Transformation in rice breeding research during last five decades at Plant Breeding Division of BRRI

Background:

Rice is the major cereal crop feeding around 180 million people in Bangladesh. The country is now almost self-sufficient in rice production, but its demand is increasing with the rapid growth of the population at an alarming rate of 1.37% under the scenario of decreasing cultivable lands annually by 0.45% due to urbanization, industrialization, and infrastructure development. Increasing production per unit area is the only option to sustain food security. Development of high yielding rice varieties with resilience to changing climates, unavailability and/or less availability of production inputs are the major thrust of rice research. Keeping the vision of the Father of the Nation Bangabandhu Sheik Mujibur Rahman "if we wish to have rice, we have to produce it by ourselves" in the core of heart, the breeders in BRRI have been working since its inception for the development of high yielding modern rice varieties resistant to pests and diseases, tolerance to drought, heat, cold, submergence and salinity. Considering consumers' needs breeders are also working on the development of rice varieties with premium grains and nutritional qualities. BRRI has far developed 106 high yielding modern rice varieties including seven hybrid varieties. Although adoption level is variable across the country, these varieties are cultivated by the farmers to meet up their needs, and thereby a few of them have emerged as the mega rice varieties contributing to major shares of the country's production.

Plant breeding act as the core component of the variety development program. Its major thrust includes the varietal development activities for favorable and marginal environments through both conventional and advanced plant breeding techniques. Plant Breeding Division was established with 13 scientists during the inception of BRRI in 1970. At that time plant breeding work was mostly based on the introduction, pure line selection, and to some extent of hybridization of exotic germplasms with local landraces/cultivars. In this context, BRRI released its first variety BR1 as 'Chandina' after the name of its location at Gazipur. BR3 was released as the first variety developed through the hybridization technique. Plant Breeding Division is now working for 18 major breeding programs with only 17 scientist at HQ and 9 scientists at RS,

although recently six more SSO positions at HQ has been created and approved by the government. Among these positions, 30% of the scientists remain always on leave/deputation for higher studies or training.

Vision: Development of sustainable, safe and profitable rice variety technologies
Mission: Ensure food security by developing climate smart high yielding rice varieties suitable favorable and marginal environments and play key role in attaining sustainable development goal by reducing poverty and hunger

Mandate:
The main responsibilities of Plant Breeding Division are –

- Development of improved rice varieties
- Improvement of traits
- Amplification of nucleus seeds and perform maintenance breeding
- Publish leaflet, booklets and provide training on new varieties to the farmers and extension workers
- Networking with national and international organization and share knowledge and ideas

Transformational changes in plant breeding research:

Since its inception, BRRI breeders are restlessly working for the development of high yielding modern rice varieties. Immediately after the independence of the country, the main focus of the government was to increase food production. Under that context, BRRI's breeding programs engaged germplasm with high yielding traits from home and abroad in the breeding programs. Until 1985 introduction of foreign high yielding varieties/breeding lines was emphasized for direct release as variety. During this period, 18 varieties were released of which eight varieties were introduced from outside the country.

The historical period of rice variety improvement in Bangladesh is generally classified into three major phases (Fig 1). The first phase was the period from 1970 to 1994 when 31 rice varieties were developed. During this time, the most important achievement of BRRI was the development and release of BR11, BRRI dhan28, and BRRI dhan29, three mega rice varieties.

Principally during this phase, the benefit of the 1st Green Revolution has been reached to the door of people with the development of locally adapted and consumers friendly modern rice varieties and their production technologies. Research on the development of stress-tolerant rice has also been initiated during this period.

