated water content was 31.4, average water content at field capacity was 25.6 and average water content at wilting point was 12.5 within the soil profile of 0-60 cm depth. At BRRI RS Sirajganj farm, the average saturated water contents varied between 31.4-28.4 average water contents at field capacity varied between 24-18.9 and average water contents at wilting point were 7.3-4.8 within the soil profile of 0-60 cm depth. At BRRI RS Rangpur farm, the average saturated water contents varied between 26.3-22.4 average water contents at field capacity varied between 19.8-17.8 and average water contents at wilting point were 3.4-2.8 within the soil profile of 0-60 cm depth. During Boro season, none of the ALART had stress tolerance capacity. ALART BR9930-2-3-3-1 produced higher yield (31.77 g/hill) with continuous standing water treatment. Performance evaluation of the proposed rice varieties under different water regimes during boro season showed that good yield could be achieved from BR11716-4R-105 and BRRI dhan92 under AWD practice. About 30% yield was increased by compaction over control followed by clay mixing during T. Aman and higher grain yield (7.54 t/ha) obtained from cowdung added at top soil layer followed by vermicompost added treatment during Boro season for improving soil-water availability for crop production in charland by amendment practices. Irrigation scheduling by CROPWAT model was found effective to save irrigation water in both Boro and T. Aman seasons. Irrigation water requirement and rainfall utilization for delayed transplanting during boro season showed that water productivity was higher with early transplanting on 15 and 31 January than delayed transplanting on 14 February and 1 March. In rainfed environment, considerable amount of yield increased (10.8-12.7%) due to drought mitigation by drought simulation model at reproductive and ripening stages compared to rainfed of T. Aman season in Kushtia. Overall water saved by following supplemental irrigation based on drought forecasting was 30.5 % compared to AWD system in the validation experiment in Kushtia. So, this model can give early warning to the farmers when to irrigate or not. This information will be helpful for farmers to save money and also to save them from probable yield loss during drought.The study revealed that the latest salt-tolerant rice variety like BRRI dhan97 and BRRI dhan67 can be grown with saline water irrigation up to 4 dS m^{-1} for getting higher yield potential during the dry season in the saline coastal zone. All the tested groundwater and surface water samples from different locations in the reporting year were safe to use in irrigation according to recommended quality indicator ranges. However, groundwater level depletion was about 42.94 m in last 24 years at BRRI HQ Gazipur farm, showing an alarming average declining rate of 1.65 m per year.There are suitable sources of surface water those can be used for irrigating crops by operating solar pumps in the Chattogram region. For the sustainable management of water resources, conjunctive use of municipal wastewater with fresh water would be a good irrigation option in Boro season. Based on the research findings in Dacope and Amtali upazilas, farmers expressed their willingness to continue the cultivation of BRRI dhan87 in medium high land and BRRI dhan76 in the medium-low to low land areas due to higher yield, short duration, and unique characters to cope with the environments. These varieties improve the land productivity, net income, and benefit cost ratio (BCR) and also facilitated the cropping intensification in the coastal areas. In haor region, AWD method successfully saved irrigation water which helped to mitigate water demand in the reproductive stage during Boro season. The study results indicated that huge yield loss occurred in the haor area due to water stress in the reproductive phase of Boro rice. Check valve installation in

Shallow Tubewell (STW) removed pump starting drudgery, and improved distribution system saved 18-20% irrigation water. Irrigation time was reduced by 20 percent due to use of polythene pipe compared to the earthen canal. Due to use of polythene pipe the irrigation time per unit area was reduced significantly. Fresh water resources development is one of the crucial issues for sustainable crop and soil salinity management in coastal areas. Surface fresh water was trapped in local canals within December for irrigation in dry season crops. Groundwater salinity was beyond the permissible limit of irrigation. Dacope area is more saline than that of Amtali areas. Therefore, special care needs to be adopted for dry season crop production. Groundwater abstraction is an important source of GHG emissions in Bangladesh. So, it is the time to harness the co-benefits of water and energy savings by adopting alternate wetting and drying practice for rice cultivation, by expansion of surface water irrigation facilities along with by selecting water use-efficient crop varieties having high yield potentials.

WATER USE EFFICIENCY IMPROVEMENT IN IRRIGATED AGRICULTURE

Determination of physical and hydraulic properties in different soil types

The study was conducted in BRRI RS, Kushtia, BRRI RS, Rangpur and BRRI RS, Sirajganj. Soil samples were collected from different soil profiles at 0-15, 15-30, 30-45, 45-60 cm using standard protocols from BRRI RS, Kushtia, BRRI RS, Rangpur and BRRI RS, Sirajganj. Soil textural classes were mostly clay, loam to silty loam, mostly loam for BRRI RS, Kushtia farm, BRRI RS, Sirajganj farm and BRRI RS, Rangpur farm, respectively. The average bulk density was from 1.30 to1.46 gm/cc. At BRRI RS, Kushtia farm, the average saturated water content was 31.4, average water content at field capacity was 25.6, and average water content at wilting point was 12.5 within the soil profile of 0-60 cm depth. At BRRI RS, Sirajganj farm, the average saturated water contents varied between 31.4-28.4, average water contents at field capacity varied between 24-18.9, and average water contents at wilting point were 7.3-4.8 within the soil profile of 0-60 cm depth. At BRRI RS, Rangpur farm, the average saturated water contents varied between 26.3-22.4, average water contents at field capacity varied between 19.8-17.8, and average water contents at wilting point were 3.4-2.8 within the soil profile of 0-60 cm depth. RETC programme was used to fit soil water release curve with measured water contents and metric potential data (Fig. 1). For fitting purpose, estimated soil parameters of clay soil was taken for BRRI RS, Kushtia soil, silt loam soil was taken for BRRI RS, Sirajganj soil, loam soil was taken for BRRI RS, Rangpur soil.

Problem and potentials for crop productivity improvement through water management in hilly areas

In 2020-21, the study was conducted in Sadar upazila of Khagrachari district. A field visit and detailed survey was conducted in that region. In the visited locations, the water resources were physically assessed, and several discussions were conducted with farmers, local stakeholders, inhabitants, local government bodies, NGO workers and obviously root level agricultural extension workers and researchers working in that area. The Sadar upazila of Khagrachari district has fourteen agricultural extension blocks. The cultivable available land in that upazila is 6,420 ha. The major corps of that area are mango, banana, malta, and rice. In the reporting year, Aus, Aman, and Boro rice was grown in 750 ha, 3,535 ha, and 1,505 ha, respectively. The total irrigated rice area in that upazila is only three percent. Sadar upazila has one river, 15 lakes, nine big canals, 12 creeks or fountains (Jiri or Chora) which are used as irrigation water sources. The small hill creeks or fountains are locally known as “Jiri” or, “Chora”. Usually, the water was conserved in the canal by constructing cross dams and applied to the agricultural field through gravity channel. The irrigated area covered by rivers, canals, and creeks are 1,279 ha, 55 ha, and 60 ha, respectively. During the study, it was also reported that irrigation water was crucial for seasonal fruit gardens established at the slope of the hills. If irrigation pumps along with pressurized irrigation distribution system could be installed, the prospect of fruit gardening in that region will be very bright. As irrigation energy source is also scarce or limited in that region, solar pump would be a solution to irrigate the crop lands. There is another constraint for agriculture and that was a proper distribution system of irrigation water. Due to bumpy land topography, it is not very easy to construct a good distribution system. If a pipe distribution network could be built in each command area of a water source, it might increase the potential utilization of water sources in agriculture. In Sadar upazila, 2,59 low lift pumps (LLP) are running to irrigate lands though they do not have any shallow tube-well or deep tube-well. The details about block-wise irrigation water sources, present irrigated area, and possible area extension of cultivable lands if irrigation pumps and distribution system is provided, (Table 1). The study in the respected area reveled that another 855 ha fallow area could be brought under cultivation with the help of irrigation facility in Sadar upazila. The possible options are: constructing rubber dams, installation of solar pump, modern water distribution systems along with high yielding crop varieties. This area is also a potential spot to spread agro-forestry technologies with the backup of irrigation equipment and power sources.

Study on water-stress tolerance for different advanced rice genotypes of BRRI

There were two ALART entries named BR9930-2-3-2-2 and BR9930-2-3-3-1 along with checks BRRI dhan50, BRRI dhan63 and BRRI dhan81under PQR supplied from Plant Breeding Division, BRRI during Boro season 2021-22 (Table 2). None of the ALART entries had stress tolerance capacity. ALART entry BR9930-2-3-2-2 produced higher yield (25.52 g/hill) with continuous standing water treatment. Yield was decreased by 12.1, 34.7 and 53.2% than that of continuous standing water with the water stress of -10, -30 and -60 kPa, respectively. Similarly, ALART entry BR9930-2-3-3-1 producrd higher yield (31.77 g/hill) with continuous standing water treatment. Yield was decreased by 10.1, 36.2 and 58.7% than that of continuous standing water with the water stress of -10, -30 and -60 kPa, respectively.

Performance evaluation of the proposed rice varieties under different water regimes

The study was conducted to find out suitable water regimes for rice varieties and proposed lines. The experiment was conducted during Boro season 2020-21 in a brick wall tank at BRRI HQ farm, Gazipur. Four long duration high yielding advanced lines of rice as- BR11715-4R-186, BR11723-4R-27, BR11723-4R-12 and BR11716-4R-105 were tested under four water management treatments as: T_1 = Maintaining continuous standing water (CSW) from 1 to 5 cm; T_2 = AWD irrigation practice (+5 to -15 cm); T_3 = Aerobic condition (AWD: 0–25 cm) up to booting stage; and T_4 = Aerobic condition (AWD: 0–25 cm) during the entire crop period. BRRI dhan92 was the check variety. Table 3 shows the amount of irrigation applied, rainfall occurred and total water use during the growth duration along with grain yield. The total number of irrigations in T_1, T_2, T_3, and T_4 are 14, 11, 20 and 19 respectively. The total amount of irrigations in T_1, T_2, T_3, and T_4 are 810 mm, 705 mm, 650 mm and 620 mm, respectively. The irrigation water saving under treatments T_2, T_3, and T_4 were 13, 20 and 23 per cent, respectively compared to treatment T_1. The amount of rainfall was 270 mm for BR11715-4R-186, BR11723-4R-27, BR11723-4R-12 and 151 mm for BR11716-4R-105 and BRRI dhan92 in all the treatments. Total rainfall recorded in January, February, March and April of 2022 were 3.6, 35.6, 17.6 mm and 58.4 mm, respectively. Only 20.6 mm rainfall was recorded during 5 February to 18 April 2022. It means that most of the vegetative phase and reproductive phase was about rainless. Sufficient rainfall was obtained after 18 April, so no irrigation was applied at the ripening phase. The experimental results show that good yield could be achieved from BR11715-4R-186, BR11723-4R-27, BR11723-4R-12 under CSW. The experimental results also show that good yield could be achieved from BR11716-4R-105 and BRRI dhan92 under AWD practice.

Improving soil-water availability for crop production in charland by amendment practices

The study has been carried out in BRRI RS farm, Sirajganj, during Aman 2021 and Boro 2021-22 to improve soil physical properties, soil water retention capacity of the root zone depth and to identify a suitable soil amendment practice to increase water use efficiency and the crop productivity of the charland. The study consists of five amendment practices as: T_1 = Compaction with clay soil at the layer of 20-30 cm, T_2 = Vermicompost added at the topsoil (0-10 cm) @ 5 t/ha, T_3 = topsoil (0-10 cm) mixed with 50% of clay soil, T_4 = Biochar added at the topsoil (0-10 cm) @5 t/ha, T_5 = Cow dung added at the topsoil (0-10 cm) @ 5 t/ha and T_6 = Control treatments in randomized complete block design with three replications. BRRI dhan100 was grown during T. Aman 2021. Among the grain yield and yield components, plant height and grain yield were statistically significant by different amendment practices (Table 4). Plant height were higher (135.85 cm) in compaction followed by cowdung added at top layer of soil (0-10 cm). Lower plant height (114.25 cm) were observed in clay mixing. Number of panicle per hill, number of grain per panicle and sterility percentages were not statistically different by amendment practices. Higher grain yield (5.73 t/ha) was found in compaction followed by clay mixing at top layer. Grain yield was increased over control by each amendment practices. About 30% yield was increased by compaction over control followed by clay mixing. BRRI dhan89 was grown during Boro 2021-22. Among the grain yield and yield components number of grain per panicle, grain yield and harvest index are statistically significant different by amendment practices (Table 5). Plant height, number of panicle per sq m area, sterility percentages and straw yield were not statistically significant different by amendment practices. However, plant height (112 cm) were higher in biocher added at the top layer of soil (0-10 cm) followed by vermicompost added at the top layer of soil. Higher panicle number per sqm area obtained from vermicompost added followed by control. Higher number of grain per panicle (184) obtained from compaction of lower soil layer (20-30cm) with clay soil followed by biocher added at the top layer of soil. Higher grain yield (7.54 t/ha) was obtained from cowdung added at the top soil layer followed by vermicompost added treatment. Harvest index was higher in vermicompost added amendment practices.

Determining minimum irrigation water requirement of rice at different regions of Bangladesh through water balance from on-farm demand and model simulation

The experiment was conducted for two seasons (T. Aman and Boro) in 2021-22 at the research field of BRRI RS, Rangpur. BRRI dhan87 and BRRI dhan58 were transplanted in T. Aman 2021 and Boro 2021-22 seasons, respectively. In Rangpur, during T. Aman season, drought occurred at the later part of the season as rain ceased. The control treatment (i.e., continuous standing water in the field) received the highest amount while CROPWAT treatments required comparatively less irrigation. Both AWD and CROPWAT treatment saved irrigation compared to continuous standing water treatment. Yields the similar in AWD and CROPWAT treatments and yield of control treatment was different than other two treatments (Table 6). During Boro 2021-22 season, the total growth span of BRRI dhan58 was 150 days, however, 105 days after transplanting (vegetative, reproductive, and ripening stage) was taken into consideration in this study. The actual water requirement was calculated using the total measured evapotranspiration (ET) during this time (105 days). Predicted water requirement was simulated by CROPWAT model. Presumably, treatment T1 received the highest amount of irrigation water in response to total irrigation requirement (Table 1), because the field was kept almost saturated all the time during the experiment. The AWD treatment (T2) received comparatively lower irrigation than continuous standing water treatment. Generally, received amounts of irrigation in T2 and T3 were closer. In Rangpur, AWD treatment had the highest yield among the treatments, but irrigation application and yields of AWD and CROPWAT treatments did not have any major difference in Rangpur. Irrigation scheduling by CROPWAT model might be a potential approach to save irrigation water, but still needed in depth evaluation in terms of irrigation demand, irrigation received and yields.

Optimization of Water Use Efficiency Through Subirrigation and Mini-sprinkler Irrigation System in Fine (light) Textured Soils of Bangladesh

Subirrigation is a water table management method (reverse process of subsurface drainage). This is the artificial addition of water to the soil profile to moisten the crop root zone. In this system, water applied through perforated drain-pipe from beneath the soil surface. Water is allowed to stand for lateral and upward movement by capillarity. Subirrigation system regulates the shallow ground water table, makes the upper layer of soil remained dry while lower layer soil moisture content remained unchanged. The advantages of subirrigation system are: (a) optimum water supply to manage crop water requirement, (b) reduce evaporation, seepage, and percolation losses, (c) increase irrigation water-use efficiency, and (d) can be used for soil having low water holding capacity and high infiltration rate. However, the system has some limitations like: (a) high initial cost and expensive to setup, (b) chance of occurring saline and alkali condition, (c) chance of N-nutrient loss through drain water, (d) soil should have high hydraulic conductivity. The design and installation of subsurface irrigation system covered a piece of land in IWM research plot at BRRI farm in Boro 2021-22. The length of the installed system area was 10 m and the width of the system was 6 m. Total area of the installed subirrigation system was 60 sq. m. For design purpose, the soil physical and hydraulic properties of the selected fields were considered. Then, the lateral (drain) spacing and lateral and main (drain) size were determined using available equation and models (Hooghoudt equation, DRAIN CALCULATOR, etc.). The design spacing was found 1.2 m and design depth was found 30 cm from ground surface. For both lateral and main pipe size, 4 in diameter PVC pipe was selected for the subirrigation system. For subsurface irrigation, an overhead tank (1000 L) was installed to supply adequate irrigation water to crop root zone of the field. A flowmeter (4 in diameter) was set up at the inlet of the system to measure the amount of water supplied to the field. Basically, in the first season of the subirrigation system installation, the system was observed carefully so that the system could run successfully. Any major constraint was not marked during the whole season except some technical faults of the system. The troubleshooting was done immediately when found at the field. Figure 2 shown the detailed design of the installed subirrigation system. A high yield rice variety, BRRI dhan89 was grown in the research field. The average yield was found 6.13 t/ha.

Irrigation water requirement and rainfall utilization for delayed transplanting of Boro rice in different locations of Bangladesh

The experiment was conducted at BRRI HQ farm, Gazipur in 2021-22 season to find out the variation of irrigation water requirement in relation to the delayed transplanting. BRRI dhan81 was tested with four transplanting dates (T1 = 15 January, T2 = 31 January, T3 = 1 February, T4 = 1 March). The plot was arranged with randomized complete block design (RCBD) and four replications. Forty-day-old seedlings were transplanted in conventional puddled plots with 20 x 20 cm spacing. The fertilizers urea, TSP, MOP, gypsum and zinc sulphate rate were 300, 100,160,112 and 10 kg/ha, respectively. Irrigation water was applied according to AWD practice. Throughout the growing season, total water requirement and irrigation water varied with transplanting date. Plant water requirement was higher in January transplanting than February and March transplanting (Table 7). Transplanting on 14 February (T3) and 1 March (T4) had 63 and 129 mm lower water requirement than transplanting on 15 January (T1). Similarly, applied irrigation water was around 15 and 19% lower in transplanting on 14 February (T3) and 1 March (T4) compared to transplanting on 15 January (T1). Although, irrigation water requirement decreased with delayed transplanting, the utilization of rainfall was increased. Transplanting on 14 February (T3) and 1 March (T4) received about 71 and 119 mm more rainfall relative to transplanting on 15 January (T1).

Among the treatments, there was little variation of total water used due to the variation of rainfall. Growth duration was varied with transplanting dates (Table 8). Growth duration reduced by 12 and 21 days for transplanting on 14 February (T3) and 1 March (T4) than transplanting on 15 January. Transplanting on 15 and 31 January gave the highest yield about 6.6 and 6.3 t/ha, respectively. The delayed transplanting on 14 February and 1 March had around 20 and 40% lower yield than transplanting on 15 January. Water productivity was also higher with early transplanting on 15 and 31 January than delayed transplanting on 14 February and 1 March.

UTILIZATION OF WATER RESOURCES IN RAINFED ENVIRONMENT

Validation of agricultural drought forecasting for mitigating drought in T. Aman rice at Kushtia region

The experiment has been conducted at BRRI regional station Kushtia in T. Aman 2021 to validate the excel based drought simulation model (DSM). BRRI dhan87 was used as test variety. Forecasted rainfall, evapotranspiration and existing soil moisture were used as input of DSM model. Seven days daily minimum and maximum temperature, average relative humidity (%), wind speed was collected from BRRI agromet lab. Three treatments, rainfed (I_0), supplemental irrigation based on drought forecasting (I_1) and supplemental irrigation based on AWD system (I_2) were used to mitigate drought. Sufficient amount of rainfall occurred during T. Aman 2021 in BRRI rs farm, Kushtia. But early part of ripening stage received low rainfall when BRRI dhan87 transplanted on 15 August. Average agricultural drought measured in rainfed plot (I_0) was 10.5 mm under reproductive stage on 29 October and 25.6, 19.4 and 26.4 mm on 5th, 12th and 19 November of the growth duration under ripening stage (Table 9). In this week sufficient rainfall did not meet the evaporative demand of the BRRI dhan87 and encountered a drought stress when crop was transplanted on 15 August. But during the 30 August transplanting, two consecutive droughts 4.4 mm and 15.6 mm were observed at 31 October and 7 November of the growth duration, respectively at reproductive stage. Due to delayed transplanting, the crop faced a higher amount of drought at the reproductive stage compared to early transplanting in rainfed treatment. Early transplanting crop was able to escape a prolong drought. Quantification of average agricultural drought forecasting by drought simulation model (DSM) as well as soil water demand according to I_1 treatment plot was 5.9 mm in the reproductive stage at 29 October and 21.6, 18.9, 25.9 mm at 5, 12 and 19 November of the growing period, respectively in the ripening stage. So, four supplemental irrigations were applied when BRRI dhan87 transplanted on 15 August. On the other hand, observed average agricultural drought based on AWD system according to I_2 treatment plot was 18.7, 13.8 and 21.4 mm on the same date of the growing period of I_1 treatment in the ripening stage only. So, 4 and 3 supplemental irrigations were applied under I_1 and I_2 treatments, respectively when BRRI dhan87 was transplanted on 15 August. During 30 August transplanting of BRRI dhan87, quantification of drought forecasting according to I_1 treatment plot was 13.1 mm on 7th November in the reproductive stage and four consecutive droughts 19.8, 20.8, 25.1 and 18.6 mm at 14, 21, 28 November and 5 December in the ripening stage of the growing period, respectively (Table 9). Furthermore, observed average drought based on AWD system according to I_2 treatment plot was 16.8, 17.3, 21.3 and 16.0 mm on the same date of the I_1 treatment in the ripening stage. So, 5 and 4 supplemental irrigations were applied during the 30 August transplanting in the I_1 and I_2 plots, respectively. DSM model forecasted drought at reproductive and ripening stages of T. Aman rice satisfactory in Kushtia region. The model underestimated drought with overall prediction error was 20.23% compared to observed drought. Overall water saved by following supplemental irrigation based on drought forecasting was 30.5 % compared to AWD system. Considerable amount of yield increased (10.8-12.7%) due to drought mitigation (I_1 and I_2) at reproductive and ripening stages compared to rainfed (I_0) during T. Aman season (Table 10). Overall water saved by following supplemental irrigation based on drought forecasting was 30.5 % compared to AWD system. So, this model can provide early warning to the farmers when to irrigate or not. This information will be helpful for farmers to save money and also to save them from probable yield loss during drought.

Irrigation scheduling of rice (oryza sativa l.) based on weather forecasting in Gazipur

Better use of weather forecasting data is a vital strategy to save irrigation water for paddy rice. Medium range weather forecasting data following the water balance simulation model can save unnecessary irrigation applications to the field. In this study, reference evapotranspiration and rainfall events mainly focused on the input data of the water balance simulation model to estimate irrigation water for paddy rice cultivation. Based on that, 7-days medium-range weather forecasting can improve decision-making plan for applying irrigation. The results indicate that, WRF model signifies quite accurate forecasting of the mentioned weather parameters based on NRMSE and relBias. Comparing to the conventional and AWD irrigation, the newly proposed irrigation scheduling method can further save irrigation water about 22.0 and 10.5% compared to conventional and AWD irrigation system, respectively without significant yield loss. The results also showed that, weather forecasting based irrigation scheduling can increase water productivity than conventional and AWD irrigation. Nevertheless, the newly proposed irrigation scheduling method incorporated with weather forecast is suggested to apply in irrigation practice for its simplicity and effectiveness.

LAND PRODUTIVITY IMPROVEMENT IN THE COSTAL ENVIRONMENT

Saline water irrigation strategies for Boro rice cultivation in the coastal saline area

A field experiment was conducted at Dacope upazila in Khulna district of Bangladesh to understand the soil salinity dynamics and to assess the effect of saline water irrigation on plant growth and yield of Boro rice in 2021-22 growing season. The treatments were irrigating two salt-tolerant rice varieties (BRRI dhan67 and BRRI dhan97) with saline water having five salinity levels (water salinity < 1 dS m^{-1}, 4 dS m^{-1}, 6 dS m^{-1}, 8 dS m^{-1} and 10 dS m^{-1}). Strip plot design was followed with three replications. The plot size was 5 m x 4 m.rty-two-day-old seedlings were transplanted on 17 January 2022 with 20 x 20 cm spacing. Fertilizer and other cultural activities were followed according to BRRI guidelines. Freshwater was used from pond and the different levels of saline water were prepared using canal saline (varied from 2-4 dS/m) water and table salt in a 1000 litre capacity tank. The prepared water was applied in each plot through a plastic pipe. Figure 3 presented the dynamics of soil salinity with saline water irrigation. In all irrigation treatments, soil salinity was below 4 dS/m upto 28 February. Soil salinity increased gradually in all irrigation treatments with progress of the growing season. At the harvesting time, soil salinity was 6.7, 8.7, 11.2, 12.8 and 14.4 dS/m for irrigation water salinity less than 1 dS/m, 4 dS/m, 6 dS/m, 8 dS/m and 10 dS/m. Irrigation water salinity affected rice yield and yield components (Table 11). There was significant difference of rice yield with irrigation treatments but no difference with varieties. Rice yield was satisfactory (6.0 and 6.3 t/ha) in saline water irrigation <1 dS/m and 4 dS/m. Whereas, rice yield significantly reduced with increasing salinity level of irrigation water. The grain yield reductions were 9.7, 29.8, 44.3, and 58.5 % for BRRI dhan67 and 5.4, 17.3, 28.6, and 46.0% for BRRI dhan97 for saline water irrigation of 4 dS m^{-1}, 6 dS m^{-1}, 8 dS m^{-1} and 10 dS m^{-1}, respectively, compared to saline water irrigation less than 1 dS m^{-1} (recommended salinity level of irrigation water). BRRI dhan97 had a lower yield reduction than BRRI dhan67, indicating that BRRI dhan97 was more salt tolerant than BRRI dhan67. Increasing salinity level of irrigation water also increased unfilled grain and reduced plant height. The study revealed that the latest salt-tolerant rice variety like BRRI dhan97 and BRRI dhan67 can be grown with saline water irrigation up to 4 dS m^{-1} for getting higher yield potential during the dry season in the saline coastal zone.

SUSTAINABLE MANAGEMENT OF WATER RESOURCES

Monitoring of groundwater fluctuation and safe utilization in different geo-hydrological regions

In this study, available water level recorder was used for measuring groundwater fluctuation in BRRI HQ Gazipur and all the regional stations. Data were recorded weekly. Collected weekly records were calculated to obtain monthly average. In Gazipur, during 2021-22 period, maximum lowering of groundwater (-48.17 m) was observed in June and minimum (-46.55 m)) in August (Fig. 4). The fluctuation was more than 1.6 m. The fluctuation was higher than the previous year. In 1998, the minimum groundwater level was about 5.23 m below the ground surface which was 48.17 m in 2022 (Fig. 5). Therefore, the lowering was about 42.94 m in 24 years. During the initial five years (1998-2002) the lowering (3.8 m) was not so high, but during the last five years (2018-2022) the lowering was about 6.23 m. Figure 6 presented monthly groundwater levels of BRRI regional stations. Among 10 regional stations, the groundwater level was below the suction limit (> 8 m) during Boro season in Cumilla, Rajshahi and Habiganj.

Conjunctive use of wastewater and freshwater for irrigation in Boro rice cultivation

For determining the suitability of different wastewater treatments, a pot experiment was conducted with five irrigation treatments namely T1= Irrigation with freshwater(control), T2= Irrigation with municipal wastewater (MWW), T3= Irrigation with industrial wastewater (IWW), T4= Irrigation with fresh water and industrial wastewater (50% FW and 50% IWW) and T5= Irrigation with fresh water and municipal wastewater (50% FW and 50% MWW). Thirty-eight-day-old seedling of BRRI dhan89 was transplanted with RCBD and three replications. In total 16 irrigations were applied in every pot throughout the growth stages. Yield and yield contributing parameters were recorded. Irrigation with freshwater(control) produced the highest yield (76.61g/pot) followed by irrigation with fresh water and municipal wastewater (50% FW and 50% MWW) (71.01g/pot). So, along with freshwater, municipal wastewater with freshwater is a good option for irrigation practices in boro season.

Assessment of surface and groundwater quality for irrigation in selected locations of Bangladesh

The experiment was conducted in six regional stations namely Gazipur, Rajshahi, Rangpur, Barishal, Habiganj of BRRI in 2021-22. The water samples were collected from different source of ground water and surface water. The quality of water for location was assessed for its irrigational purposes. In the present study all the samples had KR less than 1.0 except Barishal. So, Kelly's ratio showed full satisfaction in using for irrigation. Soluble sodium percentage values were found in satisfactory level. Magnesium absorption ratio was found satisfactory (desired range <50) for irrigation.

Assessing On-farm Water-use Efficiency of BRRI Research Farm, Gazipur

For computing water use efficiency of BRRI west byde farm, one pump was chosen for this study and the command area was also quantified. After transplanting, operating time of pump and discharge rate was monitored and calculated. Seepage and percolation and the evapotranspiration was also measured. Required and supplied amount of water was found 68,202.6 m3 and 102,189.96 m3 respectively. The WUE was rated 66.74 %. So, 34% of applied water was not used by crop and being wasted by different ways.