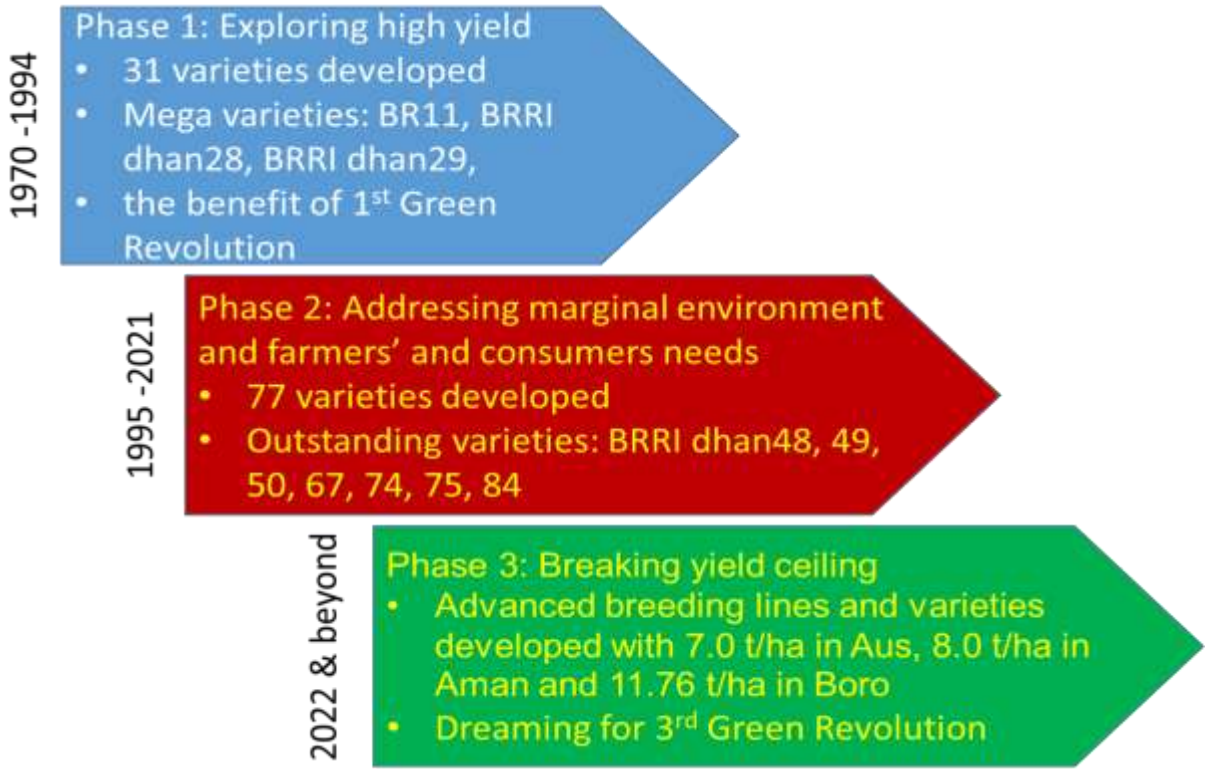
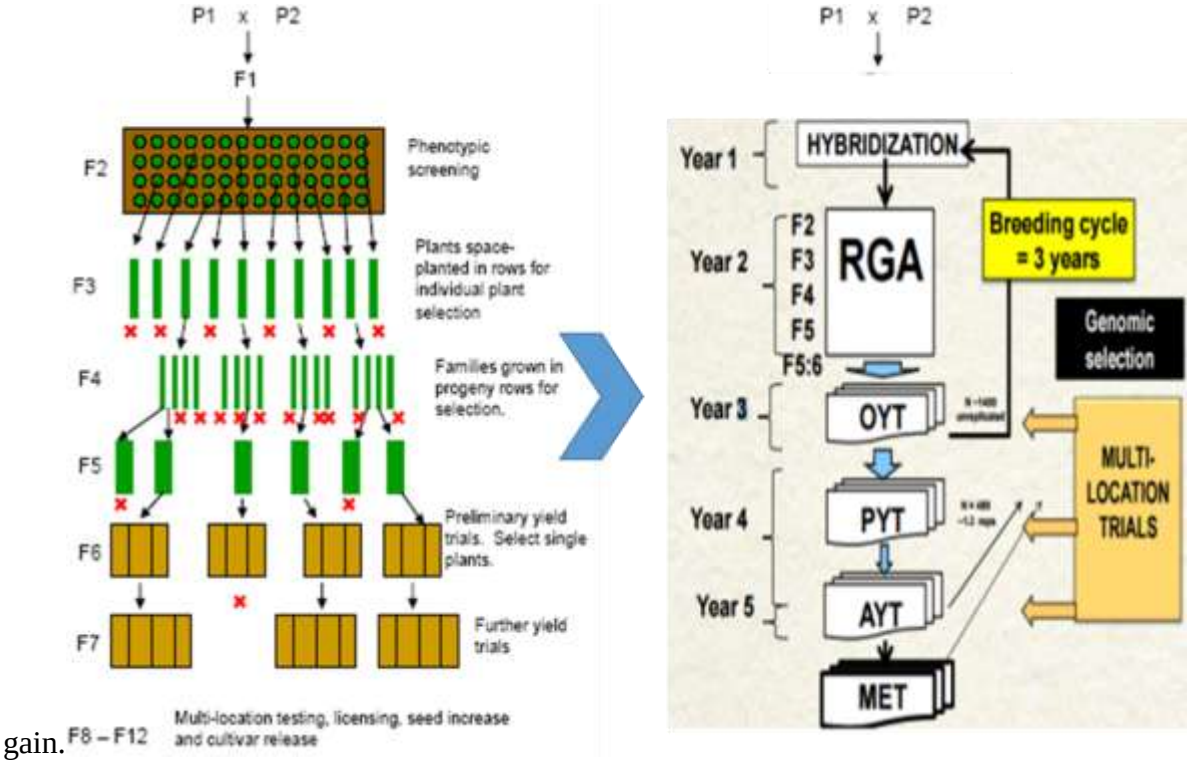