RENEWABLE ENERGY

Feasibility Assessment of Solar Pump Utilization for Irrigation Purpose in Chattogram Region

In 2021-22, the study was conducted in Dagon Bhuiyan of Feni district and Fotikchhori and Mirershorai of Chattogram district. Field visit and detailed survey was conducted in that region. In the visited locations, the water resources were physically assessed and several discussions were conducted with farmers, local stakeholders, inhabitants, local government bodies, NGO workers and root level agricultural extension workers as well as researchers working in that area. Field data were also collected from solar pump suppliers, service providers and users. Solar pumps are in operation in different locations of Chattogram region. Therefore, field-level data were collected from the relevant traders, service providers and users associated with the selected pumps. Secondary data were gathered from books, journal articles, research reports, internet, etc. We have visited three solar pump fields which were controlled by DAE. There is available solar radiation observed in Chattogram region which is very suitable to operate a solar pump (Fig. 7). Maximum radiation is obtained in April and that the minimum is found in July. January to April is the maximum water required during Boro season and those times maximum solar radiation is observed in Chattogram region. Source of water of all the pumps was surface water. River, canal, creeks or fountains (Jiri or Chora) which are used as irrigation water sources. Water levels from the field surface to water bodies of the river or canals varied from 2-6 m. Special type of single phase vertical multistage centrifugal pump is used in the visited locations. This pump is 4 kw and winding by three types of coils such as high, medium and low resistance which protected the pump from low to high voltage due to variability of solar radiations during operation. Figure 8 shown some selected fields. So, there are suitable sources of water those can be used for irrigation by operating solar pumps in the Chattogram region.

TECHNOLOGY VALIDATION IN THE FARMERS' FIELD

Mass demonstration of suitable Aman rice varieties for facilitating Rabi/Boro crops intensification

A group of farmers were selected to cultivate the same variety in a block based on the land suitability within the study locations of Dacope and Amtali. The individual farmers' plot treated as disperse replications for the same variety within the block. The tested variety were BRRI dhan87, BRRI dhan76 and BRRI dhan77 along with the farmers' popular variety BR23. In Dacope area, the tested varieties BRRI dhan87 and BRRI dhan76 covered about 12.0 and 18.8 ha with the farmers' participation of 97 and 54 farmers, respectively during Aman season 2021 along with the farmers adopted high yielding variety of BR23. Whereas, in Amtali area those varieties (BRRI dhan87 and BRRI dhan76) covered about 7.4 and 12.5 ha with the farmers' participation of 24 and 47 farmers, respectively during the same season. Mass or block demonstration of the same variety in a location creates an advantage to control the insect-pest and crop harvest. All the tested rice varieties performed well in the coastal region during Aman season 2021. Though the fluctuation of BRRI dhan87 was higher because of some pest infestation, but the average yield was comparatively higher with other tested varieties. BRRI dhan76 produced a consistent yield in both the locations. Farmers were highly interested to cultivate those varieties based on the land suitability. The yield of BRRI dhan87 in Dacope area varied from 3.39 to 6.62 t/ha with an average of 4.59 t/ha and BRRI dhan76 varied from 3.93 to 5.32 t/ha with an average of 4.63 t/ha, whereas in Amtali area BRRI dhan87 varied from 3.97 to 6.30 t/ha with an average of 4.86 t/ha and BRRI dhan76 varied from 4.03 to 5.67 t/ha with an average of 4.74 t/ha. Gross and net income per hectare of Aman rice at average yield (4.59 - 4.86 t/ha) were in the range between BDT 44,050 - 48,582 and BDT 11,783 - 14,894 in Dacope and Amtali (Table 12). Farmers are satisfied with the biophysical performance of wet season (WS) rice over the last couple of years. The yield performance of the promising T. Aman varieties (BRRI dhan87 and BRRI dhan76) were good in both Dacope and Amtali areas. Based on the research findings in both the locations, farmers expressed their willingness to continue the cultivation of BRRI dhan87 in medium high land and BRRI dhan76 in the medium-low to low land areas due to higher yield, short duration, and unique characters to cope with the environments. These varieties improve the land productivity, net income, and benefit cost ratio (BCR) and also facilitated the cropping intensification in the coastal areas.

Growing vegetable crops with rice under waterlogged lowland condition

The experiment was conducted in Dacope, Khulna during wet season of 2021. Previously we introduced plastic bags and bamboo sticks, but it damaged within two years. For considering the durability, we reused plastic drum, concrete pillar, and galvanized iron wire in this purpose. To avoid the shading effect from the vegetable crops, we synchronized the vegetable crops with T. Aman rice. This year we placed bags on the bank of Gher and planted on gher boundary (Fig.9). Among the tested fruits and vegetables, watermelon and sweet gourd produced comparatively higher yield than the other vegetables. However, yield loss was found in T. Aman rice field in integrated condition over farmers' practice (sole rice). This was the integrated effect of shading effect and land occupied by bag placement in the rice land. The mean return from integrated rice was found Tk 96,462 whereas, sole rice return was found Tk 1,02,497 resulted 6% higher return in sole rice field (Table 13). Among the integrated vegetables watermelon with sweet gourd showed the best performance among the other vegetables due to their higher productivity. Though other creeping vegetables yielded comparatively lower, it has higher unit price than sweet gourd. Besides, farmers showed interest on creeping vegetables since it met their home consumption, and these were locally unavailable during the monsoon period. Compared to the previous year's findings production costs in integrated vegetables was very minimum due to reuse of previous materials. It was found that the average vegetable production cost was Tk 1,20,882. Plastic drum, concrete pillar, iron rope etc have long durability and it can be reused in further years. Gross margin from sole rice (Tk 15,918) was Tk 4,034 higher from the integrated rice (Tk 11,884) during 2021 at Dacope, Khulna (Fig. 10). However, average of Tk 98,236 gross margin was obtained from vegetable production in the area which was significantly higher than the previous year's findings (Tk 20,361 to Tk 30,961) in the same location. Thus, the findings showed the higher profitability of integrated rice and vegetable cultivation over traditional rice cultivation in water stagnant coastal environment in Bangladesh. The integrated rice/vegetable system was not economically attractive under the initial method (plastic sac with bamboo). But after some modification by introducing durable plastic drum and concrete pillar and galvanized iron wire and synchronizing vegetable production with T. Aman rice, then two to three times vegetable production was possible. Now the farmers were interested to cultivate high value off-season watermelon and get more return compared to the other vegetables.

Water resources management for Boro/Rabi crops by canal blocking

There are plenty of freshwater resources in wet season with a huge amount of rainfall (about 2000 mm) but less in dry season. To protect the crops and habitats in the coastal zones of Bangladesh from tidal water pressure about 139 polders were made. Polders are prone to flooding and poor drainage due to lower ground level of polders than sea level at high tide. Therefore, they require carefully managed drainage, usually through sluice gates at low tide. Improper management of sluice gate sometimes creates drainage congestions and water-logged situation in wet and late monsoon season. There are several rivers and equals crisscross the coastal area, which acts as a source of water supply and drainage. But in dry season, most of the river and canal water goes beyond the permissible limit of irrigation for crops and thus a vast area remains fallow in dry season. To conserve freshwater resources and to facilitate and increase the cropping intensity and to improve the land productivity, fresh water was trapped in the existing canals of Dacope and Amtali areas (Fig.11). By using this freshwater Boro/Rabi field crops were grown.

Salinity dynamics of water and soil in coastal areas of Bangladesh

To monitor river and trapped canal water salinity, three spots were selected at a certain distance in both the locations of Dacope, Khulna and Amtali, Barguna and measured water salinity of the selected points by EC meter. An observation well was installed in one corner of the experimental field within the weather station boundary at

Pankhali village of Dacope, Khulna and very near to the experimental field at Sekandarkhali village of Amtali, Barguna to measure groundwater level and salinity. Soil salinity from rice field was measured weekly and non-rice field was measured at 15 days intervals after transplanting at 0-15, 15-30, 30-45 and 45-60 cm soil depth. The collected samples were meshed after oven drying and sieved to remove derides. Then the soil samples were mixed with distilled water at the rate of soil and water in 1:5. After shaking 30 minutes with 5 minute intervals and settling for minimum 30 minutes and measured the electrical conductivity by standard EC meter. Salinity of the river Jabjapia, Dacope, Khulna remained below 1.0 dS/m up to December (Fig. 12) and is considered highly suitable for irrigating crops. Even river water remained suitable (<4.0 dS/m) for irrigation up to end of December. After that the river water salinity gradually increased and at the end of Rabi/Boro cropping season it reached about 32 dS/m in May. The canal water was trapped within December at the period of high tide making canal water salinity of about 1.0 dS/m. Its salinity increased in a slower rate and reached up to 3 dS/m in May due to evaporation and influence of groundwater flow (Fig. 13). In Amtali area, salinity of the river Andharmanik started to increase after November and reached its peak in May (Fig 12). After the onset of rainfall in June the salinity level of river water sharply decreased and from July to November the river water became fresh and after that its salinity starts to increase. The canal water was trapped on before November and canal water average salinity was 1.3 dS/m. Groundwater level and salinity in the experimental field at Pankhali, Dacope varied between 0.21-1.21 m below the field surface and 0.31-2.26 dS/m, respectively (Figs.14 and 15) In Dacope, groundwater salinity remained less than 4.0 dS/m during the study period and is considered suitable for irrigation development. But withdrawal of groundwater from the upper low saline aquifer is a risky venture for increasing salinity by intrusion of river high saline water in dry season. Whereas, average groundwater level at Sekandarkhali, Amtali varied between 0.93 to 1.8 m from ground surface and groundwater salinity at 2.75 to 10.32 dS/m (Figs.14 and 15). The year-round soil salinity varied from 2.0 to 8.0 dS/m in Dacope and that was 1.8 to 6.0 dS/m in Amtali areas. In dry season, the soil salinity goes to its peak in April and after the onset of monsoon rainfall it reduces. However, the Amtali area is less saline compared to Dacope area. Fresh water resources development is one of the crucial issues for sustainable crop and soil salinity management in coastal areas. Surface fresh water was trapped in local canals within December for irrigation in dry season crops. Groundwater salinity was beyond the permissible limit of irrigation. Dacope area is more saline than that of Amtali areas (Fig. 16). Therefore, special care needs to be adopted for dry season crop production.

Block demonstration of Boro rice by using stored surface water in coastal areas for cropping intensification

The experiment was conducted at Dacope and Batiaghata in Khulna district, Amtali and Taltali in Barguna district and Kalapara, Patuakhali in Barishal region with the tested salt tolerant rice variety of BRRI dhan67 and the high yielding varieties of BRRI dhan74, BRRI dhan97, BRRI dhan99 and BRRI dhan89. In Khulna area, the tested varieties covered about 20.4, 2.9 and 1.2 ha with the farmers' participation of 168, 40 and 12 farmers during the 2021-22 Boro seasons. Whereas, in Barishal area it covered about 15, 10 and 3 ha with the farmers' participation of 46, 37 and 11 during the same season. All the tested rice varieties performed well in the coastal region during Boro 2021-22. In Dacope, Khulna area, BRRI dhan99 produced comparatively higher grain yield followed by BRRI dhan67. BRRI dhan97 produced the lowest yield among the three tested varieties. BRRI dhan67 produced better yield performance over BRRI dhan97. BRRI dhan74 performed the best in Taltoli whereas, similar yield performance was observed among the tested variety in Amtali, Barguna and Kalapara, Patuakhali. A large yield variation was observed for each varieties in the tested locations. This is because of the seedling age, transplanting time and intercultural practices variation among the farmers. Gross margin and net income per hectare of Boro rice based on the average yield (4.95- 6.20 t/ha) were in the range between BDT 86,036 – 107,025 and BDT 45,379-64,822 in Khulna and Barishal region (Table 14). Farmers are satisfied with the biophysical performance and successful production of dry season (DS) rice with BCR ranged from 1.41 to 1.57 over the last couple of years. All the tested varieties performed well in both the sites over the tested years. But, freshwater availability is the main constraints for cultivation of Boro rice. However, farmers are highly interested to grow Boro rice by conserving fresh water by trapped canal, because the production is less risky compared to other Rabi crops, which were more vulnerable for uncertain rainfall and cyclonic damage. Cultivation of Boro rice become profitable for its safe and higher production.

Upscaling of Improved Water Management Practices for Sustainable Productivity in the Haor areas

Boro is the main and only crop in the haor areas. Cultivated popular high yielding varieties are BRRI dhan28 and BRRI dhan29. Cultivated popular hybrid varieties are Janakraj, Chokka and Jhalak. Popular local varieties are Gochi, Lakhai, Tepi boro and Rata boro. Short duration varieties like BRRI dhan28 are popular in Matian haor due to late recession of flood water and early inundation. Long duration varieties like BRRI dhan29 are popular in the Shanir haor due to early recession and late inundation by flood water. Main source of irrigation is the surface water from river, canals, ponds, ditches and beels. Except river, other sources of irrigation water dries up during later part of February. As a result, crops suffer from severe water stress if sufficient rainfall does not occur in March. Due to water stress at the reproductive phase yield of Boro rice is very low (2-3 t/ha) though land is fertile compared to other regions of Bangladesh. In the farmers' opinion main problem for sustainable production are the irrigation water scarcity and early flash flood at the maturity stage. Other problems inciude labour scarcity during transplanting and harvesting, high labour wage, lack of technological knowledge etc. A total of 12 demonstrations were conducted in the haor areas. Out of the 12 demonstrations 10 were conducted in Shanir haor and two were in the Matian haor. Varieties used were- BRRI dhan29, BRRI dhan84, BRRI dhan89, Chokka, Jhalak and Janokraj. The last three were hybrid varieties. Amount of irrigation was measured each time. Crop-cut was done to measure the yield. The irrigation and yield data were compared with farmers practice plots. The yield of the AWD plots was 3.13-6.36 t/ha. The highest yield (6.36 t/ha) was obtained from BRRI dhan29. Out of 12 plots, seven produced yield of more than 5.0 ton/ha. Lower yield (<4.5 ton/ha) in some plots were due to damage by hailstorm (15 April 2022). The average yield obtained in the AWD plots was similar to the farmers practice plots. Generally, 2-3 irrigations were saved in AWD irrigation practice than the farmers practice (maintaining saturation to standing water). Polythene pipes were supplied to 3 LLP and 1 DTW irrigation systems. Two LLPs were at Sreepur and Borodol of the Matian haor. One LLP and one DTW were at Moddho Tahirpur and Ujan Tahirpur of the Shanir haor. A low lift pump was installed at the Bank of Boulai river to cultivate a portion of fallow land in Shanir haor. The distance was more than 1000 ft out of which 600 ft was settlements. So, 600 ft PVC pipe was used to carry the water through the settlements. As the construction of earthen canal was very difficult due to undulation of land, about 800 ft Polythene pipe was supplied to carry water to the plots. Around five hectares of lands were brought under cultivation with the irrigation water. Around 500 ft polythene pipe was provided to a newly installed DTW of Ujan Tahirpur to carry water to remote places. Pumping time was higher in the earthen canal due to leaching loss. A comparison between earthen canal and polythene pipe was made to assess the performance. Two adjacent plots at a distant place were irrigated by earthen canal and polythene pipe. Area of each plot and time required for irrigation were recorded. Irrigation time was reduced by 20 percent due to use of polythene pipe compared to earthen canal. Due to use of polythene pipe the irrigation time per unit area was reduced significantly. Check valve was installed in 3 STWs. Among the shallow tubewells two were used for supplementary irrigation in Boro rice. The discharge of the pump was measured before and after installation of the check valve. No significant difference was found in discharge. The pump operation became very easier after installation of the check valve. It takes 2-3 persons to start the pump any time before installation of the check valve. Only one person could easily start the pump after installation of the check valve. A total of 21 plots were monitored in Both Matian and Shanir haor. Plots were categorized as- no stress, less stress, moderate stress, severe stress and very severe stress. Perforated PVC (AWD) pipes with 50 cm depths were installed in the plots to monitor the parched water table. Pipes having 50 cm depth were installed in the plots to assess the water stress. Based on the continuous stress period below the specified stress limit, an indicator was developed to assign the stress category. The yield was compared to assess the impact of water stress. A total of 3 and 6 plots were under no stress and less stress group, respectively. Four plots were under each of moderate stress, severe stress, and very severe stress groups. Highest yield was obtained in no stress plots and the lowest in very severe stress plots. The average yield of the plots under no stress, less stress, moderate stress, severe stress, and very severe stress groups were 6.23, 5.43, 4.55. 3.90 and 3.16 t/ha, respectively. The average yield reduction in less stress, moderate stress, severe stress, and very severe stress plots were 12.9%, 27.0 %, 37.5% and 49.3%, respectively compared to the no stressed plots. The study results indicate that huge yield loss occurred in the haor area due to water stress in the reproductive phase of Boro rice.

Mass block demonstration of Aus, Aman and Boro rice by using high yielding varieties, improved agricultural practices in the coastal areas to cropping intensification

The demonstrations were setup in farmers' field at Barishal, Khulna and Satkhira district. During Aus season, BRRI dhan48 covered 29 hectares with 10 demonstrations. The average yield was 4.0 – 5.5 t/ha. During Aman season, the new and high yielding varieties BRRI dhan76, BRRI dhan75 and BRRI dhan87 along with the farmers' popular varieties BR10, BR11 and BR23 were tested in the selected area. The area covered with these improved varieties was 83 ha by 70 demonstrations. The highest yield was from BRRI dhan87 in all locations which varied from 4.1 to 6.0, 5.6 to 6.4 and 5.8 to 6.2 t/ha with an average of 5.4, 6.1 and 6.0 t/ha in Khulna, Barishal and Satkhira, respectively. The average yield of BRRI dhan76 was 4.6 to 5.3 t/ha. BR23 and BR11 also had satisfactory yield which varied from 3.8 to 5.6 t/ha. In Boro season, high yielding rice varieties BRRI dhan74, BRRI dhan81, BRRI dhan89, BRRI hybriddhan5 and salt tolerant rice varieties BRRI dhan67, BRRI dhan97 and BRRI dhan99 were demonstrated in a block with a range of 10-80 Bigha area in low saline areas of Barishal and high saline areas in Khulna and Satkhira region. In all the locations, total area was 430 ha with 100 demonstrations. In Batiaghata, Khulna, the range of yield was 7.2 t/ha to 8.8 t/ha and 6.5 t/ha to 7.7 t/ha for BRRI hybrid dhan5 and BRRI dhan89. On the other hand, in Dacope Khulna, BRRI dhan67 had higher yield than BRRI dhan97 and BRRI dhan99. The yield range was 5.2 t/ha to 6.6 t/ha and 5.0 to 6 t/ha for BRRI dhan67, BRRI dhan97 and BRRI dhan99, respectively. In Barishal region, the highest yield was from BRRI dhan89 and BRRI hybrid dhan5 which ranged from 6.8-8.4 t/ha and 6.5-9.0 t/ha. Whereas BRRI dhan74 performed well than BRRI dhan67. The range of yield was 6.2-7.8 t/ha and 5.4-6.7 t/ha for BRRI dhan74 and BRRI dhan67. In Satkhira region, BRRI dhan67 and BRRI dhan81 had higher yield ranged from 6.0 to 7.2 t/ha than BRRI dhan50 and BRRI dhan63.

Assessment of improved agricultural practices to maximize rice yield in the coastal area during T. Aman season

The experiment was conducted in farmer's field at Dacope upazila in Khulna and Patuakhali sadar upazilla in Patuakhali in 2021 season. Four Aman rice varieties viz BRRI dhan76, BRRI dhan87, BR23 and local cultivars Jatibalam and Sadamota were tested with improved agricultural practices (optimum seedling age, timely transplanting, spacing, recommended fertilizer, supplemental irrigation) and farmer practices. In both the locations, improved practices increased 12-22% rice yield than the farmers' practice.

Impact of alternate wetting and drying irrigation for Boro rice cultivation in the coastal saline area

Ten demonstrations were implemented in Barishal and Khulna to assess the AWD practices on rice yield and irrigation water. In Barishal, AWD practice saved three irrigations than continuous irrigations without any yield sacrificed. Whereas, in Khulna region, AWD practices saved two irrigations than continuous irrigations without any yield loss. The results indicate that the adoption of AWD irrigation practice in the coastal areas can save irrigation water and increase Boro rice cultivation.

Greenhouse gas emissions from irrigated agriculture in Bangladesh and reduction policies/strategies

Water demands in Bangladesh for agricultural and non-agricultural uses are mostly met from groundwater sources. As a result, groundwater table is declining in different parts of the country which necessitate pumping water from deeper layers. It is a great concern not only for sustainable uses of groundwater resources but also for increasing pumping cost. Pumping of water for irrigation is one of the most energy-consuming processes, which is also related with greenhouse gas (GHG) emissions. This issue has not been addressed yet in Bangladesh. We have considered surface and groundwater irrigation devices and area coverage during 2019-2020 for GHG estimation (Table 15). Based on water lifting heads, area coverage and fuel used, GHG emissions varied among locations and sources of irrigation water (Fig.17). Total GHG emission for crop fields irrigation was about 2.82 million tons (Mt) CO2-e (which is about 5% of the emission of agricultural sector) of which 0.26 Mt CO2-e for surface and 2.56 Mt CO2-e for groundwater irrigations. The hotspots of GHG emissions were Rajshahi region followed by Rangpur and Mymensingh regions (Table 16). Area coverage by shallow tube wells (STWs), deep tube wells (DTWs) and low lift pump (LLPs) were 56.8%, 19.2% and 24.0% of cultivated areas; but GHG emissions were 35.4%, 55.5% and 9.2%, respectively. The present findings showe that groundwater abstraction is an important source of GHG emissions in Bangladesh. So, it is the time to harness the co-benefits of water and energy savings by adopting alternate wetting and drying practice for rice cultivation, by expansion of surface water irrigation facilities along with selecting water use-efficient crop varieties having high yield potentials.

Intervention in surface water utilization through integrated minor irrigation schemes for escalating water and land productivity in coastal region

Agricultural land use and crop productivity in the Barishal region are decreasing day by day. The main constraint that affecting the productivity of this region is lack of good quality irrigation water. However, all river waters or canal waters are not saline according to water salinity monitoring conducted during the past 15 years by Irrigation and Water Management Division of BRRI. Based on the findings, water from the river Tentulia, Buriswar, Bishkhali, and Boleswar was less than 1.0 dS/m round the year. The results suggest that water from the selected rivers is suitable for irrigation when the water is applied from the upstream of the saline-sweet water interface of the river which is located about 20 to 30 km north from the estuaries. The fallow, or single cropped agricultural lands in the coastal region of Barishal is a potential target for expansion of Boro rice cultivation and thus to increase the cropping intensity. For this purpose, less saline surface water, particularly water from Burishwar and Bishkhali river water, can be used through integrated minor irrigation schemes. Therefore, the project's primary research is to increase water and land productivity through efficient water diversion, modern distribution systems, and judicious water management practices. Other research initiatives include identifying the most water-efficient cropping pattern in the project area. Six experiments have been established in Patuakhali Sadar and Taltoli upazila under the project. The close monitoring of water salinity under multiple sampling locations, the range of suitable water sources is wider in terms of distances in the polder. Boro rice cultivation, that is dependent on the irrigation with fresh or less saline water, can be done in the areas that are located at the closer vicinity of the river Burishwar. The cultivable area can be extended to even more southern part of the polder using less saline water not from the river but from the canals, the water source of which is from the upstream side of the saline sweet water interface. Thousands of fallow lands can be brought under Rabi crops coalition using the surface water available in all canals in Polder number 44. However as discussed in the first experiment, all canals do not store or flow fresh of less saline water, instead the canals alongside the Burishwar river, which connects the salinity monitoring points 2B, 2A, 1, 12,13 15, 16A, 16B, 17 contains fresh or less saline water during the Rabi season. Therefore, the dead canals (length about 35 km) that represents these non-saline points are recommended for re-excavation. In Patuakhali Sadar upazila of Patuakhali district, about 41 hectares (300 bigha) of fallow area have been brought under Boro cultivation establishing 12 block trials. The minimum size of a block is about 25 bigha, whereas the maximum size is 100 bigha. In total 165 farmers cultivated modern high yielding BRRI varieties such as BRRI dhan67, BRRI dhan74, and BRRI dhan89. In Taltoli upazila of Barguna district, about 27 hectares (200 bigha) of fallow area have been brought under Boro cultivation establishing eight block trials. The minimum size of a block is about 25 bigha, whereas the maximum size is 50 bigha. In total 100, farmers cultivated modern high yielding BRRI varieties such as BRRI dhan67, BRRI dhan74, and BRRI dhan89. All Boro trial fields have been irrigated with less saline river/canal water that the salinity of water is being continuously monitored.

Table 1. Irrigation water sources, present irrigated area, and possible area extension of cultivable lands in Sadar, Khagrachari.

Irrigation resource	Block	Present irrigated Area coverage (ha)	Extendable irrigated Area coverage in future (ha)
Creek	Bhai Bon Chora	45	45
Creek	Bahi Bon Chora	52	30
Canal	Dur Chori	10	60
Canal	Dur Chori	20	30
River (Chengi)	Gamari Dhala	80	60
River (Chengi)	Muni Gram	100	300
Creek	Kuki Chora	50	100
River (Chengi)	Pourashova	80	120
Creek	Pourashova	20	30
Creek	Pourashova	50	80

Table 2. Rice yield of premium quality rice (PQR), ALART-1, 2 and check variety along with irrigation treatment at BRRI HQ farm, Gazipur during Boro 2022.

ALART and check variety	Grain yield (g/hill)				Tolerance capacity
	CS	**-10 kPa**	**-30 kPa**	**-60 kPa**	
BR9930-2-3-2-2	25.52	22.43(-12.1%)	16.67 (-34.7%)	11.95 (-53.2%)	CS
BR9930-2-3-3-1	31.77	28.55 (-10.1%)	20.26 (-36.2%)	13.13 (-58.7%)	CS
BRRI dhan50 (ck)	33.79	28.06 (-17.0%)	13.39 (-60.4%)	13.13 (-61.1%)	CS
BRRI dhan63 (ck)	27.34	21.16 (-22.6%)	14.97 (-45.2%)	12.86 (-53.0%)	CS
BRRI dhan81 (ch)	36.51	27.52 (-24.6%)	16.91 (-53.7%)	15.75 (-56.9%)	CS
$lsd_{0.05}$					ns (6.802)
cv%					4.3

Table 3: Irrigation, rainfall and grain yield of the selected Advanced lines under different water management treatments during Boro season 2021-22 at BRRI HQ farm, Gazipur.

Variety	Treat	Number of irrigation	Irrigation applied (mm)	Rainfall (mm)	Total water use (mm)	Average yield (kg/ha)	Irrigation water saving than T1 (%)	Change in yield than T1 (%)
BR11715-4R-186	T1	14	810	270	1080	7195		

	T2	11	705	270	975	6930	-13.0	-3.7
	T3	20	650	270	920	6163	-19.8	-14.3
	T4	19	620	270	890	5844	-23.5	-18.8
BR11723-4R-27	T1	14	810	270	1080	7624		
	T2	11	705	270	975	7152	-13.0	-6.2
	T3	20	650	270	920	6786	-19.8	-11.0
	T4	19	620	270	890	6206	-23.5	-18.6
BR11723-4R-12	T1	14	810	270	1080	6744		
	T2	11	705	270	975	6582	-13.0	-2.4
	T3	20	650	270	920	6507	-19.8	-3.5
	T4	19	620	270	890	6119	-23.5	-9.3
BR11716-4R-105	T1	14	810	151	961	6270		
	T2	11	705	151	856	6482	-13.0	3.4
	T3	20	650	151	801	6072	-19.8	-3.2
	T4	19	620	151	771	5925	-23.5	-5.5
BRRI dhan92	T1	14	810	151	961	7154		
	T2	11	705	151	856	7210	-13.0	0.8
	T3	20	650	151	801	6782	-19.8	-5.2
	T4	19	620	151	771	6647	-23.5	-7.1

Table 4: Effects of amendment practices in charland on Yield and yield components of BRRI dhan100 during T. Aman, 2021.

Treatments	Plant height (cm)	Panicle/hill (no.)	Grain per panicle (no.)	Sterility (%)	Grain yield (t/ha)	Yield increased over control
T_1	135.85	10.47	114.5	13.35	5.73	30.5
T_2	114.25	11.13	112.8	12.27	4.72	15.7
T_3	117..63	11.6	115.7	18.21	4.69	15.1
T_4	117.99	10.33	114.9	15.82	4.13	3.6
T_5	122.16	10.73	118.5	11.82	4.55	12.5
T_6 (Control)	118.34	10.13	112.7	14.33	3.98	--
$lsd_{0.05}$	6.68	ns	ns	ns	0.99	
cv%	2.4				4.3	

Table 5: Effects of amendment practices in charland on Yield and yield components of BRRI dhan89 during boro 2021-22.

Treatment	Plant height (cm)	Panicle/m^2 (no.)	Grain per panicle (no.)	Sterility (%)	Straw yield (t/ha)	Grain yield (t/ha)	HI
T_1	109	233.3	184	10.41	6.07	6.98	0.54
T_2	106	268.3	176	12.58	6.73	6.87	0.51
T_3	110	285.0	154	12.92	6.11	7.30	0.55
T_4	112	261.7	180	12.32	7.13	6.86	0.49
T_5	106	241.7	179	10.86	6.54	7.54	0.54
T_6 (Control)	108	271.7	176	10.33	6.31	6.91	0.52
$lsd_{0.05}$	ns	ns	9.12	ns	ns	0.35	0.027
cv%			2.9			2.7	2.8

Table 6. Treatment-wise irrigation applied and average yield in T. Aman 2021 and Boro 2021-22, Rangpur**.**

Treatment	**Irrigation (mm)**		**Avg. yield (t/ha)**	
	T. Aman	**Boro**	**T. Aman**	**Boro**
Control (T1)	**260**	**1150**	**4.45**	**6.76**
AWD (T2)	232	963	5.20	7.71
CROPWAT (T3)	145	790	5.43	7.50

Table 7: Water requirement and water applied for Boro rice in Gazipur in 2021-22.