Figure 1. Phasic changes in rice breeding at BRRI during last fifty years (1970 to date)

The period from 1995 to 2021 is considered the 2nd phase when 75 varieties have been released. The remarkable achievements of the period are mitigation of Monga (Shortage of food), development of premium grain quality and micronutrient enriched modern rice varieties, biotic and abiotic stress tolerant rice varieties, and breaking yield ceiling. During this period yield level of MVs reached to 8.0- 9.0 t/ha breaking the yield regime of 5.5 – 8.0 t/ha. Research on New Plant Type was initiated during this period and the 2nd Green Revolution came to light silently. The major outcome of this period was the development of BRRI dhan48, BRRI dhan49,

BRRI dhan50, BRRI dhan67, BRRI dhan74, BRRI dhan81, BRRI dhan84, BRRI dhan87, BRRI dhan89, and BRRI dhan92.

The 3rd phase constitutes the period from the present time to the upcoming future and shines with the development of breeding lines having yield potential of more than 9.0 t/ha. This period has started its journey with the development of Aus hybrids with 7.0 t/ha yield potential, breeding lines having 8.0 t/ha yield potential for T. Aman, advanced breeding lines with more than 11.8 t/ha for Boro season, and 12-13 t/ha yield giving Boro rice hybrids using the techniques of the theory of population improvement and heterosis breeding. BRRI has adopted RGA based single seed descent method of population development replacing the conventional pedigree breeding method (Fig. 2), which enabled a shortening breeding cycle in 4-5 years from 8-10 years. Different cutting edge technologies such as forward breeding with trait-based markers, genomic selection, germplasm enhancement through pre-breeding through line augmentation, and native QTL deployment are in routine use in the current breeding programs. Furthermore, breeding programs have been mechanized and automatized through the use of modern post-harvest processing equipment for threshing, drying, and storage of breeding germplasm (Fig 3-5). Different digital devices are being used for recording data and are being uploaded into the breeding database automatically. Mechanization and digitization of breeding programs have enabled faster capturing of genetic variation with higher accuracy, which is essentially required for accelerating genetic



gain.

Figure 2. Transformation in rice breeding strategies for accelerating genetic gain

In the coming future, using these outcomes and other emerging innovative ideas, e.g. speed breeding, haplotype breeding, bioinformatics, phonemics, artificial intelligence, precision agriculture will enrich the inception of 3rd Green Revolution in the world.

Figure 3. Modern threshing and drying equipment are in use in the breeding program

Figure 4. Automation equipment are in use for digitized data recording

Figure 5. Modern facilities for storage of breeding germplasm are in use in the breeding program

The major achievements so far made:

The major achievements of Plant Breeding Division are the development of high-yielding modern rice varieties (MVs) for both favourable and unfavourable ecosystem. BRRI has so far developed and released 108 MVs (101 inbred and 7 hybrids):

- 48 for Boro (Including both for Boro and Aus)
- 26 for Aus (Broadcast and Transplanted)
- 45 for T. Aman
- 12 for Boro and Aus
- 1 for Boro, Aus and T. Aman
- 1 for B. Aman