Treat-ment	Water requirement (mm)			Water applied (mm)				
	Evapo-transpiration (ET)	Seepage and Percolation (S&P)	Total water required (mm)	Number of irrigation	Water applied in land preparation	Applied irrigation	Rainfall	Total amount of water used (mm)
T_1	406	400	806	13	200	780	115	1095
T_2	407	390	796	12	200	720	145	1065
T_3	387	357	743	10	200	660	186	1046
T_4	358	320	677	9	200	630	234	1064

Table 8: Yield and water productivity of different transplanting dates of Boro rice in Gazipur in 2021-22.

Treatment	Growth duration (days)	Total water use including rainfall (mm)	Yield (t/ha)	Water productivity (kg/ha-mm)
T1	139	1095	6.6a	6.0
T2	135	1065	6.3a	5.9
T3	127	1046	5.3b	5.0
T4	118	1064	3.7c	3.5

Table 9: Amount of average agricultural drought (mm) quantified in different growth stages under different treatments of BRRI dhan87 at Kushtia during T. Aman 2021

Growth duration (Week)	Growth phase	15 Aug DoT			Growth duration (Week)	Growth phase	30 Aug DoT		
		(I_0)	**(I_1)**	**(I_2)**			**(I_0)**	**(I_1)**	**(I_2)**
15-Aug	Vegetative	0	0	0	30-Aug	Vegetative	0	0	0
21-Aug		0	0	0	05-Sep		0	0	0
28-Aug		0	0	0	12-Sep		0	0	0
04-Sep		0	0	0	19-Sep		0	0	0
11-Sep		0	0	0	26-Sep		0	0	0
18-Sep		0	0	0	03-Oct		0	0	0
25-Sep	Reproductive	0	0	0	10-Oct	Reproductive	0	0	0
02-Oct		0	0	0	17-Oct		0	0	0
09-Oct		0	0	0	24-Oct		0	0	0
16-Oct		0	0	0	31-Oct		4.4	0	0
22-Oct		0	0	0	07-Nov		15.6	13.1	0
29-Oct		10.5	5.9	0	14-Nov	Ripening	25.6	19.8	16.8
05-Nov	Ripening	25.6	21.6	18.7	21-Nov		27.4	20.8	17.3
12-Nov		19.4	16.4	13.8	28-Nov		30.4	25.1	21.3
19-Nov		26.4	23.4	21.4	05-Dec		22.5	18.6	16.0
26-Nov		0	0	0	12-Dec		0	0	0
03-Dec		0	0	0	15-Dec		0	0	0
05-Dec		0	0	0		Total	125.9	97.4	71.4
	Total	**81.9**	**67.3**	**53.9**					

Table 10. Yield increased due to drought mitigation during T. Aman 2021 in Kushtia.

Treatment	Yield on 15 Aug transplanting (t/ha)	% yield increased than I_0	Yield on 30 Aug transplanting (t/ha)	% yield increased than I_0	% yield loss due to delay transplanting
I_0	6.5	-	5.5	-	18.2
I_1	7.2	10.8	6.1	10.9	18.0
I_2	7.3	12.3	6.2	12.7	17.7

Table 11. Effect of different level of irrigation water salinities on yield and yield contributing parameters.

Saline water Irrigation	Variety	Yield (t ha^{-1})	Number of filled grain per panicle	Number of unfilled grain per panicle	Plant height (cm)
I1	V1	6.7	152	6	122
I2		6.1	148	17	110
I3		4.7	122	16	104
I4		3.8	109	33	102
I5		2.7	106	35	105
I1	V2	6.0	149	11	112
I2		5.8	145	18	110
I3		4.9	134	24	106
I4		4.3	117	30	101
I5		3.2	112	35	106
			Treatment means		
I1		6.3	151	9	117
I2		6.0	147	17	110
I3		4.8	128	21	105
I4		4.0	113	32	102
I5		2.9	109	35	100
V1		4.9	128	22	109
V2		4.8	139	26	107
P-values					
Irrigation		0.001	0.05	0.001	0.01
Variety		NS	NS	NS	NS
Irrigation x variety		0.001	NS	NS	NS
$LSD_{0.05}$					
Irrigation		0.28	19.8	7.0	7
Variety		-	-	NS	NS
Irrigation x variety		0.39	-	-	-

Table 12. Cost and return of Aman rice at Dacope and Amtali during 2021.

Item	Costs and returns (BDT/ha)	
	Dacope	Amtali
Total paid-out cost (VC) (cost of inputs including fertilizer, pesticides, irrigation, herbicides and hired labour)	52,700	51,968
Total imputed cost (opportunity cost of land and family labour and interest on operating capital)	32,267	33,688
Total cost (TC)	84,967	85,656
Mean grain yield (t/ha):	4.61	4.80
Market value of grain (BDT/ha)	92200	96000
Market value of straw (BDT/ha)	4,550	4,550
Gross benefit (BDT/ha)	96,750	100,550
Gross income (BDT/ha)	44,050	48,582
Net income (BDT/ha)	11,783	14,894
Benefit over cost (full cost basis)	1.14	1.17

Farm gate price of paddy is BDT 20.00/kg

Table 13. Cost and returns from vegetables with T. Aman rice at Dacope, Khulna during 2021.

Sl. #	Gross return (Tk ha^{-1})				Total variable cost (Tk ha^{-1})			
	Vegetable	Integrated rice	Total (Rice with vegetable)	Sole rice	Vegetable	Integrated rice	Total (Rice with vegetable)	Sole rice
F1	240340	96696	337036	102900	108051	84779	192830	86779
F2	233020	96300	329320	101380	114899	83779	198678	85779
F3	154770	94360	249130	100564	175386	85779	261165	87779
F4	257448	96372	353820	102820	102287	83527	185814	85527

F5	210016	98584	308600	104820	103787	85027	187314	87027
Mean	**219119**	**96462**	**315581**	**102497**	**120882**	**84578**	**205160**	**86578**

F1= Okhil Halder, F2= Pobitra Mistre F3= Md. Sain gazi, F4= Gofinat Boiragi, F5= Refatul Gazi

Table 14. Cost and return of Boro rice at Dacope and Amtali during 2021-22.

Item	Costs and returns (BDT/ha)				
	Dacope	Amtali	Kalapara	Taltali	Batiaghata
Total variable cost (Cost of inputs including fertilizer, pesticides, irrigation, herbicides and hired labour)	69,224	70,214	70,654	71,555	72,111
Total imputed/ fixed cost (Land rent, family labour and interest on operating capital)	41,067	40,657	40,107	42,203	41,067
Total cost	110,291	110,871	110,761	113,758	113,178
Grain yield (t/ha)	5.62	5.25	5.74	6.02	5.81
Selling price (BDT/t)	25,000	25000	25,000	25,000	25,000
Market value of grain (BDT/ha)	140,500	131,250	143,500	150,500	145,250
Market value of straw (BDT/ha)	26,480	25,000	26,960	28,080	27,240
Gross income (BDT/ha)	166,980	156,250	170,460	178,580	172,490
Gross margin (BDT/ha)	97,756	86,036	99,806	107,025	100,379
Net return (BDT/ha)	56,689	45,379	59,699	64,822	59,312
Benefit over cost (full cost basis)	1.51	1.41	1.54	1.57	1.52

Table 15. Region-wise pumping lifts of different irrigation devices and water use for *Boro* rice production in Bangladesh.

Region/Division	Pumping lifts (m)*			Water use (m^3 ha^{-1})
	DTW	STW	LLP	
Rangpur	10.75-16.47	5.57-7.60	5.50-5.70	7236 - 7835
Rajshahi	14.39-40.08	7.68-8.00	4.50-5.50	6835 - 7636
Khulna	8.50-18.00	4.57-8.00	4.57-5.50	6237 - 7637
Mymensingh	14.80-25.50	7.90-8.00	4.40-5.50	6037 - 7337
Dhaka	10.20-20.40	5.07-8.00	5.07-5.66	6236 - 7737
Barishal	3.50-8.50	3.83-5.00	2.62-4.25	6235 - 7236
Sylhet	8.50-15.05	5.73-7.91	5.50-5.89	6136 - 5636
Chattogram	8.50-20.10	3.94-7.80	3.94-5.91	6235 - 7537

* Considering all agricultural use and excluding all city areas.

Table 16. Region-wise total GHG emission (Kt CO_2-e) of different irrigation devices in Bangladesh.

Region/Division	Ground water			LLP/SW	Total GHG
	DTW	STW	Total		
Rangpur	257.35	255.48	512.83	4.93	517.76
Rajshahi	768.14	228.53	996.68	17.00	1013.68
Khulna	75.02	188.87	263.88	26.67	290.55
Mymensingh	293.70	115.10	408.80	23.63	432.43
Dhaka	91.19	129.57	220.76	47.48	268.24
Barishal	NA	0.04	0.04	28.12	28.16
Sylhet	6.59	21.16	27.75	45.23	72.98
Chattogram	74.24	59.32	133.56	65.77	199.33
Bangladesh	**1566.23**	**998.07**	**2564.30**	**258.82**	**2823.12**

NA = Data not available

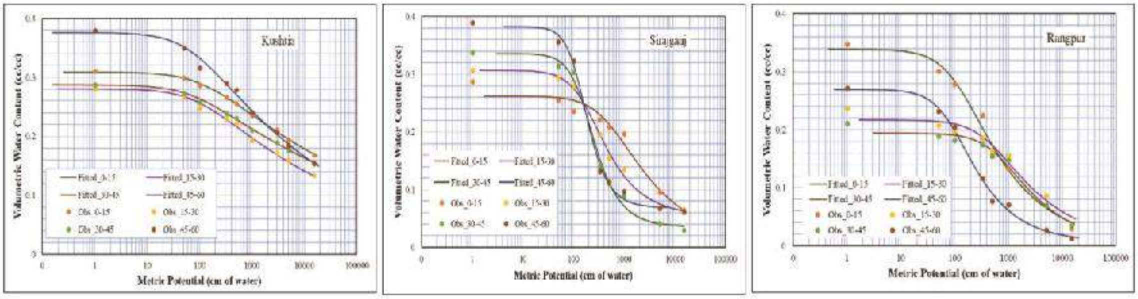


Fig. 1. Fitted soil water release curves at different depths of soil profile for Kushtia, Sirajganj and Rangpur.

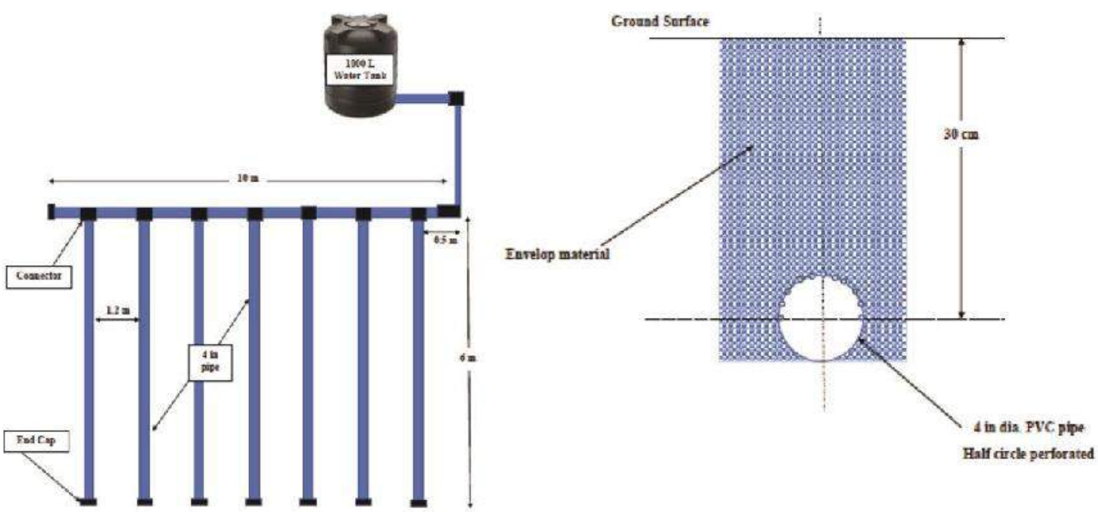


Fig. 2. Subirrigation system detail design.

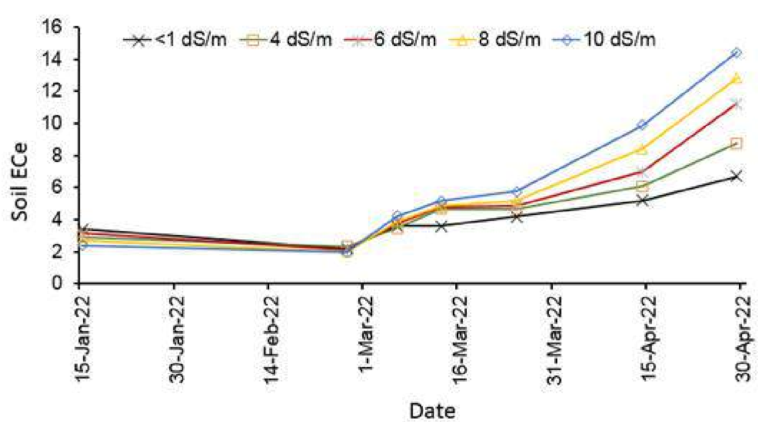
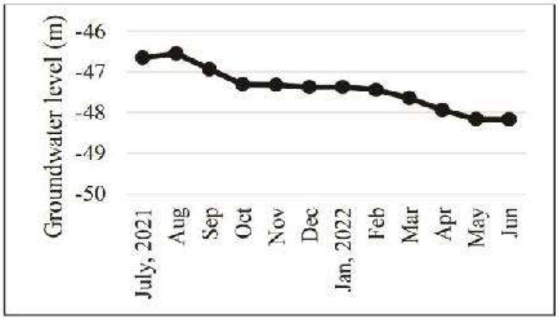


Fig. 3. Soil salinity dynamics at 0-10 cm soil depth with saline water irrigation during the growing season of Boro rice in Dacope, Khulna in 2021-22.



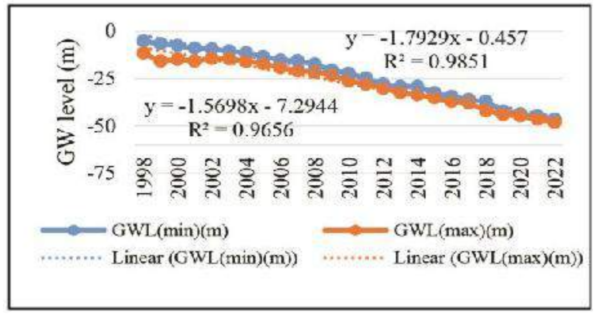


Fig. 4. GW fluctuation (2021-22) at BRRI HQ farm Gazipur.

Fig. 5. Long-term GW declination (1998-2022) at BRRI HQ farm, Gazipur.

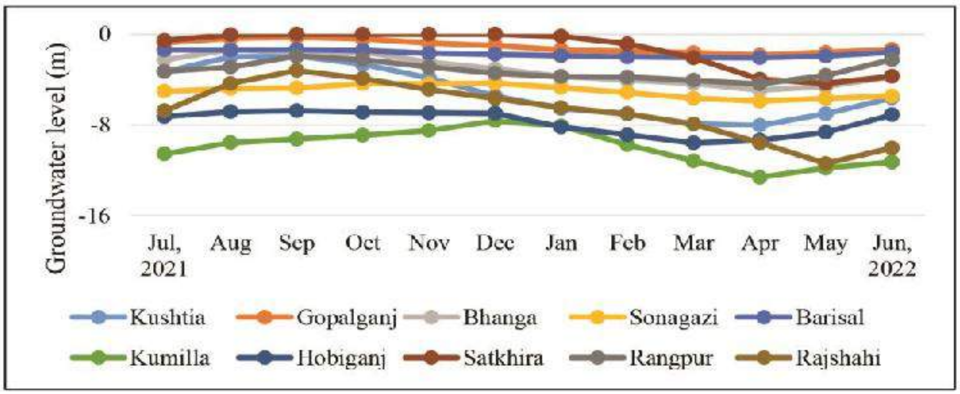


Fig. 6. Yearly GW level fluctuation at different BRRI RS during 2021-22.

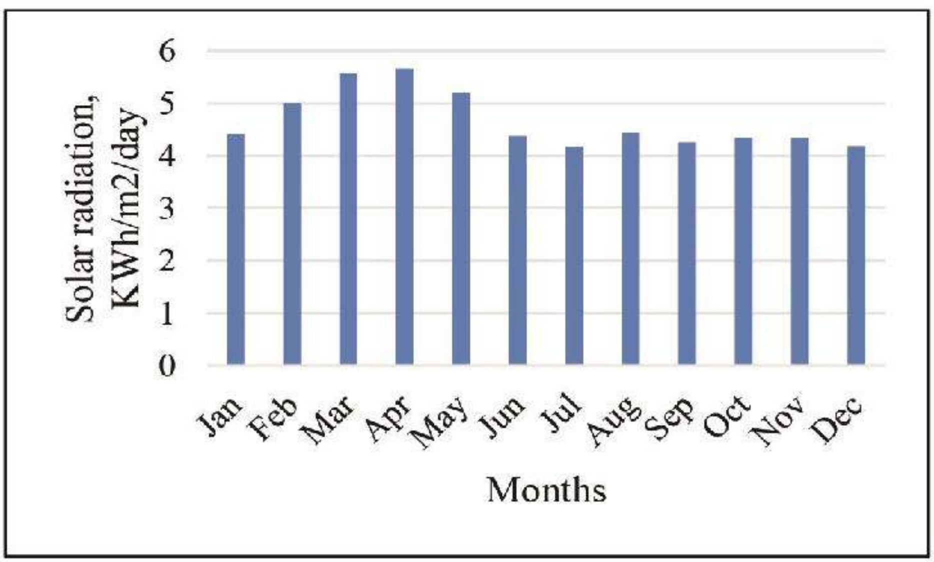


Fig. 7. Monthly solar radiation distribution in Chattogram region.

Village-Khushipur, Union-Joylaskar, Upazilla-Dagon bhuiyan, District-Feni

Village-Hapania, Union-3 no Narayanhat, Upazilla-Fotikchhori, District-Chattogram

Village-North Durgapur, Union-8 no Durgapur, Upazilla-Mirershorai, District-Chattogram

Fig.8. Some selected locations of solar pumps in Chattogram region.

Fig. 9. Off-season watermelon with T. Aman rice at Dacope, Khulna, 2021.

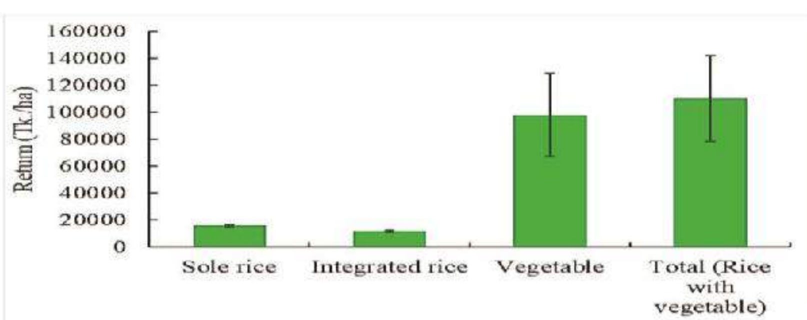


Fig. 10. Gross margin of sole rice and integrated rice-vegetables at Dacope, Khulna during 202.

Fig. 11. Trapped fresh water by earthen embankment, Dacope, Khulna, Rab, 2021-22.

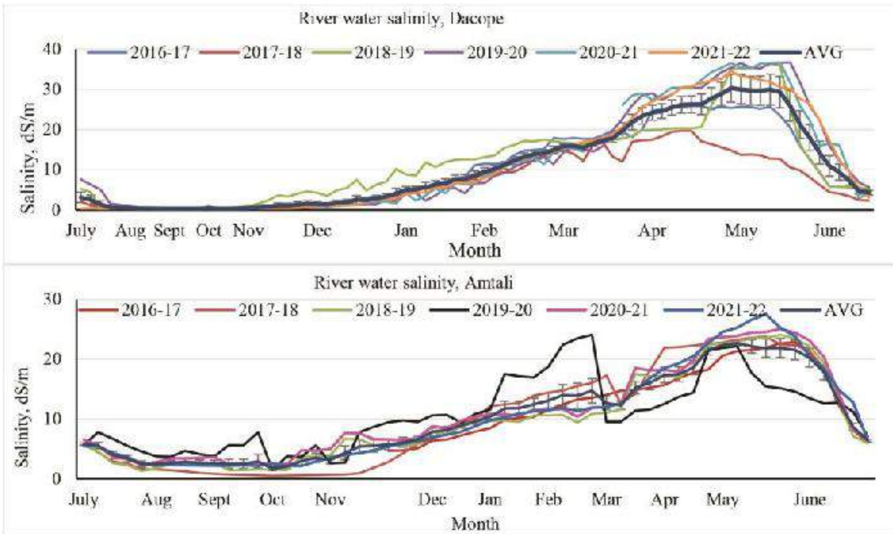


Fig. 12. River water salinity at Dacope and Amtali during 2016-22

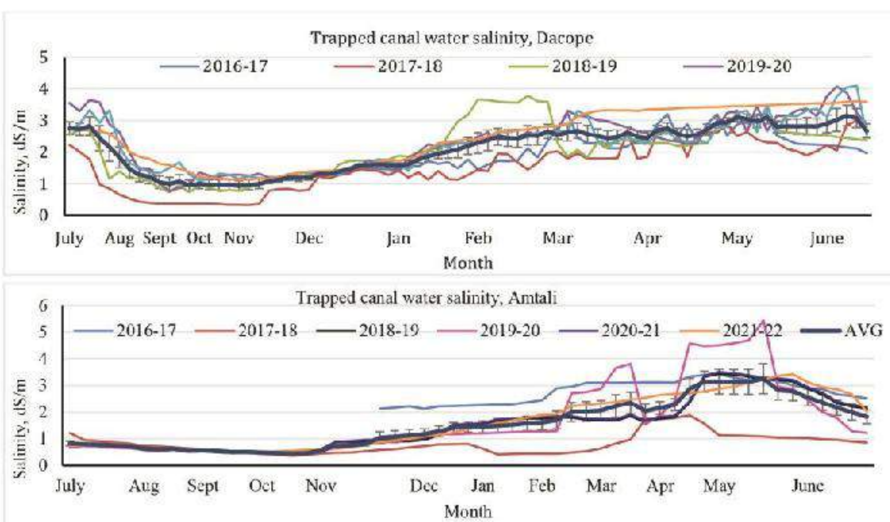


Fig. 13. Trapped canal water salinity at Dacope and Amtali during 2016-22.

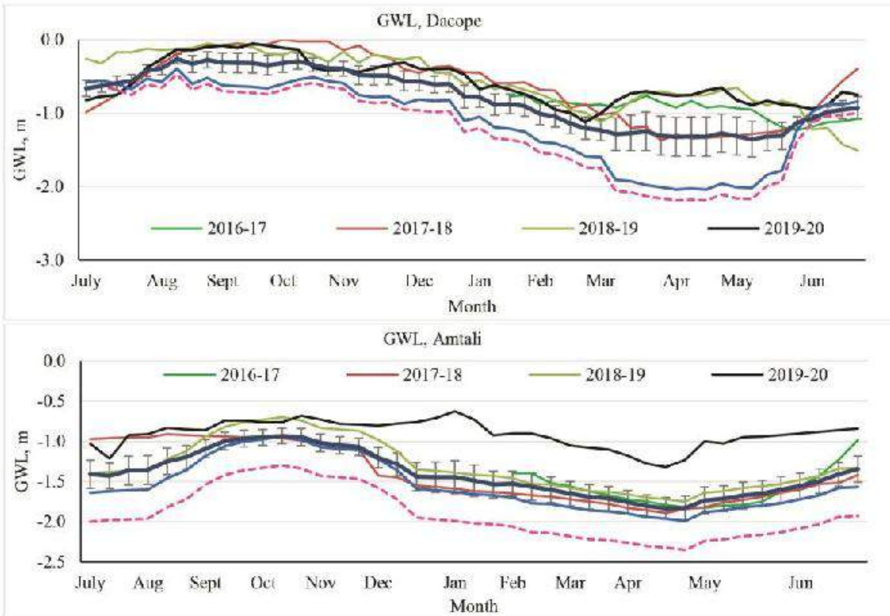


Fig. 14. Groundwater level at Dacope and Amtali during 2016-22.

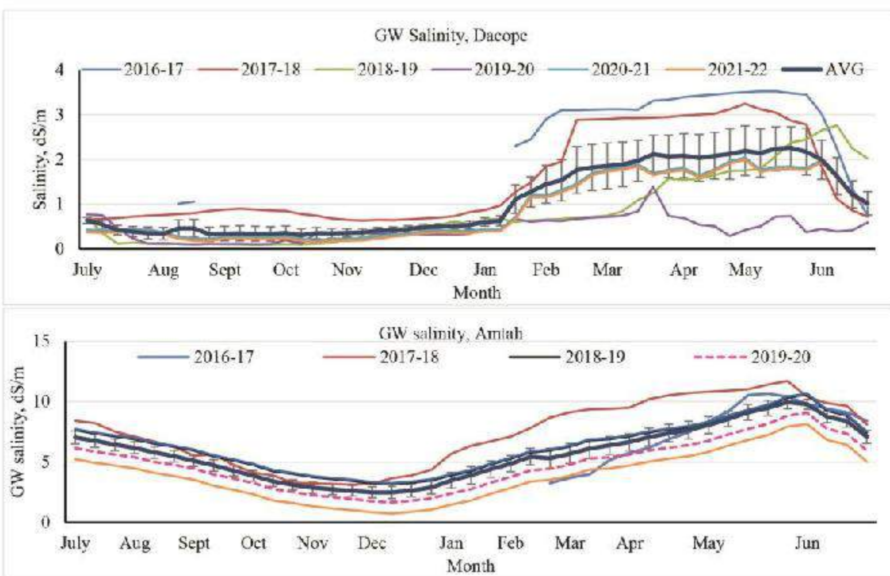


Fig. 15. Groundwater salinity at Dacope and Amtali during 2016-22.

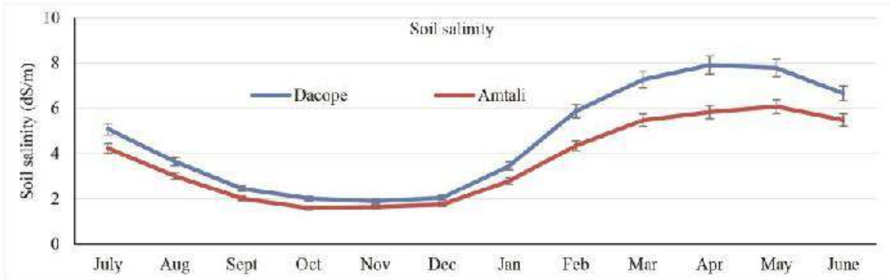


Fig. 16. The average year round soil salinity in Dacope and Amtali areas, 2016-22.

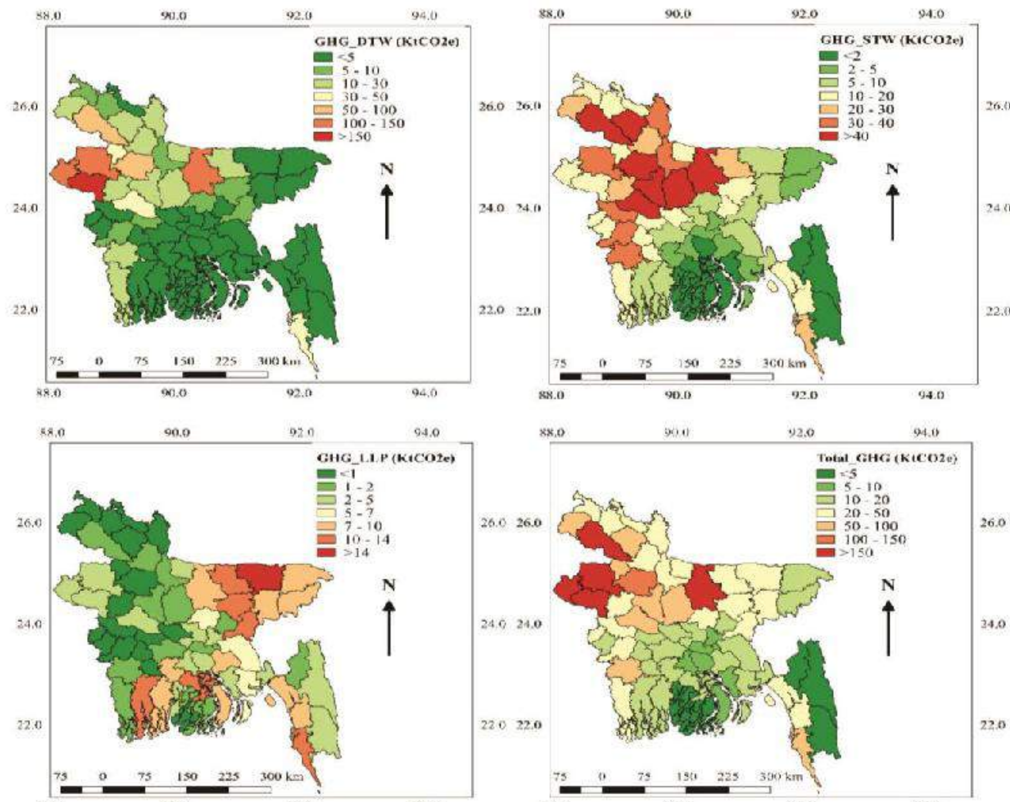


Fig. 17. GHG emission from different irrigation devices and water sources.

Plant Physiology Division

SUMMARY

A total of 31 experiments under seven different projects have been carried out during 2021-22 in Plant Physiology Division of BRRI. In salinity stress, around 400 germplasm and 300 advanced breeding lines were characterized of which 39 genotypes were found tolerant to moderately tolerant at seedling stage. Salinity resistance at reproductive stage, BRRI dhan47 and BRRI dhan99 showed the lowest reduction (6-48% and 22-48% respectively) in grain per panicle followed by BRRI dhan97 (11-56%) under different salinity stress. The yield reduction of tolerant and susceptible check was 27-35% and 35-61% respectively. At 8 dS/m salinity level, the highest yield reduction was observed in PN191 (~59%) followed by CN6 (~52%) and the lowest in BRRI dhan67 (~3%). Increasing salinity level to 10 dS/m, yield reduction ranged from ~51 to ~78% for all the tested lines excluding BRRI dhan67 which was ~42%. Days to heading were also earlier for PN151, BRRI dhan67 and IR58443-6B-10-3 than the other tested genotypes at all salinity levels. For improving salinity tolerance of rice through CRISPR/cas9 system, guide sequence of *OsRR22* gene was properly cloned into the binary vector pC1300-Cas9. Plants were regenerated through *Agrobacterium*-mediated transformation. Genomic DNA was extracted from the leaves of transformed plants using the sodium dodecyl sulfate (SDS) method. Hygromycin phosphotransferase positive plants were identified using HPT primer pair designed from Hygromycin phosphotransferase resistant zone of the Cas9 vector. Some 114 germplasm and 13 advanced breeding lines were screened for two weeks of complete submergence where one germplasm (Acc. no. 1710***)*** were found moderately tolerant. Elongation ability of BRRI dhan91 was evaluated under deep flooding condition. The plant height of the tested varieties ranged from 104.06 cm in BRRI dhan52 to 242.22 cm in Hbj AII and tillering ability ranged from 2.5/hill in Higol digha to 7/hill in Lal digha under 1.5 m deep water condition. The plant height of the attempted variety BRRI dha n91 was found 161.87 cm with poor tillering ability (3.3/hill). In drought tolerance, 343 germplasm and four advanced breeding lines were tested of which 46 germplasms were selected for further evaluation and seven germplasms were selected for donor parent. Two advanced breeding lines BR10540-4-1-2-4-1 and BR10538-2-1-2-3-2 were performed better which were selected for ALART. Selection of new high temperature tolerant breeding lines, an experiment having eight spikelet fertility QTL introgression lines were evaluated with high temperature (35±3 ^{0}C) and high humidity (75±5%) condition during flowering. Out of eight lines, four lines scored 5 and classified as moderately heat tolerant. The rest four lines scored 7 and classified as moderately sensitive to heat stress. Two tolerant donor, N22 and Kachalath scored 3 and 5 respectively. High temperature induced spikelet fertility QTL introgression advanced lines in the background of BRRI dhan28 was tested for observation yield evaluation. A total of 81+52 = 133 lines of BRRI dhan28 and BRRI dhan29 were evaluated in the field condition along with parents for yield potential. Out of the 133 lines, 4 and 21 lines in the background of BRRI dhan28 and BRRI dhan29 respectively, having >0.5 t/ha yield advantage were selected for further evaluation. A marker-assisted introgression of high temperature induced spikelet fertility QTL (qHTSF4.1) for the T. Aus and T. Aman seasons was carried out for BRRI dhan48, BRRI dhan62 and BRRI dhan71 respectively. A total of 60 BC_1F_1 of BRRI dhan48, BRRI dhan62 and BRRI dhan71were planted and after genotyping with R4M30 markers the selected progenies were backcrossed with respective parents and 110 BC_2F_1 seeds were produced. Some 250 rice germplasms and 1,411 advanced breeding lines were screened for seedling stage cold tolerance of which 65 germplasm and 269 advanced breeding lines were selected as moderately cold tolerant at seedling stage. Some 28 advanced breeding lines were characterized in natural field condition where BR11894-R-329 and BR10717-5R-82 was found as moderately cold tolerant at reproductive phase. Three advanced breeding lines (BR8781-16-1-3-P2, BR9829-78-1-2 and BR9830-5-2-2-3) along with two check varieties namely BRRI dhan27 and BRRI dhan48 were evaluated for lodging tolerance.

Advanced breeding lines BR8781-16-1-3-P2 showed lodging tolerance due to their shorter 4^{th} internode length, better wrapping score and higher stem density (51.17 mg/ cm), although they had longer plant height (126.81 cm) and higher moment (1321.67 g.cm). The lodging characters of five BRRI varieties viz. BRRI dhan49, BRRI dhan87, BRRI dhan93, BRRI dhan94 and BRRI dhan95 along with lodging tolerant check variety BR11 were determined. Stem thickness of tested varieties was similar to the check variet BR11. Flag leaf angle was 2-4 degree more in tested varieties than BR11 except BRRI dhan95 which had it 2 degree less. Total wrapping score of BRRI dhan95 was similar to BR11 but other varieties had less score. Panicle weight of tested varieties was 0.16 to 0.2 g higher than check variety BR11 except BRRI dhan95 which had 0.24 g less. Less panicle weight and well wrapped stem of BRRI dhan95 might be the main reason of its lodging tolerance. Five different types of polythene covering on Boro rice seedbed along with control were evaluated. The highest seedling strength was recorded from seedbed having polythene covering during cold wave followed by covering for all the time with opening at both ends and covering for whole night. The lowest seedling mortality rate after transplanting in the main field was recorded from covering during cold wave which was statistically similar to the control. Seedling mortality after transplanting was comparable between covering for all the time with opening at both ends, covering for whole night and covering from 11.0 am to sun set although it was slightly higher than control the treatment. Polythene covering for all time at seedbed had lower seedling strength but higher seedling mortality. Some 246 advanced breeding lines along with Nazirsail, BR22 and BR11 as check varieties were tested to measure the level of photosensitivity at net house of Plant Physiology Division. Two breeding lines (BR11032-4R-31 and BR11046-4R-95) showed strong response in flowering with an increase in photoperiod similar to BR22. On the other hand one local deep-water genotype (Khoiamotor) and one shallow-deep water line (BR10230-7-19-B) showed fairly strong sensitive having RPS (~80%). On the basis of germination percentage BRRI dhan50, BRRI dhan60, BRRI dhan69, BRRI dhan86 and BRRI dhan89 was found highly susceptible to pre-harvest sprouting and BR19, BR16, BRRI dhan63, BRRI dhan45, BRRI dhan36, BR27, BRRI dhan55, BRRI dhan48, BRRI dhan88, BRRI dhan82, BRRI dhan67, BRRI dhan84, BRRI dhan42 and BRRI dhan28 found moderately tolerant to pre-harvest sprouting which had less than 5% pre-harvest sprouting spikelet. Investigation of anatomical differences in the leaves, in comparison to rice, Uri dhan has a greater number of veins and a denser vascular bundle. The mesophyll cells and vascular bundle in the Uri dhan were both well-organized and highly composed compared to rice. The chlorophyll fluorescence-based imaging to characterize the salinity tolerance of rice at seedling stage, IR58443 (standard tolerant check) and IRRI154 (standard sensitive check) were evaluated under soil-based salinity stress for 0, 6 and 12 dS/m stress. Chlorophyll fluorescence image was taken 24 (Day 1), 48 (Day 2) and 72 hrs. (Day 3) after stress application. Initial Fv/Fm values (Day1) were noticeably low, but they progressively increased and were kept very near to normal for the tolerant genotype (IR58443), whereas the pattern was exactly the opposite for the sensitive genotype (IRRI154). For developing male sterile line through CRISPR/cas9 system, guide sequence of TMS5 gene was properly cloned into the binary vector pC1300-Cas9. Plants were regenerated through Agrobacterium-mediated transformation. Genomic DNA was extracted from the leaves of transformed plants using the sodium dodecyl sulfate (SDS) method. Hygromycin phosphotransferase positive plants were identified using HPT primer pair designed from Hygromycin phosphotransferase resistant zone of the Cas9 vector.

SALINITY TOLERANCE

Screening of rice germplasm for salinity tolerance

About 400 rice germplasm along with tolerant check IR58443 and susceptible check IR154 were screened to find out saline tolerant germpaslm at seedling stage at 12 dS/m. Among them only 20 germplasm (namely Genebank Acc. No. 3291, 3141, 3142, 3155, 3157, 3163, 3195, 3196, 3197, 3201, 3204, 3218, 3306, 3346, 3347, 3393, 3397, 3406, 3431 and 3603) were found moderately saline tolerant with SES score 3. The SES score of tolerant and susceptible check was 3 and 9 respectively.

Screening of rice advanced breeding lines for salinity tolerance at Aman 2021

About 100 rice advanced breeding lines along with tolerant check IR58443 and susceptible check IR154 were screened for salinity tolerant at 12dS/m at seedling stage. Among the breeding lines nine genotypes (namely SV1154, SV1155, SV0525, SV0529, SV1176, MTU1010, IR93354:34-B-5-1-23-1RGA-2RGA, M202 and Sahel134) were found moderately tolerant to salinity with SES score 3. The SES score of tolerant and susceptible check was 3 and 9 respectively.

Screening of rice advanced breeding lines for salinity tolerance at Boro 2021-22

About 200 rice advanced breeding lines were screened for salinity tolerance at 12dS/m at seedling stage where tolerant and susceptible check was IR58443 and IR154 respectively. Standard susceptible and tolerant check was used as BRRI dhan89 and BRRI dhan67, BRRI dhan97 respectively. Among the breeding lines 10 genotypes (namely BR11712-4R-333, BR11722-4R-73, BR11722-4R-398, TP24493, IR18T1073, IR15T1319, BR11714-4R-69, BR11714-4R-74, IR 108604-2-1-AJY 3-B-1 and IR16T1661) were found moderately tolerant to salinity with SES score 3. The SES score of tolerant and susceptible check was 3 and 9 respectively and all the standard check had SES score 7.

Characterization of salt tolerant varieties in artificial saline condition for whole growth period during Aman season

An experiment was conducted to know the of salinity tolerance level of newly released saline tolerant BRRI varieties. BRRI dhan47, BRRI dhan67, BRRI dhan97 and BRRI dhan99 was used as saline tolerant variety where IR58443 and IR154 used as tolerant and susceptible check. Soil-based methods described by Gregorio et al. (1997) were followed. Salinity label was maintained as 0, 3, 6, 9 and 12 dS/m. Here it is observed that, BRRI dhan47 and BRRI dhan99 Showed the lowest reduction (6-48% and 22-48% respectively) in grain per panicle followed by BRRI dhan97 (11-56%) under different salinity stresses. The yield reduction of tolerant and susceptible check was 27-35% and 35-61% respectively **(Fig. 1).**

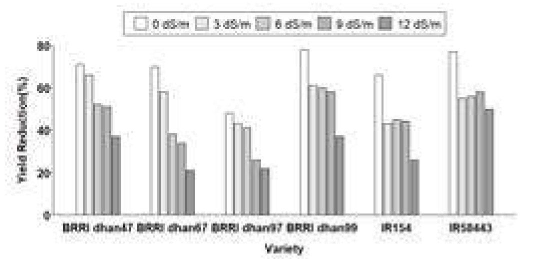


Fig. 1 Percent yield reduction under different levels of salinity stress.

Characterization of advanced breeding lines for salinity tolerance at reproductive stage

The experiment was conducted to evaluate the performance of one PVT and three advanced breeding lines at different salinity levels in the net house condition during Boro 2021-22. Plants were grown in the perforated plastic pots (drilled and lined with canvas) filled with grinded soil. The soil was fertilized with NPKS @ 100, 25, 40 and 25 mg/kg soil. The pots were placed inside a bucket serving as water bath. Three to four pre-germinated seeds were sown at the soil surface of each pot. Seedlings were thinned to two plants per pot two weeks after sowing. Salt stress was applied 50 days after sowing; stress was made by adding NaCl in the bucket at 6, 8 and 10 dS/m. One set of plants were used as control. The experiment was laid out in RCB design with three replications. Different morphological and yield related traits were measured to evaluate the tested genotypes. In this study, genotypes × salinity interaction showed significant results for all the tested parameters except total dry matter per plant. Yield potentiality is the most important indicator for selecting a genotype as future tolerant variety at stress condition. Yield of tested genotypes was decreased gradually with the increasing level of salinity. But with the increase of salinity to 8 dS/m, genotypes BRRI dhan67 produced the highest yield followed by PN232. Increasing salinity level to 10 dS/m, genotypes BRRI dhan67, PN151, PN232 and IR58443 performed better than the other genotypes (**Fig. 2**). All the tested genotypes and checks had shown increasing trends of yield reduction with increasing salinity level (**Fig. 3**). But the reduction was very minimum which was below 50% for all the tested genotypes upto 6 dS/m salinity stress. At 8 dS/m salinity level the highest reduction was observed in PN191 (~59%) followed by CN6 (~52%) and the lowest in BRRI dhan67 (~3%). Increasing salinity level to 10 dS/m, yield reduction ranged from ~51 to ~78% for all the tested lines excluding BRRI dhan67 which was ~42% (**Fig. 3**). Growth duration is another criterion for selecting a variety at salt stressed condition. Days to heading were also earlier for PN151, BRRI dhan67 and IR58443-6B-10-3 than the other tested genotypes at all salinity levels (**Fig. 4**).

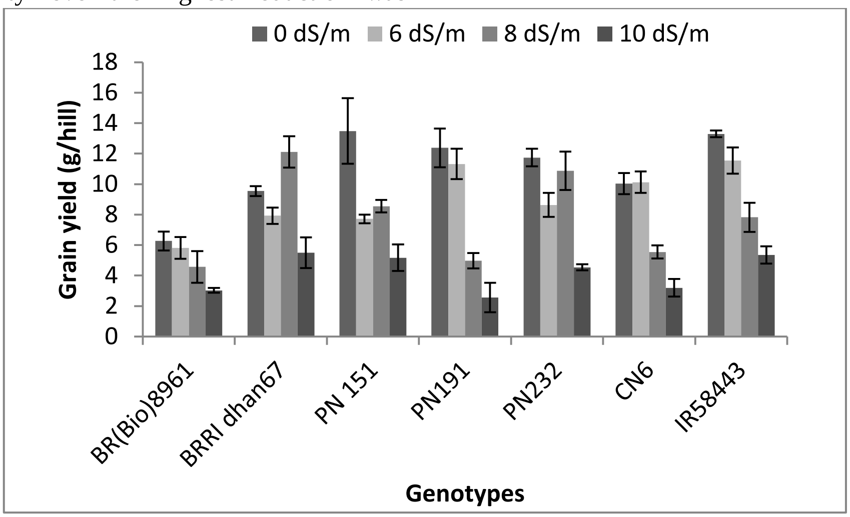


Fig. 2 Yield potential of tested genotypes in varying salinity level. Error bar represents ±SE.

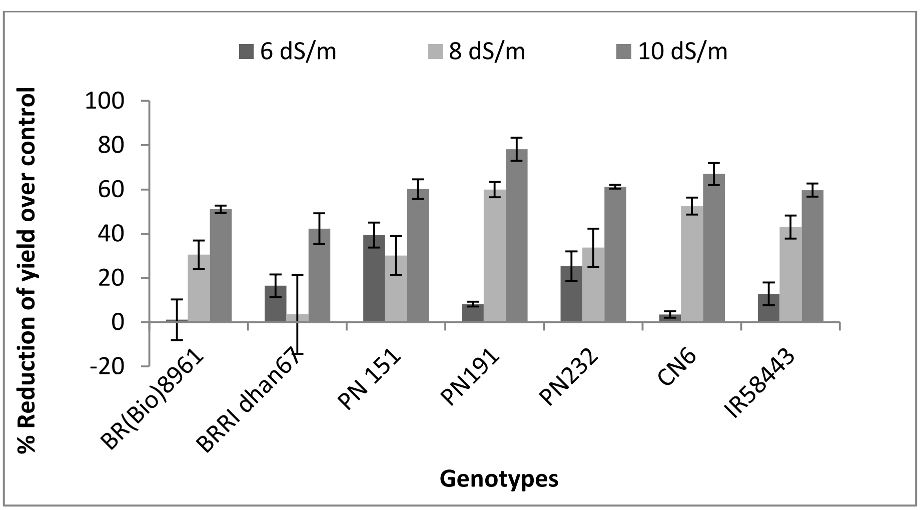


Fig. 3 Reduction of yield over control (%) among the tested genotypes at saline condition. Error bar represents ±SE.

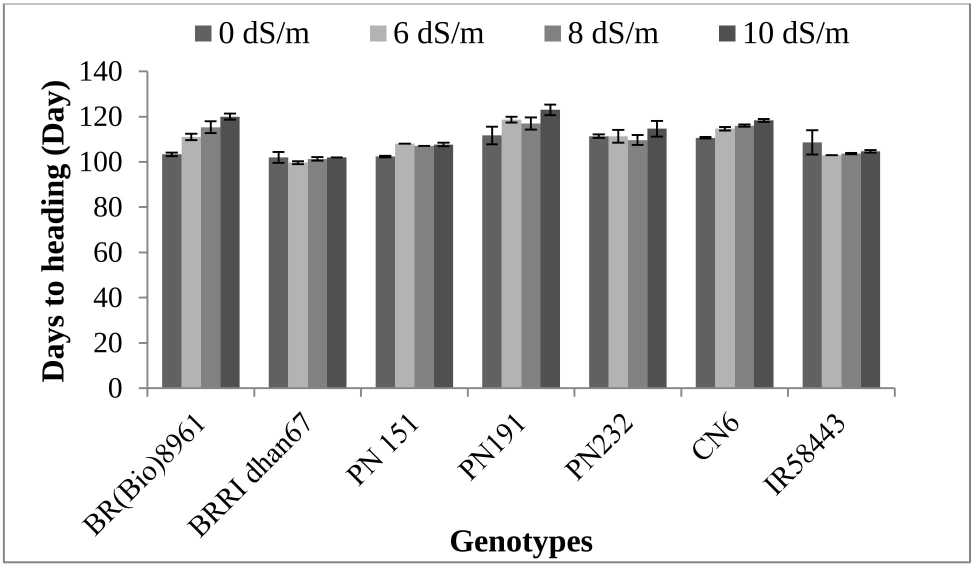


Fig. 4 Days to heading of tested lines and checks in varying salinity levels. Error bar represents ±SE.

CRISPR-Cas9 mutagenesis of the *OsRR22* gene for improving salinity tolerance of rice

Salinity is one of the most important abiotic stress affecting the world rice production. Numerous salt tolerance quantitative trait loci were identified and few of them had been transferred into popular rice varieties via marker-assisted selection (MAS) but none of them showed greater promise. The *OsRR22* gene encodes a 696–amino acid B-type response regulator transcription factor that is involved in both cytokinin signal transduction and metabolism; its loss of function has been reported to significantly increase salt tolerance. To design a CRISPR/Cas9 targeting the *OsRR22* gene in rice, a 19bp guide sequence (5′-AGAGGGATCAATTCCCCGT-3′) was a protospacer adjacent motif lying within the *OsRR22* coding sequence (*LOC_Os06g08440*). The guide sequence was properly cloned into the binary vector pC1300-Cas9 (**Fig. 5**). The binary vector pC1300-Cas9 harboring Cas9/*OsRR22* sgRNA was mobilized into *Agrobacterium tumefaciens* LBA4404 by freeze-thaw method and confirmed through PCR-gel electrophoresis (**Fig. 6**). Plants were regenerated through *Agrobacterium*-mediated transformation. Genomic DNA was extracted from the leaves of transformed plants using the sodium dodecyl sulfate (SDS) method. Hygromycin phosphotransferase positive plants were identified using HPT primer pair designed from Hygromycin phosphotransferase resistant zone of the Cas9 vector (**Fig. 7**). PCRs amplifications are being performed using primer pairs, which generated an amplicon harboring the target site, and the resulting amplicons are being sequenced using the Sanger method.

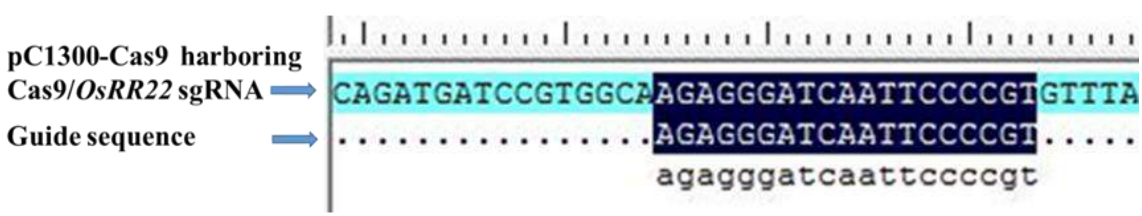


Fig. 5 Confirmation of vector constructs alignment by of recombinant pC1300-Cas9 harboring Cas9/*OsRR22* sgRNA with guide sequence.

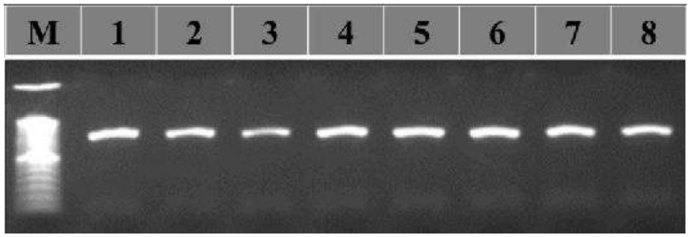


Fig. 6 Confirmation of *Agrobacterium* transformation through PCR-gel electrophoresis. *Agrobacterium tumefaciens* LBA4404 with recombinant pC1300-Cas9 harboring Cas9/*OsRR22 sgRNA* **(Lane 1-8)**. **M**: marker (50 bp DNA ladder).

Fig. 7 Hygromycin phosphotransferase positive plants for salinity tolerance.

SUBMERGENCE TOLERANCE

Identification of rice germplasm and advanced breeding line for two weeks flash flood submergence tolerance

A total of 114 local germplasm, 13 advanced breeding lines were tested along with tolerant checks (FR13A and BRRI dhan79) and sensitive checks (IR42 and BR5) to identify the tolerant germlasm for two weeks under complete submerged condition at the vegetative phase. Eighteen seedlings (6 hills x 3 rows) with 20 cm x 20 cm spacing of 20 day-old for each germplasm were transplanted in a concrete submergence tank. Two weeks after transplanting plants were submerged completely at 1 meter water level and kept submerged condition for 14 days. During submergence period the water of the tank was made turbid twice daily, and the water pH, temperature, dissolved O_2 and turbidity were measured. After 21 days of drain out of water, recovery or survivability score was taken. Survival scoring was done by following standard evaluation system (SES) (IRRI, 2014). The results showed that most of the germplasms were elongating type i.e. plant height exceeds the 1m water level during submerged condition and survivability was very poor. Out of 114 germplasm only one germplasm (Acc. 1710) was found tolerant (SES score 1) having survivability 100 percent but elongating type. The rest of the germplasms were found less tolerant (SES score 9) having survivability 0-38.9 percent with elongating type. Survivability of the tolerant check varieties FR13A and BRRI dhan79 had 100% and 84.9%, respectively whereas susceptible check varieties survived 0%. The average water pH, temperature and dissolved O_2 of the submergence tank were 8.01, 30.48 ℃ and 12.08 mg/L, respectively. The average turbidity of the water tank was 68.15 and 136.95 FNU (Formazin Nephelometric Units) before and after made turbid, respectively during submergence.

Screening of advanced breeding lines for Anaerobic tillering ability under water stagnant condition at T. Aman season

A total of 220 advanced breeding lines along with two BRRI varieties BR10 and BRRI dhan30 were tested to observe the anaerobic tillering ability of the advanced breeding lines under water stagnant conditions. Six seedlings (6 hills x 1 row) with 20 cm x 20 cm spacing of 20 day-old for each line were transplanted in a concrete tank. The water pressure @ 5 cm/week was started from seven days after transplanting and was continued up to 60 cm. The stagnant water was maintained up to maturity. The experiment was conducted to observe the anaerobic tillering ability under medium stagnant (60 cm water pressure) conditions. The plant height, tiller number/hill and survivability were found to ranges from 88-158 cm, 2-8 tillers/hill and 50-100% respectively. Out of 220 advanced breeding lines, 44 lines produced higher tiller/hill (>5) compared to the check varieties BR10 and BRRI dhan30 under water stagnant conditions. Among the 44 higher tiller producing lines, BR11921-4R-356, BR11925-4R-162 and BR11920-4R-521 produced the highest number of tiller/hill under water stagnant conditions. Further validation could be done to confirm the above mentioned lines for anaerobic tillering ability with other agronomic and phenotypic characters.

Evaluation for elongation ability of BRRI dhan91 under deep flooding condition

An experiment was conducted to see the elongation ability of BRRI dhan91 under deep flooding condition. BRRI dhan91 along with FR13A, BRRI dhan79, BRRI dhan51, BRRI dhan52, BR5, BR10260-7-19, Lal khama, Lal digha, Hbj AII, Higol digha, Laxmi digha, Hbj AIV, Hbj AVIII and Koiamotor were tested in this study. Twenty-day-old seedlings were transplanted and two weeks after transplanting water level was increased @ 2 cm per day and stopped when the water level was up to 1.5 m. Data on plant height and tillering was recorded after reaching the water level 1.5 m. The plant height of the tested varieties ranged from 104.1 cm in BRRI dhan52 to 242.2 cm in Hbj AII and tillering ability ranged from 2.5/hill in Higol digha to 7/hill in Lal digha under 1.5 m deep water condition. The plant height of the attempted variety BRRI dhan91 was found 161.9 cm with poor tillering ability (3.3/hill).

DROUGHT TOLERANCE

Screening of rice germplasm for drought tolerance at reproductive phase, T. Aman 2021

Three hundred rice germplasm collected from BRRI genebank along with the check varieties BRRI dhan56, BRRI dhan71 and IR64 were tested during T. Aman season 2021 at farmer's field in Alimganj, Paba, Rajshahi following Field-managed screening protocol (IRRI, 2008). Thirty-day-old seedlings were transplanted at a spacing of 20 cm x 20 cm. The experiment was laid out in Alpha lattice design with two replications. Standard agronomic management practices were followed. Irrigation was withheld four weeks after transplanting and the field drained out properly for not allowing any standing water until maturity. Out of 300 germplasm, 46 genotypes showed better performance in relation to yield under rainfed condition at reproductive phase, which were selected for further confirmation under control condition in rainout shelter.

Confirmation of performance for advanced breeding lines under control drought condition at reproductive phase

Four advanced breeding lines along with the check varieties BRRI dhan56, BRRI dhan71 and IR64 were evaluated in Plant Physiology net house shaded by polythene sheet at BRRI HQ, Gazipur during T. Aman season 2021. Twenty-five-day-old seedlings were transplanted in drum (56 cm x 43 cm) containing 110 kg puddled soil in two sets where the 1st set was grown in well-watered conditions and 2nd set under stress condition. At panicle initiation stage water was drained out from the 2nd set so that the plants experiences drought stress from the reduction division stage. The water table depth and soil moisture was recorded. At severe drought stress some life saving water was applied and calculated as follows: = $\Pi r^2 h$

Where, r = 56/2 = 28 cm (The radius of the circumference of pot at the base of the hill.)

h = 0.5 cm/day (the approximate evapotranspiration at the period of November December.

Out of four advanced breeding lines BR10540-4-1-2-4-1 performed better followed by BR10538-2-1-2-3-2 (**Table 1**).

Table 1 Grain yield, Filled grain no. and % sterility of four tested genotypes as affected by water stress at reproductive phase.

Designation	Grain yield (g/plant)			Filled grain no./plant		%Sterility	
	Control	Stress	% Reduction	Control	Stress	Control	Stress
BR10538-2-1-2-3-2	39.00	19.87	49.1	1802	1080	27.1	39.5
BR10539-8-1-3-2-2	34.40	10.39	69.8	1579	613	29.7	62.9
BR10539-43-1-1-1-1	30.86	11.29	63.4	1412	656	38.8	67.9
BR10540-4-1-2-4-1	45.94	25.78	43.9	2068	1342	27.4	30.6
BRRI dhan56	35.78	21.7	39.4	1619	1234	24.5	32.9
BRRI dhan71	43.25	25.09	42.0	1878	1270	25.9	28.4
IR64	33.67	10.23	69.6	1475	512	29.4	65.8
LSD (5%)	7.9		-	390.5		9.5	
CV (%)	20.0		-	20.7		17.5	

Evaluation of previously selected germplasm under drought stress at reproductive phase in the rain-out shelter

This experiment was conducted in the rain-out shelter, Plant Physiology Division at BRRI HQ, Gazipur during T. Aman season, 2021 to evaluate previously selected 43 germplasm with the check varieties BRRI dhan71 and IR64. Thirty-day-old seedlings were transplanted in puddled soil at a spacing of 20 cm x 20 cm. Standard agronomic management practices were followed. Weeds were controlled when needed. Four weeks after transplanting, the plots were drained out for inducing drought stress at reproductive phase. The water table depth was below 1 m and soil moisture was around 20%. Under control drought condition in the rainout shelter, out of 43 germplasm BRRI Genebank Acc. no. 1934 yielded the highest followed by Acc. no. 1996, 2022, 2288, 2290, 2292 and 2420. The sterility percentage of these genotypes was less than 50 (**Table 2**).