Plant Breeding Division has rendered considerable efforts to develop modern varieties with tolerance against abiotic stresses like salinity, submergence, drought, cold, etc. The division has developed BRRI dhan47, BRRI dhan61, and BRRI dhan67 for boro season which can tolerate 12-14 dS/m salinity at the seedling stage and also withstand 6-8 dS/m salinity during the whole life cycle. Newly released BRRI dhan97 and BRRI dhan99 are suitable for boro season which can tolerate up to 14 dS/m salinity at the seedling stage and also withstand 8-10 dS/m salinity during the whole life cycle. Nonetheless, BRRI dhan40, BRRI dhan41, BRRI dhan53, BRRI dhan54, and BRRI dhan73 are the salinity tolerant varieties for T. Aman with 8 dS/m salinity tolerance at the reproductive stage. Three submergence tolerant varieties such

as BRRI dhan51, BRRI dhan52, and BRRI dhan79 have been developed which can survive against 2-3 weeks of submergence. Four varieties viz. BRRI dhan56, BRRI dhan57, BRRI dhan66, and BRRI dhan71 have been developed for T. Aman season, which is suitable for drought-prone areas of Bangladesh. Two Zinc (Zn) enriched varieties i.e. BRRI dhan62 and BRRI dhan72 (short duration) with 20 and 22.8 ppm Zn, respectively have been developed for T. Aman season. Four Zinc (Zn) enriched varieties i.e. BRRI dhan64, BRRI dhan74, BRRI dhan84, and BRRI dhan100 with 25.5, 24.2, 27.6, and 25.7 ppm Zn, respectively developed for Boro season. BRRI dhan50 popularly known as Banglamati (Basmati type) and BRRI dhan63 (slender Balam type) are the high yielding Boro rice varieties with premium quality for favourable ecosystem. Plant Breeding Division has also been applying Marker-Assisted Breeding tools to introgress stress tolerance genes including submergence, salinity, cold tolerance, and disease resistance into modern varieties with high yield potential. The MVs like BR17, BR18, and BR19 are suitable for haor areas (depressed basins) in Boro season of Bangladesh. In addition, BR18, BRRI dhan36, BRRI dhan55 and BRRI dhan69 possess cold tolerance at vegetative stages and are suitable for cold stress-prone areas of the northern region of Bangladesh. BR21, BR24, BRRI dhan42, BRRI dhan43, and BRRI dhan65 are the rice varieties suitable for the high rainfall upland situation (direct-seeded Aus). BRRI dhan65 is an upland Aus rice variety with around 0.5 t/ha more yield potential than BRRI dhan43. Moreover, this variety has better weed competitiveness than BRRI dhan43 at the earlier growth stages. BRRI dhan42, BRRI dhan43, and BRRI dhan83 are the broadcast Aus rice varieties suitable for drought-prone areas. BRRI dhan83 is a newly released B. Aus variety with a moderate level of drought tolerance at the vegetative stages. The grain colour of this variety is reddish like the local LIV Kataktara. Under optimum management, this variety can produce on an average 4.0 t/ha which is around 1.0 ton higher than BRRI dhan43. This variety is particularly suitable in the Charland areas of Noakhali and Feni. BR26, BRRI dhan48, BRRI dhan55, BRRI dhan82 and BRRI dhan98 are the T. Aus varieties. BRRI dhan55 as T. Aus variety is 10 days earlier than BRRI dhan27 and can produce 1.0 ton higher yield than that of BRRI dhan27. Under optimum management, BRRI dhan55 can produce 5.0 t/ha grain yield in T. Aus season. BRRI dhan82 has been developed through pure line selection of NERICA10. Under optimum management, BRRI dhan82 can produce 4.5-5.5 t/ha grain yield. The growth duration of this variety is 4-5 days shorter than