Table 2 Observed growth characteristics, yield and yield components of tested 43 genotypes.

BRRI Gene bank Acc. no.	Filled grain no./plant	Sterility (%)	Grain wt. (g)/plant
1934	580.2	28.5	11.53
1939	379.2	57.7	5.86
1942	145.2	82.3	2.59
1946	247.8	58.1	4.67
1947	240.0	49.0	4.02
1950	164.0	64.3	3.56
1953	196.3	58.7	4.28
1955	438.7	44.3	8.60
1996	641.3	34.6	9.58
1998	592.3	39.3	5.89
2004	654.2	27.9	6.22
2022	672.3	30.6	10.13
2036	315.5	33.3	5.69
2134	496.7	35.9	7.79
2285	273.0	55.7	4.11
2286	597.3	42.7	5.92
2288	440.8	45.3	9.17
2290	495.0	25.3	9.10
2291	392.8	22.8	6.79
2292	520.2	31.4	9.45
2293	458.0	17.2	8.46

2294	417.7	31.9	8.02
2298	441.8	34.1	8.75
2364	405.7	35.9	8.99
2390	269.2	60.4	5.96
2400	268.8	49.5	5.57
2402	316.3	37.8	6.14
2405	412.8	34.4	4.70
2409	524.7	41.8	7.99
2415	156.5	54.5	3.41
2416	368.7	41.2	7.28
2420	423.2	32.3	9.50
2425	207.0	50.8	4.15
1995	253.5	50.3	5.30
1997	312.2	60.7	3.89
2010	222.8	52.4	5.48
2027	210.8	35.6	4.04
2297	271.0	42.1	5.18
2327	277.2	51.6	4.87
2385	466.5	43.2	8.12
2389	255.7	58.6	4.59
2401	298.5	43.7	5.84
2410	371.5	56.3	7.30
BRRI dhan71	926.9	18.8	18.95
IR64	237.3	54.8	4.35
--	306.3	26.7	5.2

HEAT TOLERANCE

High temperature tolerance of spikelet fertility QTL introgression lines under controlled high temperature condition

Global warming has become a serious threat to the productivity of rice in the tropical and sub-tropical regions like South-Asia including Bangladesh. It was estimated and reported that, every 1°C increase in global mean temperature will reduce global rice yields by 3.2%. Considering the role of rice in Bangladesh food security and the negative effect of global warming on rice productivity, there is an urgent need to breed thermotolerant rice. Selection of tolerant breeding lines from current breeding materials is necessary for the development of new high temperature tolerant variety with high yield potential. To facilitate breeding for heat tolerance, an experiment having eight spikelet fertility QTL introgression lines were evaluated with high temperature (35±3 ^{0}C) and high humidity (75±5%) condition during flowering. Out of eight lines, four lines scored 5 classified as moderately heat tolerant. However the rest four lines scored 7 classified as moderately sensitive to heat stress (**Table 3**). Two tolerant donor, N22 and Kachalath scored 3 and 5 respectively.

Table 3: Spikelet fertility (%) under controlled high temperature (35±3^{0}C) and high humidity (75±5%) condition during flowering of 8 *qHTSF4.1* introgression lines along with parents and checks. Values are the mean±SE (n=9).

Line/Parent	Spikelet fertility under control condition	Spikelet fertility under HT* stress condition	SES# based on spikelet fertility under HT stress
Line-2	68.94±4.49	48.99±3.60	5
Line-3	75.59±4.94	46.45±7.70	5
Line-4	73.46±2.18	29.01±5.15	7
Line-5	68.20±3.90	58.02±5.70	5
Line-6	60.48±4.73	46.83±5.62	5
Line-7	63.38±6.96	27.34±2.93	7
Line-8	70.95±2.65	28.11±1.23	7

Line-9	52.09±4.23	29.99±6.39	7
BRRI dhan28	61.92±6.52	33.14±4.37	7
BRRI dhan29	76.92±5.55	37.00±6.40	7
N22	76.39±6.56	65.61±60.00	3
Kachalath	66.01±9.04	47.9±11.71	5

*HT = High temperature, #SES = Standard evaluation system.

Observational trial of high temperature induced spikelet fertility introgression lines in the background of BRRI dhan28 and BRRI dhan29

High temperature induced spikelet fertility QTL introgression advanced lines in the background of BRRI dhan28 was tested for observation yield evaluation during Boro 2021-22. A total of 81+52 = 133 lines of BRRI dhan28 and BRRI dhan29 were evaluated in the field condition along with parents for yield potential. A total of 100 plants per line were planted in rows of 25 plants x 4 rows per line during 29 November 2021 sowing and 9 January 2022 planting. Out of the 133 lines, 4 and 21 lines in the background of BRRI dhan28 and BRRI dhan29 respectively, having >0.5 t/ha yield advantage were selected for further evaluation.

Marker assisted introgression of high temperature induced spikelet fertility QTL (qHTSF4.1) in the background of BRRI dhan48 and BRRI dhan62

Bangladesh already faces increasingly extreme weather including droughts, floods and storms, but high temperatures/heat waves/heat shock have become a serious danger to rice production in recent years. During the anthesis/flowering stage, rice is susceptible to high temperatures (generally seven days before and after heading). Previously, high temperature stress was thought to be a problem only for Aus rice; later, it was thought to be a problem for long duration Boro and late Boro (Boro rice grown after potato harvest) during April to May, and sometimes extended to June/July when rainfall becomes very low or non-existent. However, due to the introduction of short-season T. Aman varieties, the issue has been extended to T. Aman rice as well. If rainfall is low during September-October, the short-duration T. Aman cultivars are at risk of high temperature-induced spikelet sterility. In light of this, a marker-assisted introgression of high temperature induced spikelet fertility QTL (qHTSF4.1) for the T. Aus and T. Aman seasons was carried out for BRRI dhan48, BRRI dhan62 and BRRI dhan71 respectively. A total of 60 BC_1F_1 of BRRI dhan48, BRRI dhan62 and BRRI dhan71were planted and after genotyping with R4M30 markers the selected progenies were backcrossed with respective parents and 110 BC_2F_1 seeds were produced.

COLD TOLERANCE

Screening of rice genotypes for seedling stage cold tolerance

Some 250 BRRI genebank germplasm and 1411 advanced breeding lines along with four check varieties namely BRRI dhan28, BRRI dhan36, Vhutan and HbjB-VI were tested for seedling stage cold tolerance in cold water tanks at artificial condition. Seeds were sown in plastic trays (60 cm length x 30 cm breadth x 2.5 cm height) filled with gravels and crop residue free granular soil and allowed to grow until 3-leaf stage. The plastic trays were then placed into cold water tanks adjusted to constant temperature at 13°C. Out of 250 Genebank germplasm, 38 accessions (Genebank Acc. no. 2556, 2558, 2559, 2560, 2561, 2563, 2564, 2565, 2566, 2575, 2576, 2577, 2578, 2579, 2588, 2589, 2618, 2635, 2637, 2639, 2646, 2656, 2657, 2658, 2659, 2660, 2661, 2663, 2664, 2667, 2670, 2671, 2674, 2684, 2685, 2686, 2688, 2691) showed moderately cold tolerant at seedling stage. Out of 1411 advanced breeding lines 334 lines were selected of which 65 and 269 lines were found cold tolerant and moderately cold tolerant at seedling stage, respectively. Rest of the genotypes were susceptible to highly susceptible.

Evaluation of advanced breeding lines for reproductive stage cold tolerance

Some 15 advanced breeding lines along with the check varieties namely BRRI dhan28, BRRI dhan67, BRRI dhan88, BRRI dhan89, BRRI dhan92 and BRRI dhan96 were evaluated for reproductive stage cold tolerance at natural field condition. There were two seeding times 21 October and 25 November (control). Thirty-five-day-old seedlings were transplanted in the main field. Early planting was done with a view to falling rice reproductive phase at cold stress. Cold tolerance of rice genotypes were measured visually based on vegetative growth and leaf discoloration score at vegetative phase. We mainly focused on spikelet sterility for reproductive phase cold tolerance. However, data on date of flowering and maturity, plant height, panicle per hill, panicle length, last internode length, last leaf sheath length, panicle degeneration and exertion, filled and unfilled grain per panicle, grain yield and yield components were recorded for better understanding of cold tolerance of specific rice genotypes. An advanced breeding line BR11894-R-329 showed cold tolerance at vegetative phase as it had very little or no leaf discoloration with better vegetative growth. While, BR11894-R-169 was found the most cold susceptible at vegetative phase although it had sufficient growth but leaf discolored greatly. Growth duration increased by natural cold in early planting of BR11894-R-134, BR10715-5R-1, BR11894-R-110, BR10715-5R-9, BR11894-R-309 was less than BRRI dhan67. In early sowing/planting, grain yield of BR11894-R-110 and BR11894-R-134 was significantly higher than BRRI dhan28, BRRI dhan67, BRRI dhan96 and BRRI dhan88 but statistically similar to BRRI dhan89 and BRRI dhan92. Another three lines BR11894-R-3099, BR11894-R-169 and BR11894-R-299 had comparable yield to BRRI dhan67. Two long duration breeding lines BR10715-5R-1 and BR10715-5R-9 had statistically similar yield to BRRI dhan89 and BRRI dhan92 (**Table 4**).

In 25 November sowing, none of the tested rice genotypes out yielded BRRI dhan89 and BRRI dhan92. However, nine advanced lines BR10715-5R-1, BR11894-R-134, BR11894-R-110, BR10715-5R-9, BR11894-R-329, BR11894-R-230, BR11894-R-233, BR11894-R-105 and BR11894-R-169 had significantly higher yield than BRRI dhan88 but statistically similar to BRRI dhan67, BRRI dhan89 and BRRI dhan92 (**Table 4**).

Percent sterility was increased significantly in early planting over usual planting time. In 21 October sowing, percent sterility of BR10715-5R-9, BR10715-5R-1, BR11894-R-134, BR11894-R-110, BR11894-R-169, and BR11894-R-309 were statistically similar to BRRI dhan67.

Table 4 Growth duration, yield and sterility of tested rice genotypes.

Genotypes	Growth duration (day)		Yield (t/ha)		Sterility (%)	
	21Oct	25Nov	21Oct	25Nov	21Oct	25Nov
BR11894-R-105	177.0	154.6	3.25	6.71	42.05	20.28
BR11894-R-169	178.0	150.0	3.98	6.67	31.82	15.64
BR11894-R-230	178.0	149.0	3.64	6.72	39.42	18.93
BR11894-R-233	177.0	150.3	3.63	6.72	37.52	15.34
BR11894-R-270	177.6	150.0	3.33	6.48	37.76	16.10
BR11894-R-329	176.0	150.6	3.68	6.79	39.79	16.60
BR11894-R-110	172.5	155.0	5.34	6.83	31.76	17.54
BR11894-R-134	172.3	155.3	5.21	6.84	31.27	15.76
BR11894-R-165	178.3	150.6	2.85	6.15	43.20	18.64
BR11894-R-299	172.6	152.0	3.90	6.10	39.58	21.32
BR11894-R-304	177.0	148.3	2.86	5.56	39.80	16.81
BR11894-R-309	173.0	154.0	4.16	6.56	32.54	18.83
BR11894-R-80	179.3	149.6	2.87	6.40	39.63	19.53
BR10715-5R-1	180.3	163.0	5.56	6.84	30.00	20.22
BR10715-5R-9	178.3	160.3	5.62	6.81	29.01	16.43
BRRI dhan28 (ck)	173.6	148.6	3.61	6.01	40.65	14.92
BRRI dhan67 (ck)	170.0	150.3	4.14	6.84	29.16	13.26
BRRI dhan96 (ck)	175.6	150.0	3.60	6.59	40.49	12.41
BRRI dhan89 (ck)	179.0	163.0	5.53	7.07	28.50	16.61

Genotypes	Growth duration (day)		Yield (t/ha)		Sterility (%)	
	21Oct	25Nov	21Oct	25Nov	21Oct	25Nov
BRRI dhan92 (ck)	180.0	163.3	5.62	7.08	27.94	18.13
BRRI dhan88 (ck)	177.6	149.6	2.58	6.02	43.00	15.87
LSD $_{5\%}$ Genotype (G)	3.07		0.41		3.37	
$LSD_{5\%}$ Sowing time (S)	0.94		0.24		1.01	
$LSD_{5\%}$ for G*S	4.34		0.62		4.63	

Considering all these parameters five short to medium duration advanced breeding lines (BR11894-R-110, BR11894-R-134, BR11894-R-169, BR11894-R-299 and BR11894-R-309) and two long duration lines (BR10715-5R-9 and BR10715-5R-1) were selected as moderately cold tolerant (**Table 4**).

Characterization and evaluation of some selected rice genotypes for cold tolerance

Some 11 advanced breeding lines, two exotic varieties along with five check varieties namely BRRI dhan28, BRRI dhan67, Minasahi and HbjB-VI were characterized and evaluated in natural field condition. There were three seeding times 15 October, 1 November and 15 November (control). Thirty five-day-old seedlings were transplanted in the main field. Early planting (15 October and 1 November) was done with a view to falling rice reproductive phase at cold stress. Changes in different parameters of rice after natural cold treatment were compared with control treatment. In early planting, all rice genotypes experienced cold stress at reproductive phase. Cold stress caused longer growth duration, shorter last internode length as well as plant height, poor panicle exertion and higher percentage of sterility over control treatment in all rice genotypes. Considering above parameters previously selected advanced rice genotypes BR10717-5R-82 was selected as moderately cold tolerant line which was similar to BRRI dhan67. Other four rice genotypes such as Black rice (Phil), GB-34, BR11001-5R-37 and BR11000-5R-27 were found moderately cold susceptible lines at reproductive phase. However, rest of the rice genotypes viz BR11001-5R-2, TP30753, BR11662-11-5-3, BR11663 (132A3)-6-2, BR11000-5R-4, BR11894-R-R-R-345, BR11338-5R-39 and BR11338-5R-12) were susceptible at reproductive stage.

Evaluation of lodging tolerance of some advanced breeding lines, T Aus 2021

Three advanced breeding lines (BR8781-16-1-3-P2, BR9829-78-1-2 and BR9830-5-2-2-3) along with two check varieties namely BRRI dhan27 and BRRI dhan48 were evaluated for lodging tolerance in Aus 2021 season in BRRI HQ farm, Gazipur. Just after heading, 10 randomly selected plants were cut at culm base. Visible internode length (1st to 5th internode) and total internode length/culm length were measured using meter scale. Forth internode diameter and thickness were measured by slide calipers and micrometer respectively. Wrapping score were done by visual observation. Flag leaf angle was measured using 180 degree angle ruler. Stem density were measured in terms of dry weight per unit length of total stem length. Bending moment (gm cm) was calculated using total fresh weight of plant above ground (gm) and culm length (cm). Visual lodging rate of a variety was calculated as percent logged area. Panicle exertion, panicle length and panicle weight were measured at maturity.

Forth internode length of BR8781-16-1-3-P2, BR9829-78-1-2 and BR9830-5-2-2-3 were lower than BRRI dhan27 but comparable with BRRI dhan48. However, BR8781-16-1-3-P2 had the shortest forth internode length. Forth internode diameter of BR8781-16-1-3-P2 and BR9829-78-1-2 were significantly higher than BRRI dhan48 but similar to BRRI dhan27. Stem thickness of tested varieties were similar to check varieties. Wrapping score of BR9829-78-1-2 was statistically similar to BRRI dhan48 but BR8781-16-1-3-P2 had significantly higher wrapping score than the check varieties. Flag leaf angle of BR8781-16-1-3-P2 was about five degree less than the check varieties. On the other hand it had significantly higher stem density. Bending moment of BR8781-16-1-3-P2 and BR9829-78-1-2 were significantly higher than the check variety BRRI dhan48. BR9830-5-2-2-3 had similar moment to BRRI dhan48. Both panicle length and weight of tested varieties were significantly higher than the check varieties.

Panicle exertion of BR8781-16-1-3-P2 and BR9830-5-2-2-3 were similar to BRRI dhan48 but lower than BRRI dhan27. Visual lodging rate of BR8781-16-1-3-P2 (3.33%) was significantly lower than both the check varieties. However, visual lodging rate of BR9829-78-1-2 and BR9830-5-2-2-3 was statistically similar to BRRI dhan48 but lower than BRRI dhan27. Advanced breeding lines BR8781-16-1-3-P2 showed lodging tolerance due to its shorter fourth internode length, better wrapping score and higher stem density (51.17 mg/ cm), although it had longer plant height (126.81 cm) and higher bending moment (1321.67 g.cm)

Studies on lodging tolerance of T. Aman rice varieties at reproductive phase

An experiment was conducted in T Aman 2021 season in BRRI HQ farm, Gazipur to determine the lodging characters of five BRRI varieties viz. BRRI dhan49, BRRI dhan87, BRRI dhan93, BRRI dhan94 and BRRI dhan95 along with lodging tolerant check variety BR11. Four sets of seeds were sown on 20 June, 5 July, 20 July and 5 August 2021 at 15 days interval. Twenty-five-day-old seedlings were transplanted in the main field. Just after heading, data were recorded on visible internode length (1^{st} to 5^{th} internode), total internode length/culm length, internode diameter and thickness, wrapping score, flag leaf angle, stem density, bending moment and visual lodging rate. Data on panicle exertion, panicle length, panicle weight, grain yield and yield components were recorded at maturity.

When seeds sown before 15 July in first and second sets, BRRI dhan87, BRRI dhan93, BRRI dhan94 were lodged completely, while BRRI dhan49 lodged partially. BRRI dhan95 did not lodge in these two sets which was comparable to lodging tolerant check variety BR11. However, none of the varieties were lodged if seeds were sown after 15 July in third and forth set. Forth internode length was the longest in BRRI dhan87 followed by BRRI dhan93 and BRRI dhan94 which was higher than BR11. It was comparable between BRRI dhan49 and BRRI dhan95 but higher than BR11. Stem thickness of tested varieties was similar to check varieties BR11. Flag leaf angle was 2-4 degree more in tested varieties than BR11 except BRRI dhan95 which had 2 degree less. Total wrapping score of BRRI dhan95 was similar to BR11 but other varieties had less score. Panicle weight of tested varieties was 0.16 to 0.2 g higher than the check variety BR11 except BRRI dhan95 which had 0.24 g less. Less panicle weight and well wrapped stem of BRRI dhan95 might be the main reason of its lodging tolerance.

Effect of polythene covering on seedling raising in Boro season

Sprouted seeds of BRRI dhan88 were shown in puddle seedbeds on 22 December 2021. It was covered by transparent polythene sheet. Five different types of polythene covering treatment at seedbed viz. covering for all time, covering for 24 hrs during cold wave, covering from 11.0 am to sun set, covering for whole night and covering for all time with opening at both end of the seedbed cover along with control were used. The longest seedling was recorded from covering for all time followed by covering from 11.0 am to sun set and covering for all time with opening at both ends of the seedbed cover. Fresh weight of seedling was significantly higher in covering for all time with opening at both end than all other treatments. However, highest seedling strength was recorded from seedbed having polythene covering during cold wave followed by covering for all time with opening at both end and covering for whole night. The lowest seedling mortality rate after transplanting in the main field was recorded from covering during cold wave, which was statistically similar to the control. Seedling mortality after transplanting was comparable between covering for all time with opening at both ends, covering for whole night and covering from 11.0 am to sun set although it was slightly higher than control treatment. Polythene covering for all time at seedbed had lower seedling strength but higher seedling mortality.

GROWTH STUDIES

Effect of sowing time on growth and yield of newly released Aman varieties

Newly released three BRRI developed Aman varieties (BRRI dhan93, BRRI dhan94 and BRRI dhan95) along with BR11 and BRRI dhan49 were evaluated to observe the yield and growth under different seeding time during Aman 2021. The seeding was done in four different splits of set (1^{st} set = 20 June, 2^{nd} set=5 July, 3^{rd} set=20 July and 4^{th} set=5 August) highest yield of the BRRI dhan93 was observed at the 3^{rd} set (4.34 t/ha) with 128 days growth duration followed by 4^{th} set (4.21 t/ha but which were statistically similar. Statistical similar highest yield was observed in casesaf 3^{rd} and 4^{th} set for BRRI dhan94 (around 4.54 t/ha) with 122 to 128 days of growth duration. BRRI dhan95 produced maximum yield (5.84 t/ha) at 2^{nd} set of experiment with 124 days of growth duration. On the other hand the highest yield (4.92 t/ha) of BR11 was found at the 1^{st} set but which was statistically similar to 2^{nd} and 3^{rd} set with 122-133 days of growth duration. BRRI dhan49 had no significant variation in yield among the different sowing time and maximum yield (5.0 t/ha) was found at the 3^{rd} set (**Fig. 8**). The range of growth duration of BRRI dhan49 was 119 to 133 days.

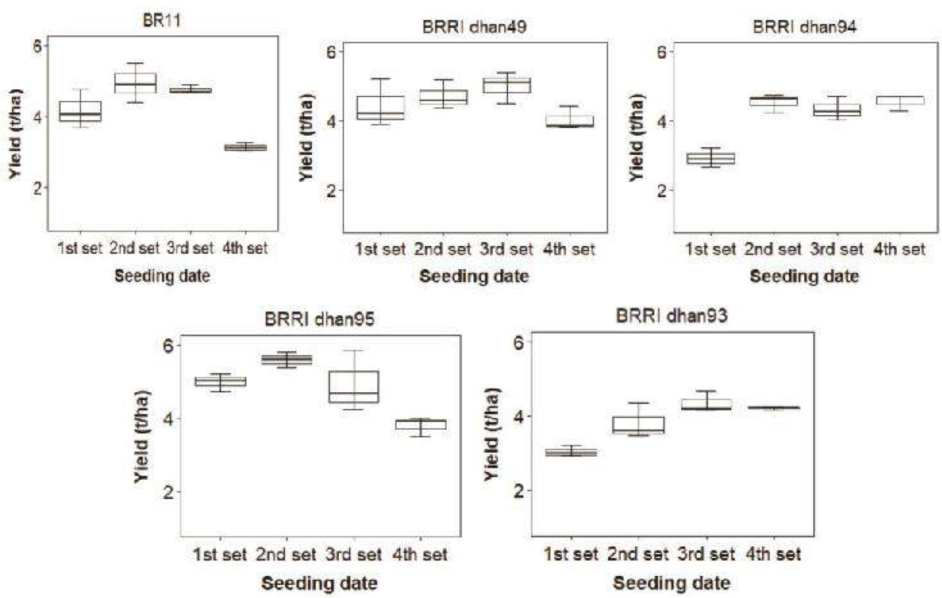


Fig. 8 Yield of the selected varieties under different seeding dates.

Effect of sowing time on growth and yield of newly released Boro varieties

Four newly released Boro varieties (BRRI dhan96, BRRI dhan97, BRRI dhan99 and Bangabandhu dhan100 were seeded at four different set between 15^{th} November to 30 December at 15 days interval to observe the growth and yield. Among the four varieties BRRI dhan96 produced the highest yield at 2^{nd} (6.5 t/ha) followed by 1^{st} set (5.9 t/ha) which was statistically similar. The highest growth duration was observed at 1^{st} set followed by 2^{nd}, 3^{rd} and 4^{th} set (154-130 days). There was no significant yield difference found among 1^{st} to 3^{rd} set for BRRI dhan97 and Bangabandhu dhan100 the yield range was 5.3 to 5.8 t/ha and 4.6 to 5.7 t/ha respectively with 145-163 days and 145-159 days of growth duration respectively. BRRI dhan99 produced the highest yield at 2^{nd} set of experiment. (6.3 t/ha) with 149 days of growth duration (**Fig. 9**).

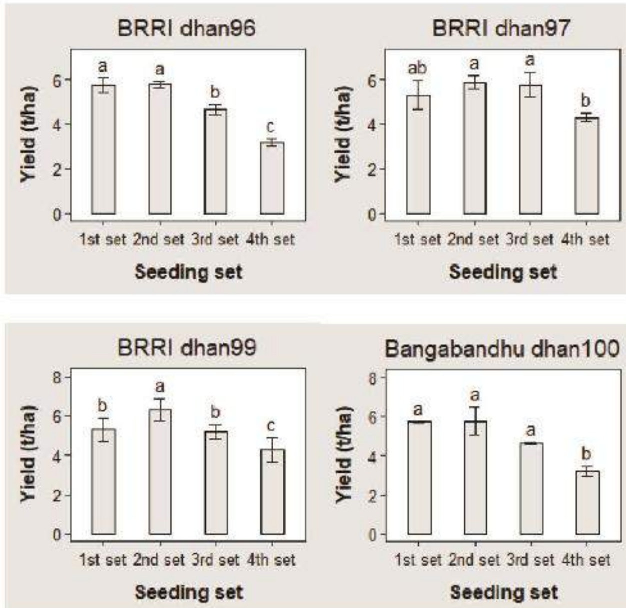


Fig. 9 Yield of four new Boro varieties under different seeding time.

Screening of Pre-harvest sprouting of some BRRI varieties

Thirty-six BRRI varieties were used to evaluate pre harvest sprouting (PHS) of spikelet. At research field artificial condition were created to sprout the seed by wrapping the selected panicle with wet cloth at 50 and 80% maturity stage for seven days. After seven days the panicles were harvested and counted the germinated spikelet. On the basis of germination percentage BRRI dhan50, BRRI dhan60, BRRI dhan69, BRRI dhan86 and BRRI dhan89 was found highly susceptible to pre-harvest sprouting and BR19, BR16, BRRI dhan63, BRRI dhan45, BRRI dhan36, BR27, BRRI dhan55, BRRI dhan48, BRRI dhan88, BRRI dhan82, BRRI dhan67, BRRI dhan84, BRRI dhan42 and BRRI dhan28 were found moderately tolerant to PHS which had less than 5% PHS spikelet (**Fig. 10**).

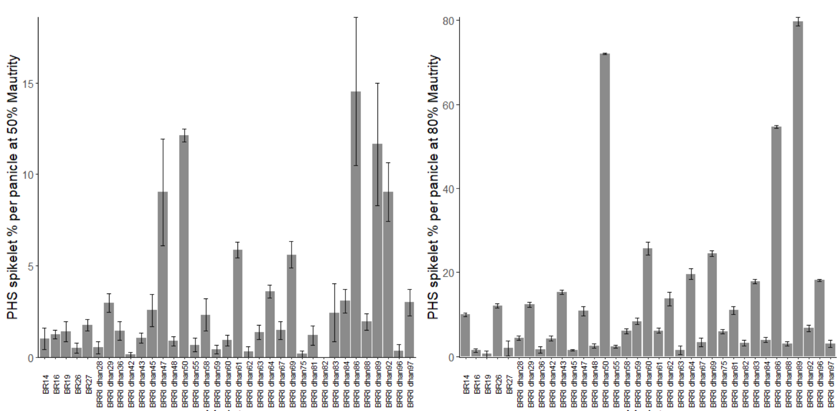


Fig. 10 Pre-harvest sprouting spikelet percentage at 50% and 80% maturity.

Identification of regeneration ability of Aus rice varieties

BRRI dhan42, BRRI dhan65, BRRI dhan83, Morichboti, Hasikalmi, DA dhan31 were used to observe the regeneration ability at the vegetative stage. Thirty-day after sowing plant were bending by mowing to break the apical dominance. None of the genotypes performed better in terms of tillering ability than the control condition.

Determination of growth phase of short duration (60 days in India) Aus rice varieties

Pande dhan and BRRI dhan42 were direct seeded to determine the duration of the different growth phases and yield of short duration Aus variety of india. Pande dhan was found higher growth duration (2 weeks more than the check BRRI dhan42).

Phenological development of two newly released BRRI varieties

Crop phenology is important for choosing cultivars with an appropriate growth period and for determining the timing of management practices such as planting, fertilizer application and harvesting. The accurate rice phenological development stages estimation is also important for rice yield estimation in different climatic conditions. The evaluation of phenology plays a pivotal role in assessment of the effects of climate change and the development of adaptation practices. BRRI developed two modern Boro rice varieties BRRI dhan88, BRRI dhan92 and IR64 were selected to execute the experiment on three different sowing dates. Three different sowing dates were 3 April, 18 April, and 3 May. Seedlings were grown in seedbed. Twenty five-day-old seedlings were transplanted in the field using single seedling per hill at 20×20 cm spacing. The plot size was 3×6 m^2. The study was laid out in RCBD with three replications

Fertilizers were applied as urea, triple superphosphate, muriate of potash, and gypsum at the rate of 165-60-105-67 $kgha^{-1}$ for urea, TSP, MoP, and Gypsum, respectively. Full doses of triple superphosphate, muriate of potash, and gypsum were incorporated at the final land preparation time. Urea was applied in the three equal splits at 10, 25 days after transplanting and 3rd dose seven days before PI. All the fertilizers were applied as per BRRI recommendation. The crop was kept weed free throughout the growth period. Adequate measures were taken to keep the insect infestation to a minimal.

The results of different parameters at Aus season indicated that there was significant difference among the varieties and seeding dates of. Plant height was found the highest at 3rd seeding. Number of panicle per m^2 varied from 197 to 302. The percent sterility was maximum in IR64 in 1st seeding and minimum in BRRI dhan88 in 2nd seeding. The highest 1000-grain weight was observed in IR64 grown at set 1 and the lowest in BRRI dhan88 grown at set 3. Grain yield drastically reduced irrespective of variety and seeding time due to high sterility. It is the number of filled spikelets and the spikelet size that govern grain yield of rice (Yoshida, 1981). Number of panicles and number of filled spikelets per unit area and (TGW) (grain size) are the major determinants of grain yield. Figure 11 shows the graphical representation of maximum. temperature of flowering period (5 days before and after 50% flowering) of the varieties shown in **fig.11**. The emerged panicle exposed to temperature higher than the critical threshold of 33°C might increase spikelet sterility in natural condition of the modern variety. The growth duration was higher in 2nd seeding irrespective of varieties (**Table 5**).

Table 5 Interaction effects between variety and date of seeding on yield and yield components

Variety × date of seeding	Plant height (cm)	Panicle per m^2	Sterility (%)	1000-grain weight (gm)	Yield (t/ha)	Duration (from seeding to maturity) (days)
BRRI dhan88 ×Set 1	92.22	280.56	58.41	20.46	2.88	105

Variety × date of seeding	Plant height (cm)	Panicle per m^2	Sterility (%)	1000-grain weight (gm)	Yield (t/ha)	Duration (from seeding to maturity) (days)
BRRI dhan88 ×Set 2	87.78	255.56	45.54	20.29	1.93	106
BRRI dhan88 × Set 3	99.67	255.56	45.62	19.05	2.51	100
BRRI dhan92 × Set 1	118.44	197.22	66.47	22.49	1.52	133
BRRI dhan92 × Set 2	116.00	222.22	62.15	22.19	1.31	139
BRRI dhan92 × Set 3	134.67	227.78	67.54	21.66	1.89	132
IR64 × Set 1	107.67	211.11	71.51	24.01	1.22	126
IR64 × Set 2	108.78	302.78	70.29	23.06	1.42	132
IR64 × Set 3	110.11	213.89	65.98	21.71	1.49	127
LSD at 5% level	9.23	39.95	15.99	1.38	1.02	0.00

Seed sowing: Set 1: 4 April 2021, Set 2:18 April 2021, Set 3: 3 May 2021

PI and flowering stage

Irrespecty of varieties there was an increase in the duration of the sprouting to panicle initiation stage in 2nd sowing and then decreased in third sowing. It took 85 days when seed was sown at the beginning of April and 91 days for mid-April sowing and then decreased to 84 days for the variety BRRI dhan92. Similar trend was observed for the variety IR64. For BRRI dhan88, the days required for PI almost similar in 1st and 2nd sowing but it was decreased when sowing was done at the beginning of May. The days required from PI to 50% flowering was taken in consideration for flowering stage. The time required for 50% flowering (from PI to 50% flowering) and maturity (from 50% flowering to maturity) more or less similar irrespective of varieties and sowing time (**Table 6**).

Growing degree days (GDD)

Degree days expresses the influence of mean temperature on the developmental rate (the reciprocal of the duration of any phase). It can be used for phenological forecasting of a rice crop. The tested varieties varied in growing degree days (°Cd) requirements both for panicle initiation and flowering (**Table 7**). The degree days (°Cd) requirements for panicle initiation were 1229.67±53.63, 1808.84±48.08, 1689.68±43.98, while for flowering 472.74±12.58, 516.83±0.507, 504.16±6.27 for BRRI dhan88, BRRI dhan92 and IR64 respectively.

Table 6 Growth stage of rice varieties as affected by sowing time in Aus season 2021, Plant Physiology Division, BRRI.

Sprouting date	Variety	Day to PI (from sprouting sprouting)	Day to 50% flowering (from PI)	Day to Maturity (from 50% flowering)	Day to Maturity (from sprouting)
2 Apr 2021	BRRI dhan88	60	23	23	106
	BRRI dhan92	85	25	24	134
	IR64	80	24	23	127
17 Apr 2021	BRRI dhan88	61	23	23	107
	BRRI dhan92	91	25	24	140
	IR64	85	24	24	133
2 May 2021	BRRI dhan88	54	24	23	101
	BRRI dhan92	84	25	23	133
	IR64	78	25	25	128

Table 7 Degree days of rice varieties as affected by sowing time in Aus season 2021, Plant Physiology Division, BRRI.

Variety	Required DD (°Cd)			
	from sprouting to PI	from PI to 50% flowering)	from 50% flowering to maturity)	from sprouting to maturity)
BRRI dhan88	1229.67 (±53.63)	472.74 (±12.58)	329.37 (±149.876)	2179.92 (±42.942)
BRRI dhan92	1808.84 (±48.08)	516.83 (±0.507)	340.67 (±155.342)	2823.92 (±45.257)

Variety	Required DD (°Cd)			
	from sprouting to PI	from PI to 50% flowering)	from 50% flowering to maturity)	from sprouting to maturity)
IR64	1689.68 (±43.98)	504.16 (±6.274)	333.96 (±152.186)	2689.59 (±37.023)

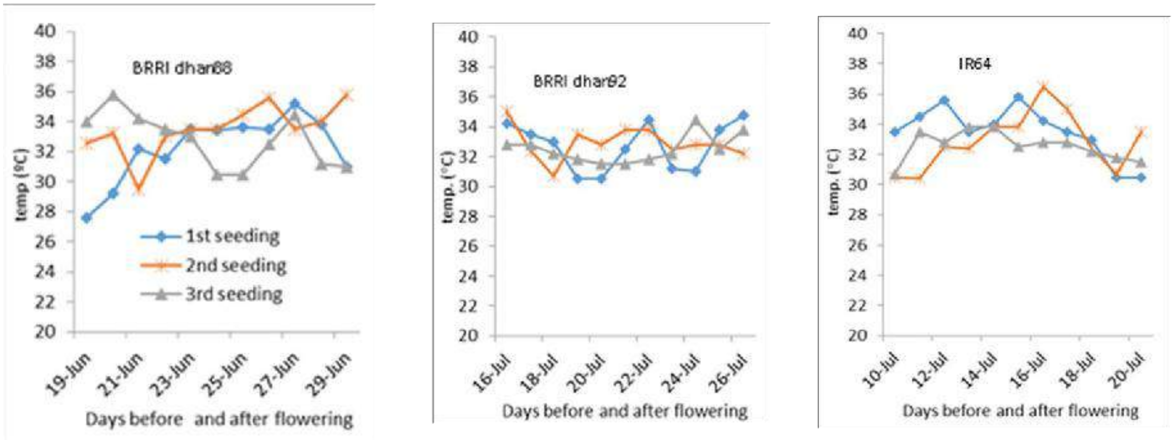


Fig. 11 Maximum temperature during flowering.

Response to photoperiod of some advanced breeding lines under controlled photoperiod condition

A study was conducted to find out the photoperiod sensitivity of some promising breeding lines. on total 230 advanced breeding lines developed for RLR ecosystem (salinity and insect resistance) were tested along with BR22, Nizersail (strong photoperiod sensitive) and BR10, BR11, BRRI dhan30 (moderate photoperiod sensitive) as standard checks. Seeds of all the tested and check varieties were directly sown to the well-prepared field beds during 11 April 2021. Ten-hour photoperiodic treatment (7.00 AM to 5.00 PM) was started from seed sowing by using black cloth cover. One set were grown at natural day length. Observations were made on date of seeding and date of heading to determine the Basic Vegetative Phase (BVP), Photoperiod Sensitive Phase (PSP) and Relative Photoperiod Sensitivity (RPS). On the basis of RPS, 2 breeding lines (BR11032-4R-31 and BR11046-4R-95) showed strong response in flowering with an increase in photoperiod similar to BR22 (**Table 8**). But rest of breeding lines showed nearly insensitive to moderately sensitive to photoperiod. The relative photoperiod sensitivity of BR10, BR11 and BRRI dhan30 was ranged from 36% to 39% compared to Nizersail, which are considered as moderately sensitive variety.

Table 8 Photoperiod sensitivity of selected promising advance breeding lines during T. Aman 2021. Each value is the mean of 5 samples (sowing date: 11 April 2021).

Designation	Basic Vegetative Phase (day)	Photoperiod Sensitive Phase (day)	Relative Photoperiod Sensitivity (%)	Remarks
BR11032-4R-31	**13±0.31**	**167±1.76**	**116**	**SPPS**
BR11046-4R-95	**13±0.38**	**166±1.15**	**115**	**SPPS**
BR10 (ck.)	38±3.03	57±3.33	39	MPPS
BR11 (ck.)	42±0.58	52±1.30	36	MPPS
BR22 (ck.)	**11±0.31**	**168±0.63**	**116**	**SPPS**
BRRI dhan30	36±0.59	57±1.00	39	MPPS

Designation	Basic Vegetative Phase (day)	Photoperiod Sensitive Phase (day)	Relative Photoperiod Sensitivity (%)	Remarks
(ck.)				
Nizersail (ck.)	**9±1.84**	**144±2.38**	**100**	**SPPS**

Note: BVP and PSP values are the Mean±SE (n=10), MPPS = Moderate photoperiod sensitive, SPPS = Strong photoperiod sensitive

PM) was started from seed sowing by using black cloth cover. One set were grown at natural day length. Observations were made on date of seeding and date of heading to determine the basic vegetative phase (BVP), Photoperiod Sensitive Phase (PSP) and Relative Photoperiod Sensitivity (RPS). On the basis of RPS, one deep-water line (BR9390-6-2-1B) showed strong response in flowering with an increase in photoperiod similar to BR22 (**Table 9**). However, one local deep-water genotype (Khoiamotor) and one shallow-deep water line the (BR10230-7-19-B) showed fairly strong sensitive having RPS (~80%) (**Table 9**). But rest of breeding lines showed weakly to moderately sensitive to photoperiod.

Photosensitivity test of deep-water, shallow-deep water and stagnant shallow water lines

Another study was conducted to find out the photoperiod sensitivity of some advanced breeding lines developed for deep-water, shallow-deep water and stagnant shallow water condition. Sixteen (16) advanced breeding lines were tested along with BR22, Nizersail (strong photoperiod sensitive) and BR11 (moderate photoperiod sensitive) as standard checks. Seeds of all the tested and check varieties were directly sown to the well-prepared soil bed under control net house condition on 16 May 2021. Ten-hour photoperiodic treatment (7.00 AM to 5.00

Table 9 Photoperiod sensitivity of deep-water, shallow-deep water and stagnant shallow water lines during T. Aman 2021. Each value is the mean of 5 samples (sowing date: 16 May 2021).

	Designation	BVP	PSP	%RPS	Remarks
	BR11	29.83	54.13	47.51	Moderately sensitive
	BR22	17.25	119.25	104.68	Strong sensitive
	Nizer sail	30.71	113.92	100.00	Strong sensitive
Deep water line					
	BR9390-6-2-2B	Segregating line			
	BR9376-6-2-2B	33.60	60.80	53.37	Moderately sensitive
	BR10260-5-15-21-6B	30.67	79.93	70.17	Moderately sensitive
	BR9390-6-2-1B	10.50	116.50	102.27	Strong sensitive
	Dudlaki	No one survived			
	Khoia Motor	27.50	90.50	79.44	Fairly strong*
Shallow water					
	BR10230-7-19-B	19.50	91.25	80.10	Fairly strong*
	BR10230-7-19-2B	37.67	50.13	44.01	Moderately sensitive
	BR10247-14-18-7-3-3B	41.67	41.50	36.43	Moderately sensitive
	BR102385-1-9-3B	37.00	51.20	44.95	Moderately sensitive
	BRRI dhan91	36.40	64.20	56.36	Moderately sensitive
Stagnant shallow deep					
	BR9377-21-3B	12.60	77.15	67.72	Moderately sensitive
	BR9892-6-2-2B	36.50	50.50	44.33	Moderately sensitive
	BR10247-14-18-4	35.50	50.67	44.48	Moderately sensitive
	BR10247-4-7-4-B	20.50	40.83	35.84	Moderately sensitive
	BR9392-6-2-3B	17.00	39.17	34.38	Weakly sensitive

Investigation of anatomical differences in the leaves of C3 and C4 species

Leaf structure strongly controls leaf photosynthesis and plays a key role in every step starting from light interception up to the biochemical fixation of carbon dioxide. However, there has been growing interest in the characterization of rice leaf anatomical differences between C3 (rice) and C4 species such as maize, sorghum, green foxtail millets etc. Engineering the leaf structure of cultivated rice could, therefore, be of direct interest to current research efforts that aim to increase photosynthetic efficiency and thereby achieve improved yields. Recently, Chowrasia and Mondal (2020) have claimed that Uri dhan (*Oryza coarctata*) should possess C4 photosynthesis based on anatomical, cell ultra-structural, and molecular evidences. Based on these information, anatomical differences between the leaves of Uri dhan and rice were investigated. In comparison to rice, Uri dhan has a greater number of veins and a denser vascular bundle. The mesophyll cells and vascular bundle in the Uri dhan were both well-organized and highly composed compared to rice (**Figs.12 and 13**).

Fig. 12 Veins and vascular bundles in the leaves of rice (left) and Uri dhan (right) (20×).

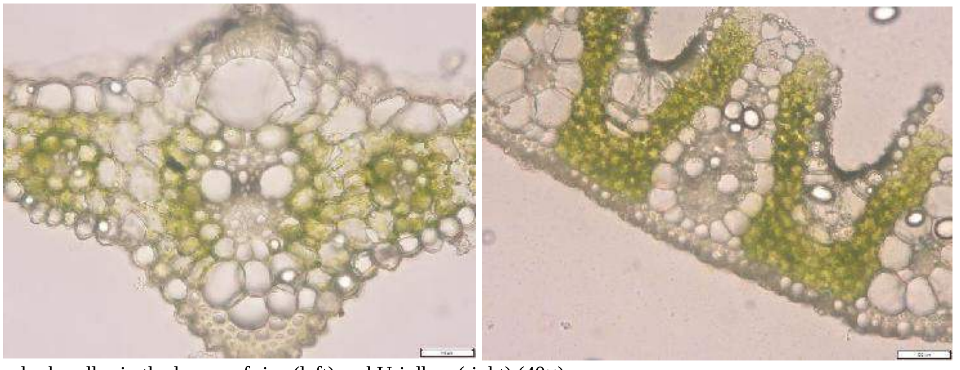


Fig. 13 Vascular bundles in the leaves of rice (left) and Uri dhan (right) (40×).

Optimizing chlorophyll fluorescence imaging system for photosynthetic efficiencies of rice in the salinity stress

Chlorophyll fluorescence is popular technique in plant physiology used for rapid non-invasive measurement of photosystem II activity. PSII activity is very sensitive to range of biotic and abiotic factors and therefore chlorophyll fluorescence technique is used as rapid indicator of photosynthetic performance of plants in different developmental stages and/or in response to changing environment. The advantage of chlorophyll fluorescence measurements over other methods for monitoring stresses is that changes in chlorophyll fluorescence kinetic parameters often occur before other effects of stress are apparent. Advances made in image-based phenotyping techniques provided an opportunity to use non-destructive imaging to screen for salinity tolerance traits in a wide range of germplasm in a reliable, quantitative and efficient way. However, the application of image-based phenotyping in the development of salt-tolerant rice remains limited. Therefore, the present investigation aimed to explore the use chlorophyll fluorescence-based imaging to characterize the salinity tolerance of rice at seedling stage. In the present study, IR58443 (standard tolerant check) and IRRI154 (standard sensitive check) were evaluated under soil-based salinity stress for 0, 6 and 12 dS/m stress. Chlorophyll fluorescence image was taken 24 (Day1), 48 (Day2) and 72 hrs (Day3) after stress application. Initial Fv/Fm values (Day1) were noticeably low, but they progressively increased and were kept very near to normal for the tolerant genotype (IR58443), whereas the pattern was exactly the opposite for the sensitive genotype (IRRI154) (**Fig. 14**).

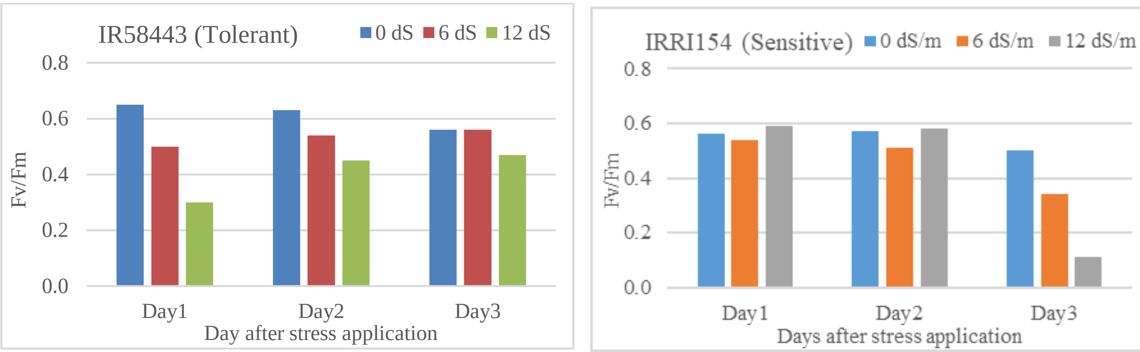


Fig. 14 Fv/Fm values at three distinct time periods at 0, 6, and 12 dS/m salinity str ess.

YIELD POTENTIAL

Generation of male sterile rice line for two-line hybrid system by editing TMS5 gene using CRISPR/Cas9 system

The two-line hybrid rice system is an important innovation for the better exploitation of hybrid vigoer (heterosis). Thermo-sensitive genic male sterile (TGMS) line has been shown to be an ideal replacement for cytoplasmic male sterility (CMS) and explored in two-line hybrid systems; particularly in rice. TGMS lines are sensitive to the temperature for the expression of male sterility or fertility. To design a CRISPR/Cas9 targeting the TMS5 gene in rice, a 19bp guide sequences (5′-ACCGTCGAGGGCTACCCCG-3′) was a protospacer adjacent motif lying within the TMS5 coding sequence (LOC_Os02g12290.1). The guide sequences were properly cloned into the binary vector pC1300-Cas9 (**Fig. 15**). The binary vector pC1300-Cas9 harboring Cas9/TMS5 sgRNA was mobilized into Agrobacterium tumefaciens LBA4404 by freeze-thaw method and confirmed through PCR-gel electrophoresis (**Fig. 16**). Plants were regenerated through Agrobacterium-mediated transformation. Genomic DNA was extracted from the leaves of transformed plants using the sodium dodecyl sulfate (SDS) method. Hygromycin phosphotransferase positive plants were identified using HPT primer pair designed from Hygromycin phosphotransferase resistant zone of the Cas9 vector (**Fig. 17**). PCRs amplifications are being performed using primer pairs which generated an amplicon harboring the target site, and the resulting amplicons are being sequenced using the Sanger method.

Fig. 15 Confirmation of vector constructs by alignment of sequence of recombinant pC1300-Cas9 harboring Cas9/*OsTMS5* sgRNA with guide sequence.

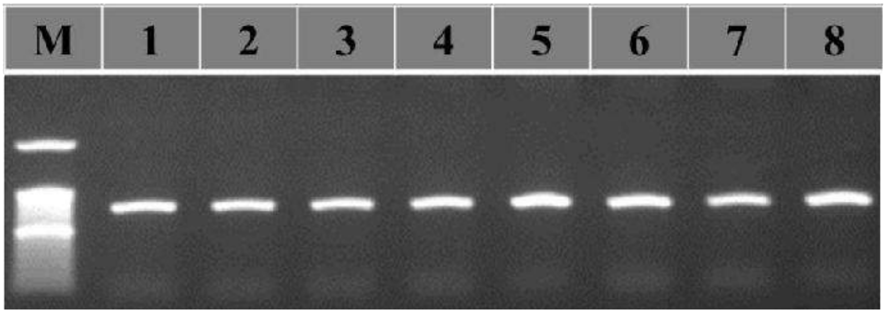


Fig. 16 Confirmation of *Agrobacterium* transformation through PCR-gel electrophoresis. *Agrobacterium tumefaciens* LBA4404 with recombinant pC1300-Cas9 harboring Cas9/*OsTMS5* sgRNA **(Lane 1-8)**. **M**: marker (50 bp DNA ladder).

Fig. 17 Hygromycin phosphotransferase positive plants for salinity tolerance.

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Entomology Division

SUMMERY

The overall insect pest incidence was low in the reporting year. Among the five habitats i.e., seedbed, grass fallow, irrigated rice, rice bund and upland rice, the highest number of GH was found in transplanted rice (T. rice) followed by rice bund, grass fallow and seedbed at BRRI research farm, Gazipur at every week throughout the year. But higher numbers of natural enemies were found in the seedbed.

The highest peak of insect pests in light trap was found in November across the locations. The highest number of BPH was observed during the month of November at Gazipur. But YSB was observed highest at Barishal and Rajshahi in November and May respectively. In case of natural enemies, the highest catch of natural enemies in light trap was recorded at Habiganj followed by Barishal, Rajshahi, Gazipur, Rangpur, Sonagazi and Cumilla.

In T. Aman season, peak of BPH and WBPH was observed in October at the village of Fatepur, Pirganj, Rangpur. Among the natural enemies spider population was found highest in August to October. In Boro season, insect pest's incidence was very low. No yield loss occurred in researchers' practice field (T_1) where insect manage meat was done without insecticide in Boro season and one time application at T. Aman season. But farmers' practice field (T_2) insecticide was used 3 to 4 times.

FAW was monitored in eight weeks but no fresh window panes and infested plant was found during scouting. On average 0 to 0.31 moth/trap/day observed at BRRI farm, Gazipur. Irrespective of sex developmental period of *Cnaphalocrosis medinalis* from egg to adult was 28.88 days at 25°C and 26.04 days at 30°C.

Ecological engineering approaches reduced insecticide use and conserved natural enemies in rice ecosystem. The highest natural enemies, % egg parasitism of YSB and larval parasitism of rice leaffolder were observed in rice field with nectar-rich flowering plants on bunds (Eco-engineering). However, least natural enemies and parasitism were found in farmers' practice rice field where 3-4 times insecticides were applied. Moreover, there was no yield reduction observed in eco-engineering field compared to farmers practice field (insecticide application).

Pathogenicity of entomogenous fungi showed around 63% mortality of BPH after seven days of inoculation.

There was no significant difference was observed in tiller and panicle per hill in YSB infested hill and uninfested hill, Percent filled grain per panicle was found the highest (80.64%) in infested hills compared to un-infested hills (79.53%). This indicated that when YSB larvae damaged any tiller of a particular hill the plant supply more nutrient to other tiller of the same hill. As a result, more filled grain number was found in the panicle of infested hill which compensate the loss of damaged tiller. So, no yield loss was found by the damage of YSB at early crop stage when dead heart and white head remain below 3 and 1% respectively.

Rice leaffolder moth catches per pheromone trap per week increases from August to October. Highest number of leaffolder catches 5 moth/trap/day observed in October.

Among the six insecticides i.e., acetamiprid, spinosad, abamectin, chlorantraniliprole, fipronil and chlorpyrifos, abmectin was found relatively safer to natural enemies of rice insect pests.

A total of 104, 16 and 4 commercial formulations of insecticides were evaluated and 85, 14 and 4 insecticides were found effective respectively against BPH, YSB and rice weevil.

Tested nano-particles of Ag, Cu and ZnO showed less than 30% mortality of BPH nymph. More experiments with new nanoparticles are planned to be tested against more insect pests including BPH, leaffolder, rice hispa and stem borer.

In pesticide residue analysis, the concentrations of chlorantraniliprole, thiamethoxam and imidacloprid were 0.00012 to 0.00013, 0.0014 to 0.0073 and 0.0008 to 0.0013 mg/kg respectively in the polished rice grain of different treatments. In another analysis the concentrations of chlorantraniliprole was found 0.00058 to 0.0015 mg/kg. However, the detected amount of

chlorantraniliprole, thiamethoxam and imidacloprid in the samples were below the maximum residue limit (MRL).

A total of 350 F_3 lines from the population of BRRI dhan87 × IR101791-10-1-4-3-2-4 cross and 300 F_3 from the population of BRRI dhan89 × IR101791-10-1-4-3-2-4 cross lines were advanced to F_4 in Rapid Generation Advance (RGA) Nursery.

For BRRI dhan89, a total of 280 F_3 lines from the population of BRRI dhan89 X Acc489 cross were advanced to F_4 generation in Rapid Generation Advance nursery.

A total of 1335 advance breeding lines were screened to identify resistance sources against major insect pest BPH. Among them 78 line showed moderately susceptible reaction (SES score 5) against BPH.

We have employed CRISPR/Cas9 tool to create novel alleles of CYP71A1 leading to introduction of insect resistance into an elite rice variety BRRI dhan92. PCR analysis of putative transformants using primers targeting the flanking regions of sgRNA of CYP71A1 identified mutation in T0 generation. Sequence analysis of T0 lines identified mutations located within sgRNA region. This study has demonstrated the use of CRISPR/Cas9 in creating novel alleles of CYP71A1 to introduce insect resistance into any susceptible rice varieties.

To identify the resistance mechanism of BRRI dhan33 against gall midge we made a cross between BRRI dhan33 and BRRI dhan49. The true F_1 population was selected using RM5770 marker and was progressed to get F_2 population.

To develop improved BPH resistance three/two gene pyramiding lines using marker assisted breeding, we made a cross between IR 101791-10-1-4-3-2-4 which has two resistance genes (*Bph2* + *Bph32*) and BRRI dhan89 susceptible to BPH. The F_1 plants were confirmed using molecular marker. The selected F_1 plants were transplanted for crossing again with IR 101796-1-2-3-20 which carrying one BPH resistance gene (*Bph20*).

Among the four rodenticides Phostoxin was very effective followed by Rat killer, Lanirat and Zinc phosphide in the rice field.

PI: Panna Ali, **CI:** Sadia Afrin

SURVEY AND MONITORING OF RICE ARTHROPODS

Pest and natural enemy incidence at BRRI farm, Gazipur

Rice insect pests and natural enemies were monitored in five habitats (seedbed, grass fallow, irrigated rice, rice bund and upland rice) at BRRI research farm, Gazipur at every week throughout the year. Data were collected using 100 complete sweeps from each habitat. The overall insect pest incidence was low in the reporting year. Green leafhopper (GLH), white leafhopper (WLH) and grasshoppers (GH) were the most abundant pests and found in all habitats. The highest number of GH was found in transplanted rice (T. rice) followed by rice bund, grass fallow and seedbed (Fig. 1).

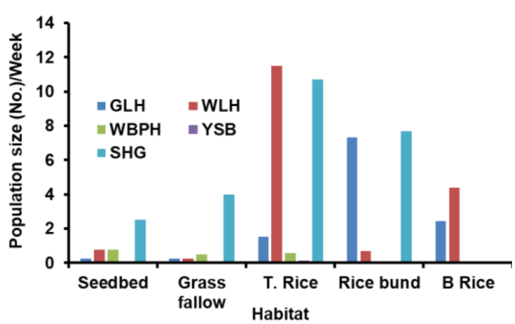


Fig. 1. Incidence of insect pest in different habitats at BRRI farm, Gazipur.

Higher numbers of natural enemies were found in the seedbed. Spider (SPD), damsel fly (DF), ladybird beetle (LBB) and carabid beetle (CDB) were the dominant predators in all the habitats of the reporting year (Fig. 2).

PI: Md Panna Ali, **CI:** Sadia Afrin, **PL:** Sheikh Shamiul Haque

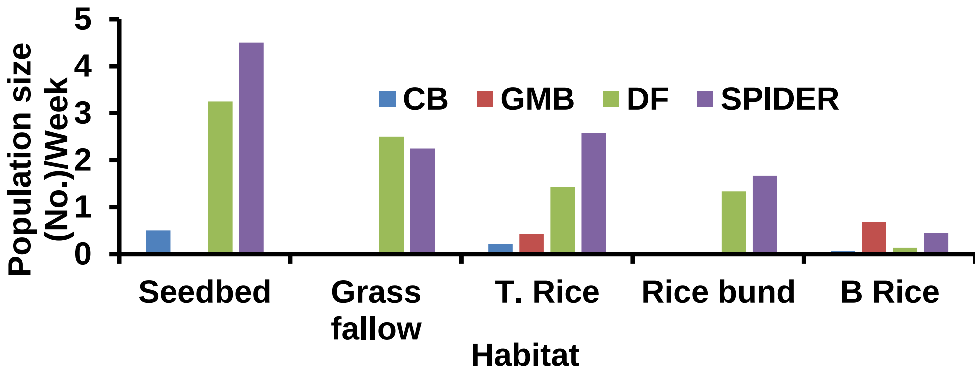


Fig. 2. Incidence of natural enemies in different habitats at BRRI farm, Gazipur

Incidence of insect pests and natural enemies in light trap

Rice insect pests and their natural enemies were monitored throughout the year by Pennsylvanian light trap from dusk to dawn BRRI HQ, Gazipur and six BRRI Regional stations. The abundance of BPH, WBPH, GLH and YSB was observed almost all the seven locations. Total number of insect pests was the highest at BRRI, Gazipur followed by Barishal, Rajshahi, Habiganj, Sonagazi, Rangpur and Cumilla (Fig.3).