BRRI dhan48. Eventually, cultivation of the T. Aus variety will open up the avenue of in-time cultivation of T. Aman varieties. BRRI dhan98 produces 5.0-5.8 ton per hectare grain yield. The grain is long slender and golden coloured. Its growth duration is 112 days which is similar to BR26. The weight of 1000 matured grains of this variety is around 22.6 grams. The grain contains 27.9% amylose and 9.5% protein. The cooked rice is whitish. BRRI dhan27 is a T. Aus variety suitable for non-saline tidal wetland areas of the greater Barishal region. BRRI dhan48 is the most popular T. Aus variety with 5.5 t/ha grain yield potential and 110 days average growth duration. BRRI dhan85 is the latest T. Aus variety suitable for comparatively low land areas of the greater Cumilla region. The grain yield potential of BRRI dhan85 is 5.5 t/ha.BR22, BR23 and BRRI dhan46 with strong photoperiod sensitivity are suitable for late transplanting in Aman Season after the recession of the floodwater. BR25, BRRI dhan32, BRRI dhan33, BRRI dhan39, and BRRI dhan75 are short to medium-duration photo-insensitive rice varieties. BRRI dhan75 is a high yielding and short-duration T. Aman rice variety with 5.0 t/ha yield potential. The cooked rice of this variety has a slight aroma. BRRI dhan44, BRRI dhan52, BRRI dhan76, and BRRI dhan77 are the T. Aman varieties suitable for tidal non-saline areas of the greater Barishal region. BR10, BRRI dhan30, and BRRI dhan31 have been developed for the rainfed lowland rice environment. These varieties are weakly photo-sensitive and have the yield potential 5.0-6.0 t/ha. Besides, BR10, BR23, and BRRI dhan30 are the T. Aman rice varieties with special adaptation ability under the water stagnant areas of the southern region of Bangladesh. BRRI dhan49 is a popular T. Aman variety with Nizersail type grain quality with one week earlier growth duration than BR11 and 5.5 t/ha grain yield potential. BRRI dhan55 is a moderately cold, salinity, and drought-tolerant variety. This variety can be cultivated in the Boro areas with a moderate level of salinity, water shortage, and cold problems. BRRI dhan55 is 5 days later than BRRI dhan28 but can produce 1.0 t/ha higher grain yield. BRRI dhan58, BRRI dhan59 and BRRI dhan60 are the three high yielding Boro varieties. BRRI dhan58 is the first variety developed through the tissue culture process from BRRI dhan29 which is 7-10 earlier than BRRI dhan29 with more or less similar yield potential. The growth duration of BRRI dhan58 is 150-155 days and grain yield potential 7.0-8.0 t/ha. Interestingly, BRRI dhan58 can be cultivated after potato harvest in the late Boro season and in the shrimp Gher of the Southern region during Boro season.

BRRI dhan59 and BRRI dhan60 have in-between growth duration compared to BRRI dhan28 and BRRI dhan29 have been developed for Boro season. Both of the varieties have yield potential ranging from 7.1-7.3 t/ha. Importantly, BRRI dhan60 has extra-long slender grain. BRRI dhan68 has been developed as standard boro rice with medium bold grain, lodging tolerance, and 13% more grain yield potential than BRRI dhan28 but with around one week later growth duration. BRRI dhan69 is a low input potential Boro rice variety with 7.0 t/ha grain yield potential. Importantly BRRI dhan69 has a moderate level of cold tolerance during reproductive stages, BRRI dhan70 and BRRI dhan80 are the long slender aromatic rice varieties for T. Aman season with shorter duration (130 days) and 5.0 t/ha grain yield potential. BRRI dhan78 is a dual tolerant T. Aman variety with tolerance against both submergence and salinity. The growth duration of this variety is 133-136 days with a grain yield potential 5.5-6.0 t/ha. The growth duration of BRRI dhan81 is 140-145 days and yield potential 6.0-6.5 t/ha. This variety containing high protein (10.3%) has all the premium quality rice characteristics except aroma. The variety can be exported as the grain size and shape of this variety is long slender like Basmati rice. Moreover, the size and shape of clean rice are as like as local Zira cultivars and therefore, the variety has demand in the local market as well. The growth duration of BRRI dhan88 is 140-143 days and grain yield potential 7.0 t/ha. This variety is particularly suitable as a short-duration Boro variety. BRRI dhan90 is a high yielding premium quality T. Aman variety. The grain size and shape of this variety is as like as BRRI dhan34. The average yield potential of this variety is 5.0 t/ha and the average growth duration is 122 days. Importantly, BRRI dhan90 is 21 days earlier than BRRI dhan34 but can produce 1.0-1.4 t/ha more grain yield. The clean rice of this variety can be used for preparing special festival cuisines like *polao* and *paes*. BRRI dhan91 is a semi-deepwater B. Aman rice variety with special adaptive capacities under up to 1.0-meter height flood water. This variety is a moderate photo-sensitive variety with average 156 days growth duration, which is 10-15 days earlier than the local deepwater cultivar like Fulkuri. The grain yield potential of BRRI dhan91 is 3.0 t/ha. BRRI dhan93 and BRRI dhan94 are the modern T. Aman varieties with 134 days of growth duration. The average yield potentials of these varieties are 5.8 t/ha. BRRI dhan95 is another modern T. Aman variety with 125 days growth duration and an average yield potential 5.7 t/ha. All these three varieties have Indian Swarna-