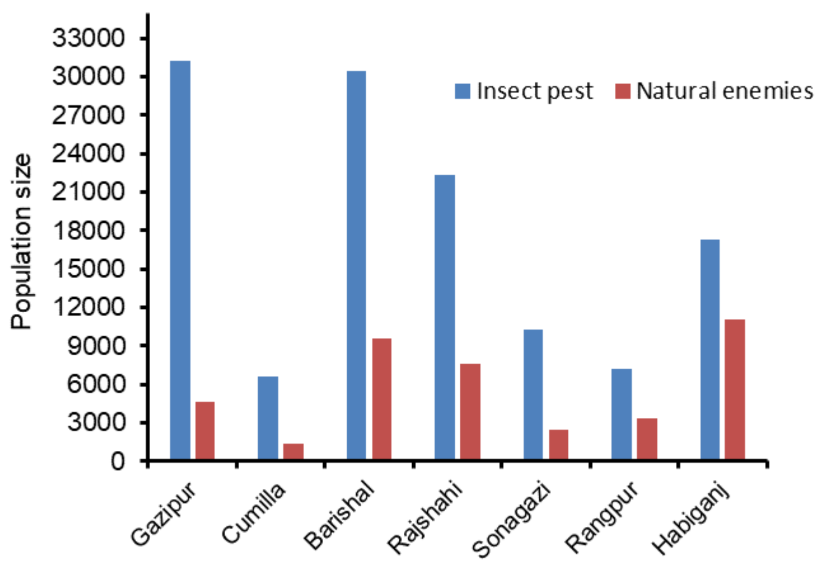


Fig. 3. Insect pests and natural enemies at BRRI HQ, Gazipur and six regional stations (RS).

Among the major insect pests, the highest number of BPH was observed in November and May at Gazipur. Three peak of WBPH was found in October, August and May at BRRI Gazipur and one peak in December observed at BRRI RS, Rajshahi. The highest peak of YSB was observed at BRRI RS Barishal in November and BRRI RS, Rajshahi in May. Usually stemborer shows two peaks in a year- one in April-May and the other in October-November (Fig 4). Higher populations of GLH was found in November at BRRI RS, Rajshahi and BRRI RS, Sonagazi. But GLH was found the highest in December at BRRI RS, Barishal (Fig. 4). In conclusion, the higher peak of insect pests was found in November-December and May to June across the locations.

PI: Sadia Afrin, **CI:** Sheikh Shamiul Haque

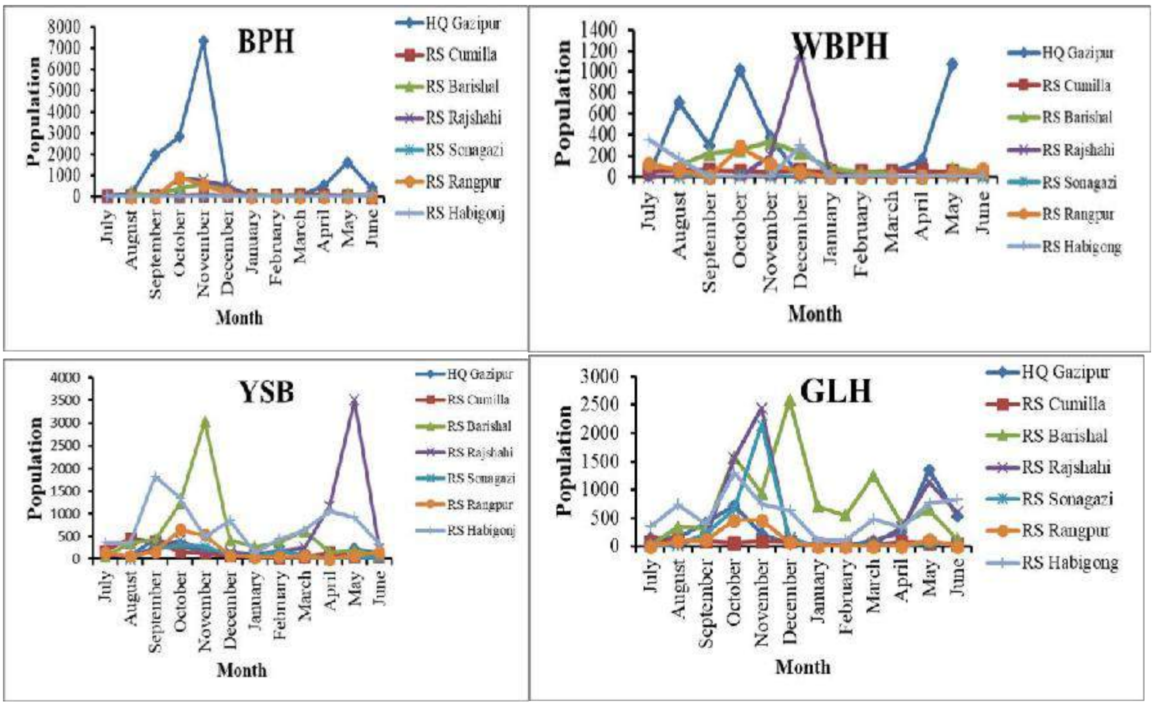


Fig. 4. Incidence pattern of major insect pests in light trap, BRRI HQ, Gazipur and regional stations during July 2021-June 2022.

On the other hand, among the natural enemies CDB showed the highest population at Habiganj in November and April (Fig. 5). GMB population of Rajshahi was higher than those of other stations. The highest peak was observed in June at Barishal. Similarly, in contrast, two peaks of STPD were observed at Barishal in March and October (Fig. 5). A small peak of STPD was observed in December at BRRI, Rajshahi. Among natural enemies, the highest peak was found in November and April for CDB, June for GMB, and March for STPD (Fig. 5).

PI: Sadia Afrin, **CI:** Md Panna Ali, **PL:** Sheikh Shamiul Haque

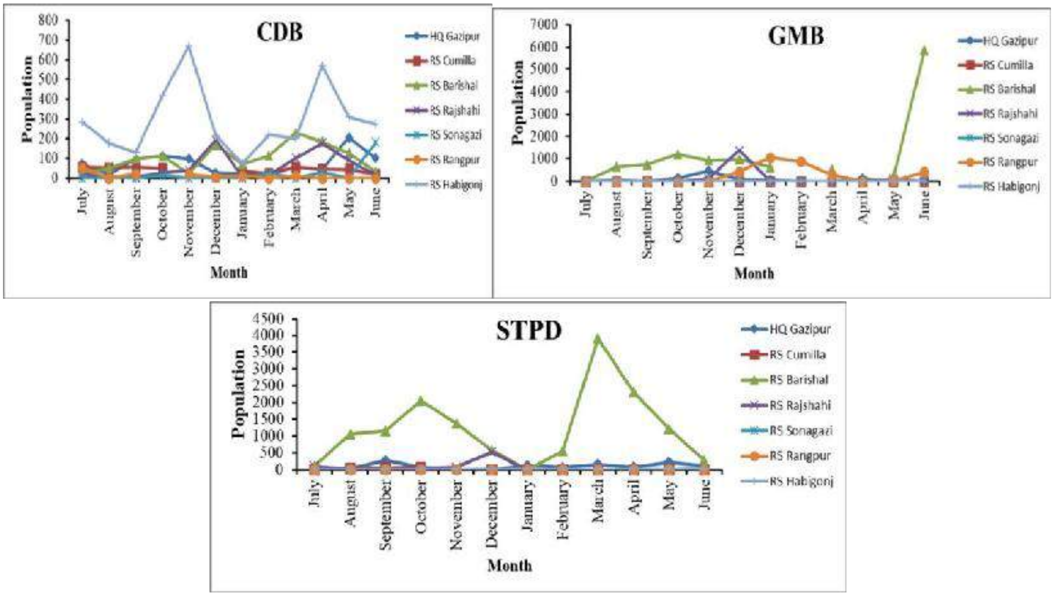


Fig. 5. Incidence pattern of natural enemies of rice insect pest in light trap, BRRI HQ and regional stations, July 2021-June 2022.

Survey and monitoring of rice arthropods and yield loss assessment in a selected village

The experiment was conducted in a block (7.92 acre) of 18 farmer's fields during T. Aman 2021 season at the selected village Fatepur, Pirganj, Rangpur. During Boro 2021-22 season, 12 experiments were conducted in 12 different farmers' field in Rangpur region. One portion of farmers' field was managed with BRRI recommended practices treated as T_1 (Researchers' practice). Another portion was remained under the respective farmers' supervision without any intervention treated as T_2 (Farmers practice). BRRI released high yielding variety BRRI dhan87 and BRRI dan89 were used in T. Aman and Boro season respectively both in T_1 and T_2 (Fig. 6). The highest brown planthopper (BPH) and white backed planthopper (WBPH) was observed in October and grasshopper (GH), in August to September (Fig. 7). Among the natural enemies Spider population found the highest during August- October (Fig. 7). Other natural enemies like damsel fly (Dam. Fly), dragons fly (Drag. Fly), LBB and green mirid bug (GMB) population reduced during October in comparison to Aug-September. That might be happened due to frequent insecticide application in neighbouring field (Fig. 7.). During Boro season, insect pest's incidence was very low. No yield loss occurred in researchers' practice field (T_1) where insect manage without insecticide in Boro season and one time insecticide application at ETL during T. Aman season. But farmers' practice (T_2) used insecticide 3 to 4 times. Similar grain yield was obtained both in research practiced field (T_1) and farmers practiced field (T_2) i.e., 5.36 and 5.13 t/ha respectively during T. Aman season and 7.81 and 7.75 t/ha in T_1 and T_2 respectively during Boro season (Fig 8). Two field days were conducted during two seasons. More than 100 neighbouring farmers were attended in each field day programme.

PI: Md Nazmul Bari, **CI:** All Entomologists

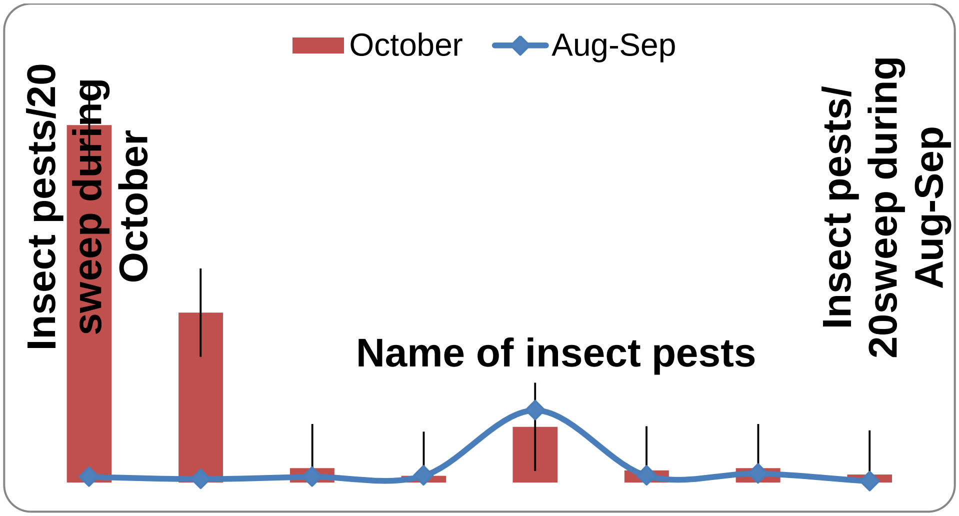


Fig. 6. Insect pests status during August-September in comparison with October at the village Fatepur, Pirganj, Rangpur during T. Aman 2021.

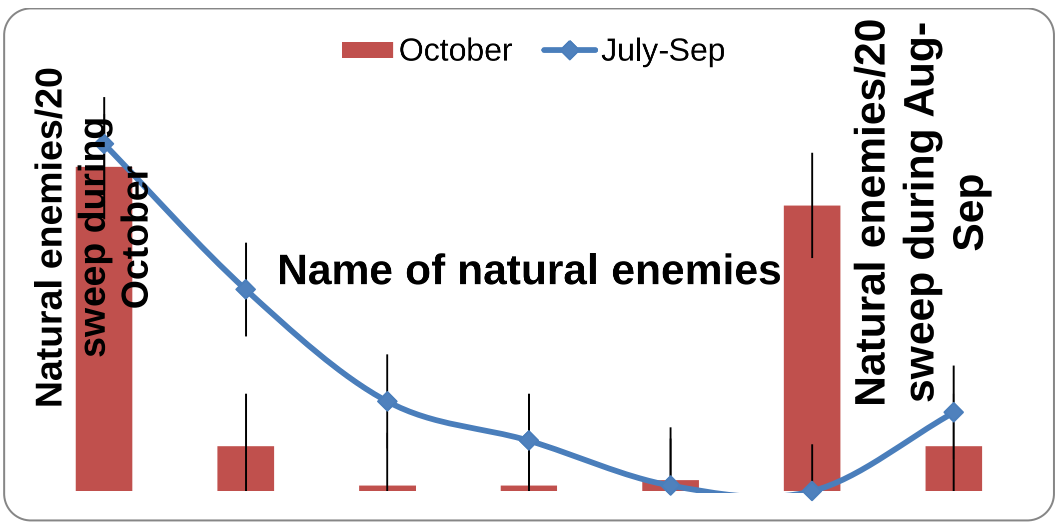


Fig. 7. Natural enemies status during August-September in comparison with October at the village Fatepur, Pirganj, Rangpur during T. Aman 2021.

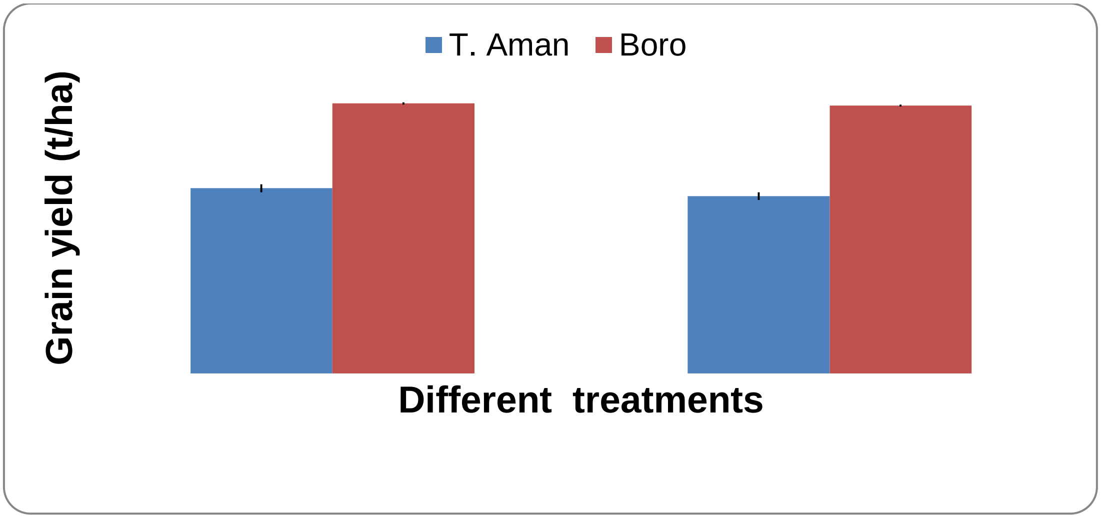


Fig. 8. Grain yield of BRRI dhan89 in researchers practice (RP) field and farmers practiced (FP) field at Rangpur during T. Aman 2021 and Boro 2021-22.

Fall Armyworm (FAW) monitoring through pheromone trap on rice crops

Five pheromone traps were set 100 m between traps (in separate fields) in rice from vegetative to ripening stage of rice crops (in separate fields) at BRRI HQ, Gazipur, during Boro 2021-22. There was no maize field at least 200 m apart. Every Monday the trap catch and field scouting data were collected and recorded. The highest population of FAW (7 moths/trap) was trapped in April 2022 at BRRI, Gazipur. FAW was monitored eight weeks but no fresh window panes and infested plant was found during scouting. On average 0 to 0.31 moth/trap/day observed at BRRI, Gazipur.

PI: Md Nazmul Bari, **PL**: Sheikh Shamiul Haque

BIO-ECOLOGY OF RICE INSECT PEST AND NATURAL ENEMY

Effect of temperature on the biology and lifecycle of rice leaffolder (*Cnaphalocrosis medinalis*)

Rice leaffolder (RLF) *Cnaphalocrocis medinalis* (Guenee) [Lepidoptera: Pyralidae] colony was maintained on BR3 plants under greenhouse conditions at BRRI, Gazipur to know the impact of elevated temperature on the development of RLF. Response to temperature will be assessed by exposing *C. medinalis* eggs to five constant temperatures (20, 25, 30, 35, and 40°C) in separate experiments in the growth chamber. Egg hatching period was almost similar in 25°C and 30°C temperature but at 20°C it was longer (Table 1).

Larval and pupal duration were higher in 20°C compared to 25°C and 30°C. Total duration of egg to adult was longer at 20°C. However in 30°C, adult longevity was higher. The growth duration of different stages was affected by temperature: the duration decreased as the temperature increased. The duration of the egg stage was similar in both the temperatures (25 and 30°C). At temperatures higher than 25°C, larval development took shorter period. At 25, and 30°C, pupal developmental duration was 7.98, and 5.9 d respectively (Table 1). At 25 and 30°C, egg - adult developmental duration was 28.88 and 26.02 d respectively (Table 1). Any deviation from the optimum temperature during their lifetime can cause changes in duration of life stages from larva to adult. More research of RLR in different temperatures is further needed to understand the mechanism of their behavioural adaptations.

PI: Farzana Nowrin, **CI:** Md Panna Ali

Table 1. Developmental duration from egg to adult (day) of leaffolder at different temperatures under 16L:8D photoperiod.

Temperature		Egg	Larva	Pupa	Egg to adult	Adult longevity
20°C	Number	36	26	24	24	20
	Mean	6	28	18	52	4.5
	Max.	7	30	19	56	6
	Min.	5	26	17	48	3
25°C	Number	66	66	62	65	35
	Mean	4.09	17.17	7.98	28.88	3.31
	Max.	5	20	13	34	7
	Min.	3	16	7	25	2
30°C	Number	29	22	21	21	14
	Mean	4.18	16.09	5.9	26.04	9.14
	Max.	6	20	8	31	13
	Min.	3	14	5	23	3
35°C	Number	50	Only 5% egg hatched (require more experiments)			
40°C	Number	50	Egg did not hatch (repeat the experiment)			

BIOLOGICAL CONTROL OF RICE INSECT PESTS

Leveraging diversity for ecologically based pest management

Two experiments were conducted with BRRI dhan87 and BRRI dhan88 at BRRI farm, Gazipur during T. Aman 2021 and Boro 2021-22 season respectively to conserve natural enemies through ecological engineering approaches and to reduce insecticide use in rice production. A large field (one acre) was divided into two blocks for two treatments. The treatments were T_1=Rice field with flowering plants (sesame and cosmos in T. Aman season Marigold and cosmos in Boro season) on bunds (to provide food and shelter for different parasitoids). T_2=Farmers practice i.e. prophylactic insecticide use. Insect pests status remained below the economic threshold level (ETL) in both the treatments and seasons. The highest numbers of natural enemies except Drag. fly were found in T_1 where insecticide was not used. Number of SPD, Dam. fly, LBB and CBB was found the highest 8.25, 8.0, 5.0 and 1.25 per 20 complete sweep respectively in $T_{1.}$ compared to T_2 (3.00, 1.25, 1.75 and 0.75 respectively) at BRRI farm, Gazipur (Fig. 9). YSB egg parasitisim and RLF larval parasitism observed the highest in T_1 (19.3 and 22.70 % respectively) compared to T_2 (0 and 2.25 % respectivley) at BRRI, Gazipur (Fig. 10). Though grain yield was observed simillar both in T_1 and T_2 (5.81 and 5.85 t/ha respectivley). But additional sesame produced in T_1 which increased the rice eqivalent yield (REY). As a result 4.25 % additional yield obtained in T_1 compared to T_2 (Fig. 10). During Boro season, the highest number of SPD, Dam. fly and LBB (3.83, 2.50 and 3.17 respectively per 20 complete sweep) were also found the highest in T_1 compared to T_2 (Fig. 11). But simillar yield (7.06 and 7.13 t/ha) was obtained in T_1 and T_2 respectively. The highest natural enemies, % egg parasitism of YSB and larval parasitism of rice leaffolder were observed in rice field with nectar-rich flowering plants on bunds (Eco-engineering). However, least natural enemies and parasitism were found in farmers' practice rice field where four times insecticides were applied. Moreover, there was no yield reduction observed in eco-engineering field compared to farmers' practice field (insecticide application). Not only that, extra profit was obtained from T_1 with no or less use of insecticide. So, farmers should avoid the toxic and hazardous insecticides to control the insect pests by growing nectar-rice flowering plants on the bunds of rice crop.

PI: Md Nazmul Bari, **PL:** Sheikh Shamiul Haque

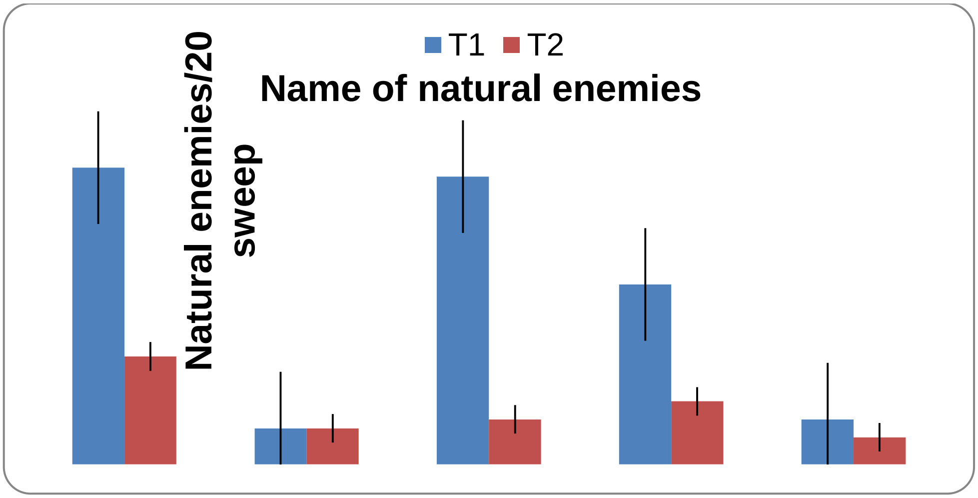


Fig. 9. Natural enemies number per 20 complete sweeps in different treatments during T. Aman 2021, BRRI, Gazipur. (T_1=Rice field with flowering plant on bunds, T_2= Farmers Practice i.e., insecticide application).

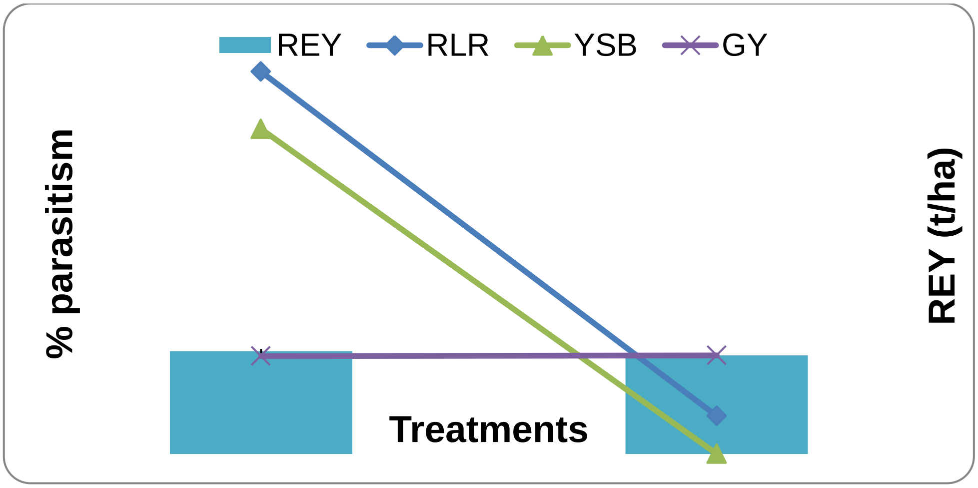


Fig.10. Rice equivalent yield (REY) and % parasitism of YSB and RLR larvae during T. Aman 2020, BRRI Gazipur. (T_1= T_1=Rice field with flowering plant on bunds, T_2= Farmers Practice i.e., insecticide application).

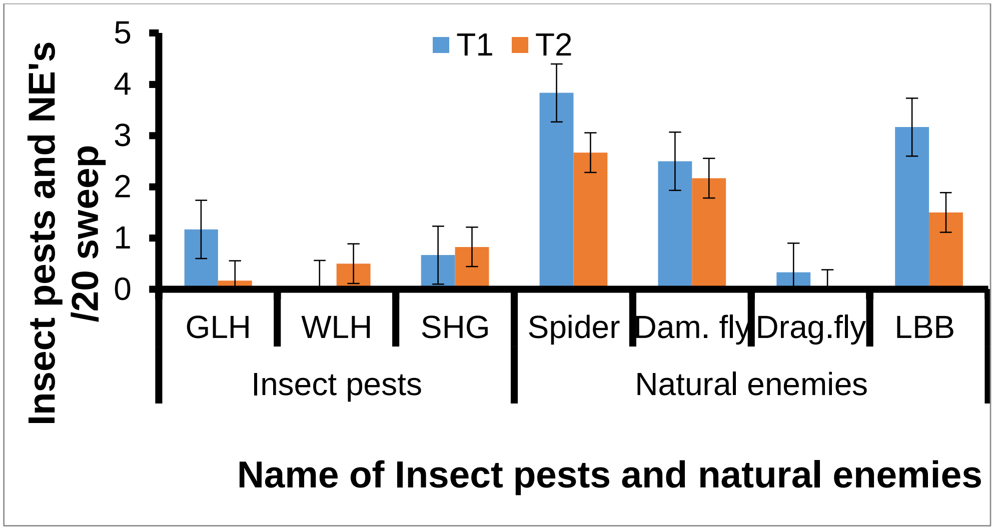
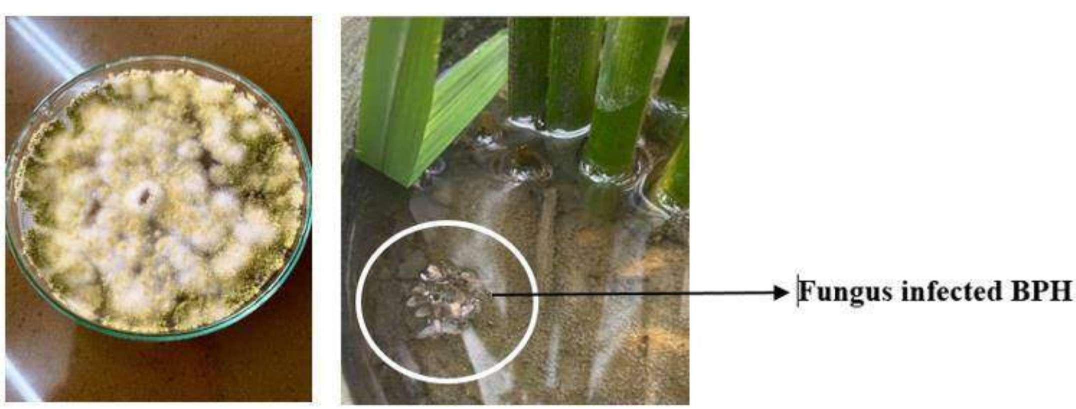


Fig. 11. Insect pests and natural enemies number / 20 sweeps during Boro 2021-22
(T_1=Rice field with flowering plants on bunds, T_2= Farmers practice i.e., insecticide application).

Study on entomopathogenic fungi to control BPH

The study was conducted at Entomology greenhouse, BRRI to isolate the fungi from naturally infected BPH and to know the pathogenicity of entomogenous fungi against BPH. The infected BPH with chalky white mass of fungus either sticking to the leaf sheath or floating on standing water was collected in sterile glass tube for isolating the causal organism in the laboratory of Plant Pathology Division, BRRI. Then fungus culture was isolated and purified by standard protocol. Potted BR3 plants were infested by ten 3rd-4th instar BPH nymphs of greenhouse populations and confined by mylar film cages. Fungus was sprayed at the rate of 1×10^6 conidia/mL per plant. Two treatments including control were used in this study. The treatments were, T_1- Fungus spray before three days of insect infestation, T_2- Fungus spray after two days of insect infestation and T_3- Control. Each treatment had six replication with CRD in pots in the net house of Entomology Division.



Photograph. 4. Fungus isolation in the petri dish and infected dead BPH.
(White circle indicates the fungus infected BPH floating on water close to rice plants).

BPH mortality was observed 63% and 60% respectively in T_1 and T_2 whereas, control treatment showed 20% mortality. This result indicates that spraying of fungus before insect infestation is more effective than spraying after infestation which means fungus need time to grow on plants to show its pathogenicity.

PI: Farzana Nowrin, **CI**: Quazi Shireen Akhter Jahan **PL:** Sheikh Shamiul Haque

CROP LOSS ASSESSMENT

Effect of dead heart and white head on grain yield of BRRI dhan89

The experiment was conducted in a randomized complete block design (RCBD) with 16 replications in Boro season with BRRI dhan89 at BRRI research farm, Gazipur to determine the yield loss and recovery abilities of BRRI dhan89 against stem borer damage. Four hills were selected diagonally from each plot and infested with the 1st instar larvae of one egg mass after 35 days after transplanting (DAT). Another four hills from the same plots were also selected as control. On average 3.13 % dead heart and 0.77% white head was observed when rice plant infested at 35 DAT. There was no significant difference was found in tiller per hill between infested and un-infested hill when average 3.13% dead heart was found at 50 DAT in BRRI dhan89 (Table 2). At maturity stage, significant difference was also not found in panicle per hill, pant height and panicle length between infested and uninfested hill (Table 2). But significantly higher filled grain number (1705.73/hill) was found in infested hill compared to uninfested hill (1,634.57/hill). As a result significantly similar grain weight was found (80.64 g/hill) in infested hill and uninfested hill, 79.53 g/hill (Table 2). Again, unfilled grain number reduced significantly in infested hill (332.59/hill) compared to uninfested hill (410.33/hill). As a result, percent filled grain per panicle was found the highest (80.64%) in infested hills compared to uninfested hills (Table 1). This indicates that when YSB larvae damaged any tiller of a particular hill the plant supply more nutrient to other tiller of the same hill. As a result, more filled grain number was found in the panicle of infested hill which compensate the loss of damaged tiller. So, no yield loss was found by the damage of YSB at early crop stage when dead heart and white head remain below 3 and 1% respectively.

PI: Md Nazmul Bari **PL:** Sheikh Shamiul Haque

Table 12. Plant characteristics, yield component and yield of BRRI dhan89 in different treatments at BRRI, Gazipur, Boro 2021-22.

Treat	Tiller/ hill (Mean ±SE)	Pani/ hill (Mean ± SE)	Pl ht (cm)	Pani. length (cm)	FGN/hill (Mean ± SE)	UnFGN /hill	%FG/panicle (Mean ± SE)	Grain wt/hill (Mean ± SE)
T_1	14.08±0.35 n=60	13.53 ± 0.35 n=60	105.38 ± 1.62 n=60	21.83±0.18 n=60	1705.73 ± 3.78a n=60	332.58 ± 1.04 b n=60	80.64 ± 1.24 n=60	41.77 ± 0.83 n=60
T_2	13.83 ±0.36 n=60	13.52 ± 0.35 n=60	104.92 ± 0.55 n=60	21.78±0.14 n=60	1634.57 ± 3.25b n=60	410.33 ± 1.21 b n=60	79.53 ± 0.91 n=60	39.87 ± 0.86 n=60
Significance	*NS*	*NS*	*NS*	*NS*	*P<0.01*	*P<0.05*	*P<0.01*	*NS*

Data were analyzed using Statistix 10 program NS= Not significant T_1= Infested hill, T_2= Un-infested hill SE=Standard error

INTEGRATED PEST MANAGEMENT

Use of sex pheromone to control leaffolder, *Cnaphalocrosis medinalis*

Pheromone lures for rice leadfolder were collected from Ispahani Biotech (Ispahani Agro Limited) and used for these studies. The test was conducted in BRRI research field at Gazipur. The optimal blend of used pheromone for leaffolder was Z11-18:Ald, Z13-18:Ald, Z11-18:OH and Z13-18:OH at a ratio of 3 : 25 : 3 : 3. For leaffolder, each trap contained one lure tube which was impregnated with a mixture of (Z)-11 hexadecenal + (Z)-9 hexadecenal in 3:1 ratio. Pheromone traps were placed at 30 cm above the crop canopy and maintained a distance 20 m from one trap to another one. Significant numbers of leaffolder were caught in each trap in Gazipur (Fig. 12). Number of moth catches varied to time. Figure 12 shows that catches per trap per week increases from August to October. However, the highest number of leaffolder catches was observed in 25 October. This result indicates that pheromone trap can be effective to monitor and control leaffolder in rice field.

PI: Md Panna Ali, **CI:** Farzana Nowrin, MM Moniruzzaman Kabir,

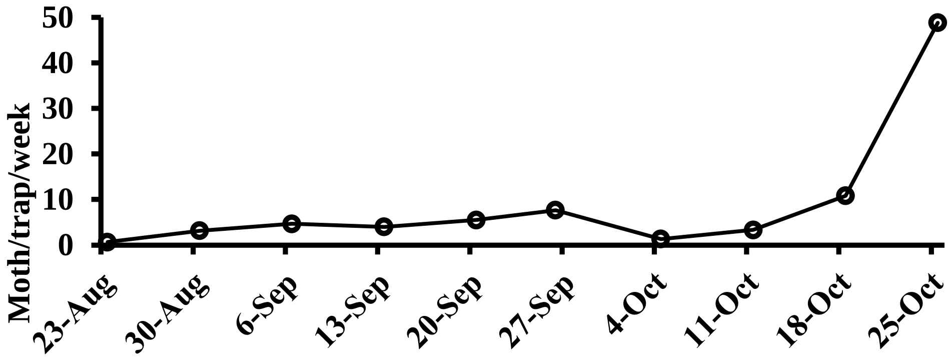


Fig. 12. Catches of leaffolder (LF) moths in sex pheromone trap in different dates of August to October. Dot represents the mean of 10 traps per week.

EVALUATION OF CHEMICALS AND BOTANICALS AGAINST RICE INSECT PESTS

Test of different insecticides against major insect pests

The effectiveness of commercial formulations of different insecticides against major insect pests of rice was evaluated in field and storage condition. A total of 104 commercial formulations of insecticides were evaluated against BPH. Among them 85 insecticides were found effective against BPH. For YSB, out of 16 commercial formulations, 14 found effective. Four insecticides were tested against RW and all were found effective. Among all the tested insecticides, one was biopesticide and it was found effective against BPH.

PI: Md Panna Ali, **CI:** Farzana Nowrin, PL: Sheikh Shamiul Haque

Use of nanoparticle to control rice insect pests

Three nanoparticles including Ag, Cu and ZnO were tested against brown planthopper (BPH). The efficacy of Ag, Cu and ZnO nanoparticles against BPH was tested at five different concentrations (4000, 2000, 1500, 1000, and 500 PPM), which were prepared by dilutions with distilled water. Distilled water was used as a negative control treatment. Ten-15-day-old rice seedlings were dipped into each nanoparticle solution at three concentrations. After one minute seedlings were removed from the solution and allowed to air dry. The treated seedlings were then placed into a 25 ml test tube. Ten 3rd -4th instar nymphs of BPH were released into each test tube and kept them at 27 ± 1°C. In addition, nanoparticles were tested against BPH using seedling spray method. Mortality was recorded after 48 and 120 h. The nymphs were considered dead if they failed to move when gently prodded with a fine bristle. The size of Ag, Cu and ZnO nanoparticles is 20, 40 and 20-30 nm respectively. Tested nano-particles showed below 30% mortality of BPH nymph (Fig. 13). It indicates that tested nanoparticles were not effective against BPH. More experiments with new synthesis nanoparticles are planned to be tested again using more insect pests.

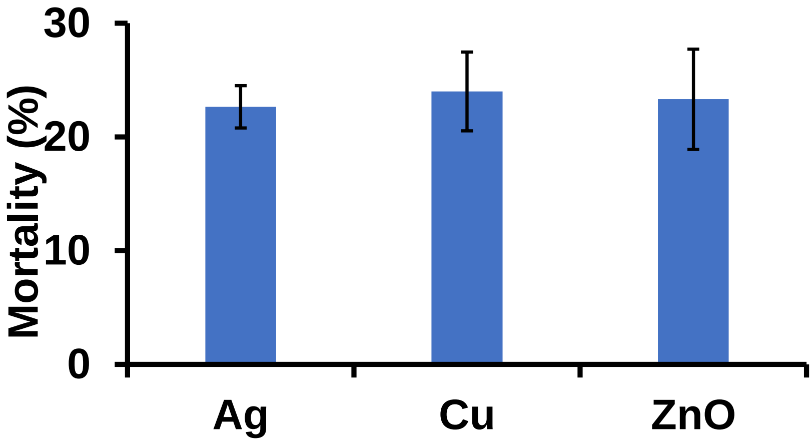


Fig. 13. Effect of nanoparticle on the mortality of brown planthopper (BPH). Error bar represents standard error.

Effect of insecticides on natural enemies of rice insect pests

Six **c**ommercially registered insecticides for rice of different chemical group were evaluated at BRRI, Gazipur to know the effect of insecticides on natural enemies of rice insect pests. The generic name of six insecticides are acetamiprid, spinosad, abamectin, chlorantraniliprole (virtako), fipronil and chlorpyrifos. Number of insect pests and non-pest insects (natural enemies and neutral insects) per 20 sweeps were counted after 48 hours of spraying. Total non-pest insects (466) were found the highest in control. But among the six insecticides, more non-pest insects were found in abamectin (311) which indicates that abamectin comparatively safe for natural enemies of rice pest.

PI: Md. Mosaddque Hossain, **PL:** Sheikh Shamiul Haque

INSECTICIDE TOXICOLOGY

Residues analysis of different insecticide in rice grain

Sample was collected from insecticide treated field and extraction was conducted using acetonitrile (ACN) following Association of Official Agricultural Chemists (AOAC) method of analysis with primary secondary amine (PSA). Pesticide residues were detected using a LC-MS2020 fitted with electrospray ionization (ESI) probe operated in the positive ion mode. The following parameters were optimized for chlorantraniliprole, thiamethoxam and imidacloprid: capillary voltage, 3500 V; ion source temperature, 150°C; desolvation gas temperature, 500°C; desolvation gas flow rate, 1000 L h-1 of nitrogen. Detection was carried out in multiple reactions monitoring (MRM) mode. The retention time of chlorantraniliprole was 2.3 minute, thiamethoxam 1.9 minute and imidacloprid 7.95 minute. The concentrations of chlorantraniliprole, thiamethoxam and imidacloprid in the tested samples were 0.00013 to 0.00012, 0.0073 to 0.0014 and 0.0008 to 0.0013 mg/kg in chlorantraniliprole, thiamethoxam and imidacloprid respectively in the polished rice grain of different treatments (Table 3). However, the detected amount of chlorantraniliprole, thiamethoxam and imidacloprid in the samples were below the Maximum Residue Limit (MRL: 0.4 mg kg-1 for chlorantraniliprole) and 0.6 mg kg-1 for thiamethoxam and imidacloprid, EU). Residue analysis of chlorantraniliprole in rice grain at different days after flowering (DAF) was also tested. The concentrations of chlorantraniliprole in tested samples were found 0.00058, 0.00060 and 0.0015mg/kg at 5, 10 and 15 DAF respectively which were also below MRL according to EU (Table 4).

PI: Md. Nazmul Bari **CI:** Md. Panna Ali, Farzana Nowrin and Sadia Afrin

Table 3. Residue analysis of chlorantraniliprole, thiamethoxam and imidacloprid in rice grain of different doses.

Treatment	Insecticide residue (PPM)			EU MRL*	EU MRL*
	chlorantraniliprole (CTP)	thiamethoxam (THM)	Imidacloprid (IMIDA)	CTP	THM and IMIDA
T_1=Prophylactic use (3times) @ std. dose	0.00013	0.0073	0.0008	0.4	0.6
T_2=Double of std.dose (one time)	0.00012	0.0014	0.0013		
T_3= Control	n.d.	n.d.*	n.d.*		

n.d.* = not detected, EU MRL*=European union Maximum residual limit

Table 4. Residue analysis of chlorantraniliprole in rice grain at different days after flowering (DAF).

Treatments	**Insecticide residue (PPM)**	**EU MRL***	
T_1= Insecticide application at 5 DAF	0.00058		
T_2= Insecticide application at 10 DAF	0.00060		R^2=0.9992597
T_3= Insecticide application at 15 DAF	0.0015	0.4	
T_3= Control	n.d.*		

n.d.* = not detected, EU MRL*=European union Maximum residual limit

Detection of chlorantraniliprole and thiamethoxam residue in different rice varieties

Different rice samples were collected from various sources including Indian and Thai rice varieties. Insecticide residues were detected using a LC-MS2020 fitted with electrospray ionization (ESI) probe operated in the positive ion mode. The retention time of chlorantraniliprole was 2.3 minute and thiamethoxam 1.9 minute. The concentrations of chlorantraniliprole and thiamethoxam in the tested samples were below the Maximum Residue Limit (MRL: 0.4 mg kg-1 for chlorantraniliprole) and 0.6 mg kg-1 for thiamethoxam, EU) (Table 5). In some samples i.e., Indian white rice, Thai home mali rice, Chinigura rice and Jasmine rice residues were not detected (Table 5).

PI: Md. Panna Ali, **CI.**: Dr. Md. Nazmul Bari

Table 5. Analysis of pesticide residues in rice grain of different varieties.

Rice variety	Insecticide residue (PPM)		EU MRL*	
	chlorantraniliprole (CTP)	thiamethoxam (THM)	CTP	THM
BRRI dhan49	0.004	0.034		
Indian white rice	n.d.	n.d.*		
Thai home mali rice	0.02	n.d.*		
Indian pusa white rice	0.05	0.39	0.4	0.6
Chinigura rice	0.03	n.d.*		
Jasmin rice	0.06	n.d.*		

n.d.* = not detected,

HOST PLANT RESISTANCE

Development of BPH resistance breeding lines through marker assisted selection

IR101791-10-1-4-3-2-4 is an indica introgression line with stable resistance to BPH, which was used for developing elite donor and introgress resistance gene into modern cultivar. BRRI dhan87 and BRRI dhan89, susceptible to BPH, was applied to develop mapping population by crossing with IR101791-10-1-4-3-2-4. For BRRI dhan87: A total of 350 F_3 lines were advanced from the population of BRRI dhan87 × IR101791-10-1-4-3-2-4 cross. For BRRI dhan89: A total of 300 F_4

lines were advanced from the population of BRRI dhan89 × IR101791-10-1-4-3-2-4 cross. F_4 generation was advanced in rapid generation advance (RGA) Nursery

PI: Sadia Afrin, **CI:** M P Ali and M R A Sarkar (PBD)

Identification of BPH resistance sources from local germplasm

Acc 489 (Digha-3) is an indica introgression line with stable resistance to BPH, which was used for developing elite donor and introgress resistance gene into modern cultivar. BRRI dhan89, susceptible to BPH, was applied to develop mapping population by crossing with Acc 489. For BRRI dhan89, a total of 280 F_3 lines were advanced from the population of BRRI dhan89 × Acc 489 cross nursery. F_4 generation was advanced in RGA Nursery.

PI: S Afrin **CI:** MRA Sarkar (PBD)

Evaluation of advanced breeding lines screening against Brown Planthopper (BPH)

A total of 1,335 advanced breeding lines were screened at green house of Entomology Division to identify resistance sources against major insect pest BPH. Among them 78 lines showed moderately susceptible reaction (SES score 5) against BPH.

PI: Sadia Afrin, **CI:** Sheikh Shamiul Haque

Screening of advanced breeding lines against major insect pests of rice

Among thirteen rainfed lowland rice (RLR), two lines BRH15-24-7-B and BRH14-9-13-16B were found moderately susceptible (score 5) against BPH. Among six drought tolerant Rice (DTR) lines, none was found resistant. Among four zinc enriched rice (ZER) two lines BR10005-25-8-4-7-20 and BR10022-2-8-9-5-22 were found moderately susceptible (score 5) against BPH. Among seven submergence tolerance rice (ALART) lines, one line IR16F1148 showed moderately susceptible reaction against GLH. Among five RYT-1 advanced breeding lines of deep water rice (DWR), one line BRH11-2-4-7B was found moderately susceptible to WBPH. Among seven RYT-2 and seven RYT-3 advanced breeding lines of deep water rice (DWR), no resistant entry was found. No entry showed any resistant reaction among ten Boro 2021-22 RYT insect resistance (IRR) lines, eight salinity tolerant rice (STR-RYT 1) lines, twelve salinity tolerant rice (STR-RYT 2) lines, three salinity tolerant rice (STR-ALART1) lines, six salinity tolerant rice (STR-ALART 2) lines, five premium quality (PQR) and five Boro 2021-22 zinc enriched rice (ZER) advanced breeding lines.

PI: Md Mosaddque Hossain, **PL:** Sheikh Shamiul Haque

Screening of INGER IRSBN lines against major insect pests of rice

A total of 21 INGER IRSBN (Set-17), T. Aman 2021 breeding lines including two local susceptible and resistant checks were evaluated against stem borer in field condition according to IRRI prescribed procedure. Infestation was not exceeded the ETL for stem borer. Among the entries dead heart ranged between 0 to 4.89% and white head ranged between 0.15% to 1.74%. Only five entries SV0245, SV1078, SV1093, SV2003 and SV2018 showed no dead heart.

PI: Md Mosaddque Hossain, **PL:** Sheikh Shamiul Haque

Suppression of serotonin synthesis in rice using CRISPR Cas9 for insect pest control

In the production of CYP71A1 knockout (CYP71A1-KO) rice plant, a 20 bp fragment (5'-TGGTCGCGTTGAGGAGGAGC -3') of CYP71A1 gene was successfully cloned into the transfer vector, Cas9/gRNA. Electrophoresis and sequencing results confirmed the generated recombinant Cas9/gRNA contained the target sequence of interest. Successful recombinant Cas9/gRNA-CYP71A1 vector was transformed into *Agrobacterium tumefaciens* LBA4404 competent cell. Electrophoresis confirmed the successful recombinant Agrobacterium with target gene of interest was confirmed by PCR and used for co-cultivation. Calli of BRRI dhan87, BRRI dhan89 and BRRI dhan92 were developed using tissue culture technique. Successful calli were co-cultivated with recombinant *Agrobacterium*. Calli were cultured with shoot and root inducing medium in MS media supplemented with different hormone and antibiotic. Shoot was developed from callus (Fig. 14) and healthy shoot was transferred to root inducing media in glass bottle (Fig. 14). After 20 days in rooting media, rooted plants were transplanted in plastic pot and kept in greenhouse for further growth (Fig. 14). Cas9 specific primers were used to confirm the genome edited plants. Electrophoresis results confirmed that five plants harbored Cas9/gRNA vector (Fig. 15). The plants confirmed with Cas9 were progressed to next stage and leaf of all growing plants were collected and stored for genomic analysis. Sequencing of genome edited plants shows mutation occurred in target part of CYP71A1 (Fig. 16). Clear mutation area was identified in CRISPR Cas9 edited plants (Fig. 16).

Fig. 14. Development of plants from callus. Shoot developed from callus in petridish (Left side); Shoot was transferred in glass bottle for rooting (middle photo) and seedling transplanted in plastic pot (right side).

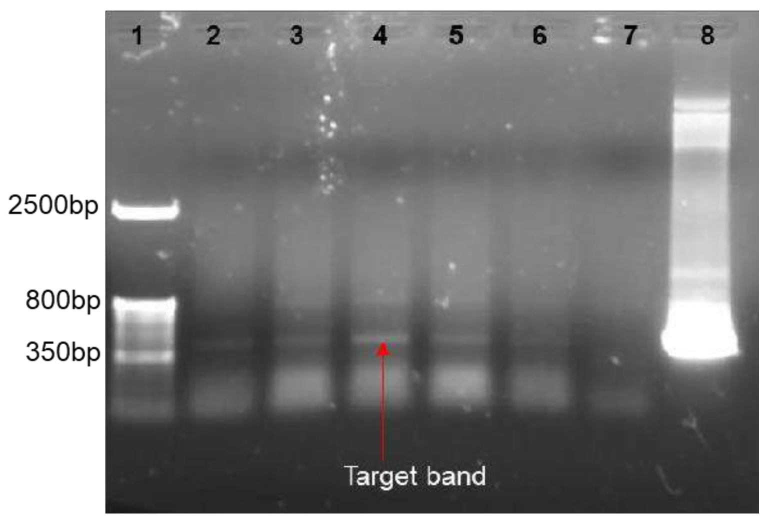


Fig. 15. Electrophoresis of PCR product amplified by SpCas9 primers. Lane 1: DNA ladder (50bp); lanes 2 - 6: CRISPR Cas9 edited plants (mutants); lane 7: BRRI dhan87 (control) and lane 8: Cas9/gRNA-CYP71A1 recombinant vector.

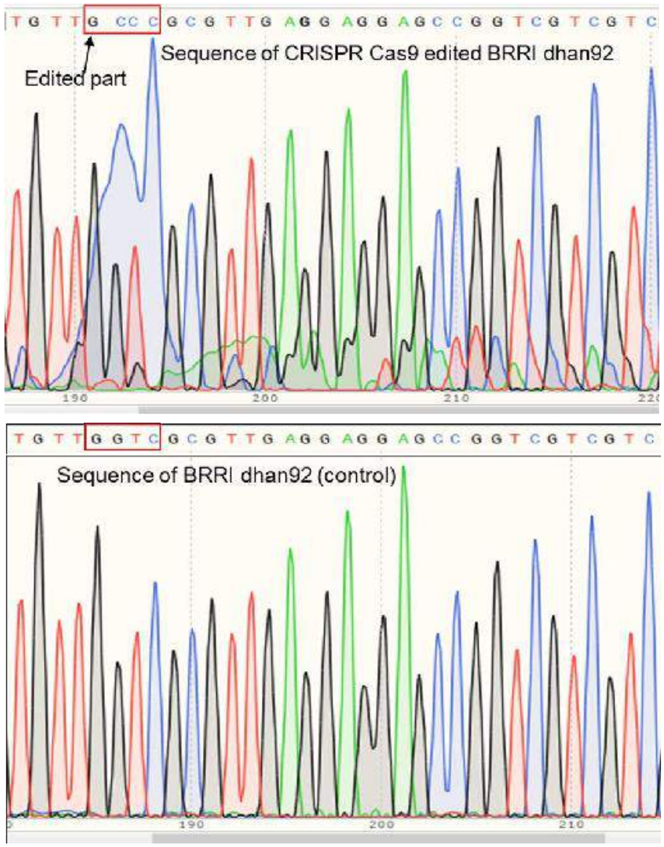


Fig. 16. Mutation area was identified in CRISPR Cas9 edited plants.

Resistance mechanism in BRRI dhan33 to rice gall midge

Previously we identified that BRRI dhan33 showed resistance to gall midge. However, mechanism of gall midge resistance is unknown. Therefore, this study was conducted to identify the gall midge resistance gene in BRRI dhan33. A gall midge resistant rice variety BRRI dhan33 was crossed with BRRI dhan49 which is highly susceptible to gall midge. The F_1 seeds were harvested and seeded to progress for next generation. We used RM5770 marker to identify the true F1 population. Selected F_1 plants were progressed to F_2 by selfing. Seeds from all F_2 plants were harvested and stored for phenotyping test against gall midge. In addition, we advanced some F_2 population and harvested seeds of F_3 population.

BRRI dhan49, an elite mega cultivar for T. Aman rice, is famous for its good quality, high yield, and wide culturing in Bangladesh. Unfortunately, such elite paddy cultivar is highly susceptible to gall midge. BRRI dhan33 was crossed with BRRI dhan49 to improve gall midge resistance of BRRI dhan49 and identify the resistance mechanism of BRRI dhan33. The F_1 population was screened using molecular marker and identified five true F_1 population. Polyacrylamide gel electrophoresis picture shows the true F_1 population derived from their cross (Fig. 17). The seeds of true F_1 population were seeded to develop F_2 population and harvested F_2 seeds. The harvested F_2 population seeds were stored for phenotyping test against gall midge.

PI: Md Panna Ali, ; CI: Sadia Afrin

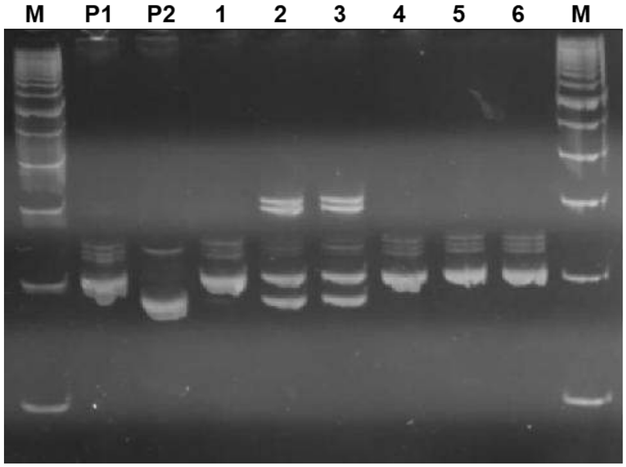


Fig. 17. Polyacrylamide gel electrophoresis patterns of SSR marker (RM5770). M = size marker; Lanes 1 - 6 = F1 population; P1 = BRRI dhan49; P2 = BRRI dhan33.

Pyramiding three BPH resistance genes (Bph2, Bph20, and Bph32) using marker-assisted selection in BRRI dhan89

We conducted this study in order to develop three/two gene pyramiding lines using marker assisted breeding. We made a cross between IR 101791-10-1-4-3-2-4 which has two resistance genes (*Bph2* + *Bph32*) and BRRI dhan89 susceptible to BPH. The F_1 plants were confirmed using molecular marker. The F_1 plant which showed two BPH resistance genes was selected and allowed to develop grains. At harvesting stage, seeds of selected plants were collected and seeded for crossing again with IR 101796-1-2-3-20 which carrying one BPH resistant gene (*Bph20*). We crossed IR 101791-10-1-4-3-2-4 and the elite indica variety BRRI dhan89 susceptible to BPH and got 5 F_1 plants. Gel electrophoresis picture shows the target gene in F1 population (Fig. 18). True F_1 plants were selected based on molecular marker and allowed to be progressed further development. Seeds from all true F_1 plants were harvested and stored for further studies. Some seeds of F_1 plants were seeded for further crossing with.

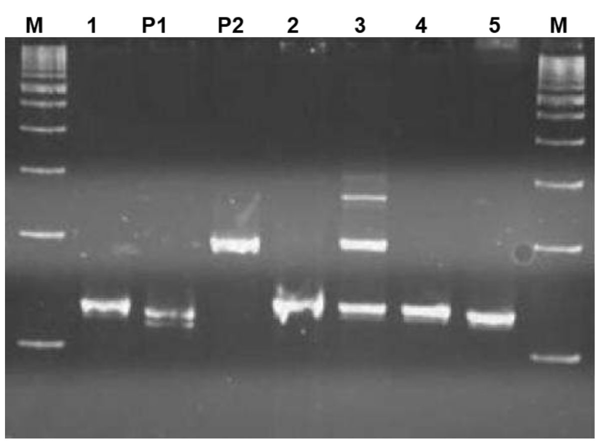


Fig. 18. Gel image (picture of the 1% agarose gel electrophoresis) showing target gene specific band after amplification. M = size marker; Lanes 1 - 5 = F1 population; P1 = BRRI dhan89; P2 = IR 101791-10-1-4-3-2-4.

PI: M P A **CI:** M R A

Molecular characterization of *Nilaparvata lugens* population in Bangladesh based on COI analysis

Brown planthopper, *Nilaparvata lugens* (Stål) is an important pest in Bangladesh. The present study analyses the genetic diversity of *N. lugens* by employing a partial fragment of the mitochondrial gene encoding cytochrome oxidase I (COI) using samples from nine different localities of Bangladesh. Nine full length COI gene sequences generated from this study with nine COI gene sequences retrieved from the Gene Bank were analyzed for genetic differentiation and haplotypes of *N. lugens* populations in order to determine the genetic structure. Based on the partial COI gene, high genetic homogeneity was detected in *N. lugens* populations of Bangladesh and they form a single genetic group. The Tajima's D test and Fu's F test also support our result, and indicate recent population expansion, while the phylogenetic tree suggests that geographically distinct populations of *N. lugens* do not exist in Bangladesh. However, our BPH population is distinctly different from Indian population (Fig. 1).

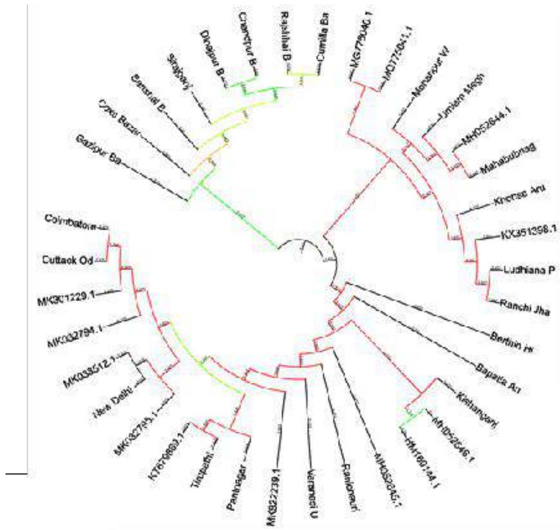


Fig.19. Phylogenetic tree of BPH population collected from nine locations of Bangladesh and compared to Indian population.

PI: Md Panna Ali, **CI:** Juel Datta

Genome sequencing of yellow stem borer (YSB)

Genome sequence information of economically important crop pests is important to provide genetic tools for designing next-generation pest-resistant rice. The development of such genomic data is crucial for understanding the epidemiological, evolutionary, and behavioural characteristics of crop pests. The importance of genomic information is evident with the increasing number of insect genomes being reported. However, genomic resources are sparsely available for YSB. With this background, genome information of YSB can provide insights into the structure, function, biology, molecular mechanisms, monophagy, and gene regulation. We reared YSB in greenhouse and collected sufficient number of adults, and females were selected based on the morphological features and were subject to whole-genome sequencing. For whole genome sequencing we sent collected samples to USDA/ARS, USA international partner. They are processing for further analysis. The DNA was isolated from the female adult YSB using a standard CTAB method and checked for quality and quantity on 0.8% agarose gel and Nanodrop, respectively.

VERTEBRATE PEST MANAGEMENT

Study on the efficacy of different commercial rodenticides against rice field rats

Efficacy of four different rodenticides available in market namely Lanirat, Zinc phosphide, Rat killer and Phostoxin were evaluated to control rat in rice field of BRRI, Gazipur in T. Aman 2021 and Boro 2021-22. Phostoxin was very effective followed by Rat killer, Lanirat and Zinc phosphide.

PI: Md Mosaddque Hossain, Md Mofazzel Hossain, **PL:** Sheikh Shamiul Haque


BRRI dhan97


BRRI dhan98


BRRI dhan99