type grain qualities and adaptive capacities. Therefore, these three varieties can be cultivated in the Swarna-growing border areas of the country.

Breeding facilities (Laboratory, Greenhouse, Phytotron, Field facility etc.)

Plant Breeding Division conducts its field trials at HQ and at RSs. Around 25-30 acres of land at Gazipur farm are used for different breeding trials every season. Similarly, 5-6 acres of land at each of 3-4 RS are being used for conducting early generation multi-location breeding trials. In recent years, Breeding Division has changed its breeding approach from pedigree selection to single seed descent-based rapid generation advance (RGA) technique. Segregating populations starting from F2 to F6 are maintained and advanced in the RGA greenhouse. This greenhouse has a capacity to accommodate more than 45,000 progenies per season. The division has three net house and one transgenic screenhouse. Breeding germplasms are processed and temporarily stored at two field laboratories. Breeding Division is using a Phytotron for screening of breeding lines/germplasms for reproductive stage cold tolerance and photoperiod sensitivity. The division has also an in-house cold screening laboratory for seedling stage cold screening. For screening breeding lines against submergence, the division has three submergence screening tanks. For applying molecular markers in the breeding program or trait discovery, the division has one molecular marker laboratory. Gel-based marker application is the main focus of this laboratory. The division has also XRF facilities for grain zinc estimation and an analytical laboratory for the analysis of transgenics. The division has one cold room (~ 500sft) for conserving breeding germplasm. For post-harvest processing and data recording, the division has advanced processing and data recording facilities in the post-harvest process laboratories. LD350 panicle thrasher, batch type drier, Harvest-Master, and Rhyno-sealer are different important types of equipment in the laboratory. Recently, a seed storage facility has been upgraded with vertical revolving racks to accommodate larger volumes of entries in small areas for better management of breeding germplasm (Fig. 5).

Limitation in terms of manpower and facilities

The major limitation is the shortage of adequate manpower in the HQ, where breeding materials are mostly generated. Only 13 scientists and four scientific staffs are on board for managing 18

major breeding programs. Furthermore, breeders at the RS are heavily engaged in the non-breeding responsibility. Land space limitation for field trials is also another shortcoming for the Plant Breeding Research. Inadequate post-harvest processing and storage facilities are also factors hindering the growth in varietal improvement. Major source of research budget at this moment comes mainly from donor-funded projects. In absence of this funding support, the on-going research projects might face challenges.

Way Forward

To expedite the rate of genetic gain for yield and other attributes with optimal accuracy, the following areas need to be addressed on an urgent basis,

- Characterization of elite breeding pool used in the different breeding programs in both phenotypic and genotypic levels to determine the elite core panel that shares the majority of the genomes with the current breeding program. Deep sequencing of this core panel will help impute the genotyping data of the current and future breeding germplasm
- Selection of high-value cross combinations based on genomic estimated breeding value (GEBV) in all breeding programs. Thus, genomic Selection should be in full operation in BRRI breeding programs
- Use of bioinformatics to identify candidate genes and, development of functional markers to be used for selection breeding
- To increase the efficiency of breeding data for capturing true variability, breeding data management should be fully functional using Breeding4Results or any other breeding data management platform
- Development of modern germplasm management system with seed drying, processing and storage facilities
- Establishment and accelerate the use of speed breeding facilities for the further shortening of breeding cycles

Conclusion

Plant Breeders are working on the development of new varieties that give at least more than 10% higher yield than the existing varieties. Once upon a time, it was believed that breaking the yield

ceiling is impossible or difficult. However, the theory of population improvement and heterosis breeding has made it possible. In addition, the application of different advanced technologies viz, C4 rice, genome editing, bioinformatics is showing promise to develop high yielding and quality enriched rice varieties.