ORIGINAL RESEARCH PAPER
Volume - 13 | Issue - 06 | June - 2024 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

HYBRID RICE RESEARCH AND CULTIVATION IN BANGLADESH: POTENTIALITY AND PROSPECTS

Agriculture

Priya Lal Biswas Hybrid Rice Division, Bangladesh Rice Research Institute, Gazipur.
S. M. Hisam Al Rabbi Biotechnology Division, Bangladesh Rice Research Institute, Gazipur.
Anowara Akter Hybrid Rice Division, Bangladesh Rice Research Institute, Gazipur.
Hirendra Nath Barman Plant Physiology Division, Bangladesh Rice Research Institute, Gazipur.
Laila Ferdousi Lipi Hybrid Rice Division, Bangladesh Rice Research Institute, Gazipur.
Md. Ruhul Quddus Hybrid Rice Division, Bangladesh Rice Research Institute, Gazipur.
Tomalika Saha Plant Breeding Division, Bangladesh Rice Research Institute, Gazipur.
Gayatri Goswami Department of Genetics and Plant Breeding, Patuakhali Science and Technology University, Patuakhali.
Ujjal Kumar Nath* Department of Genetics and Plant Breeding, Bangladesh Agricultural University. Mymensingh-2202. *Corresponding Author

ABSTRACT

Hybrid rice is developed by crossing two genetically different parents and has a higher yield potential than inbred varieties. This could be used to bridge the gap between rice demand and yield in 40 rice growing countries. In Bangladesh, hybrid rice yielded 20-25% higher than HYV in an irrigated ecosystem. Therefore, hybrid rice offers great hope to farmers to compensate differences in rice yield and production costs. The purpose of the study is to highlight the status and future prospects of hybrid rice cultivation, seed production and research activities in the public and private sectors. So far, 235 hybrid rice have been registered in Bangladesh, of which only 27 have been domestically developed. Of these, 18 hybrids were developed by private and 9 by public sectors. However, 90 percent of the hybrid seeds available in the Bangladesh market are covered by hybrid rice varieties developed and introduced by private companies. Currently, hybrid rice covers approximately 10.40% of the rice area in Bangladesh (1.21 Mha out of 11.64 Mha). Unfortunately, most of the hybrid rice cultivation is concentrated in the Boro season, which covers approximately 24.95% of the total rice area of Boro season. By 2050, we need to increase hybrid rice coverage by approximately 40.51% of the total area (3.97 Mha from 9.80 Mha) to meet the demand of ever-growing population. A total of 17 rice types in Bangladesh, but registered hybrid varieties are adapted to only four types; such as Boro (short duration), Boro (long duration), Favorable Aman and Premium quality rice. We need to develop versatile hybrid varieties that could adapt in many ecosystems. BRRI could therefore be piloted a long-term public-private partnership project to establish a National Hybrid Rice Research Institute to develop demand-driven smart hybrid rice varieties to ensure future food security of the country.

KEYWORDS

Rice ecosystems, Progress, Prospects, Hybrid rice, Heterosis, BRRI.

INTRODUCTION

Heterosis is a unique way to harness the hybrid power of plants. Due to their yield advantages and economic importance, several hybrid rice varieties have been commercialized in more than 40 countries. Hybrid rice creates a huge opportunity for the development of the seed industry to ensure higher rice yields worldwide. It is the greatest innovation and easy-to-use technology that increases productivity and grain yield using hybrid vigor. The yield potential of hybrid rice is at least 15-20% higher compared to high-yielding inbred varieties using the same input (Singh et al, 2009). In addition, it increases farm incomes and stabilizes grain prices among urban and rural consumers (Azad et al, 2008; Spielman et al, 2012). Hybrid rice cultivation has been practiced since 1978, increasing production by a total of 44.1% on a 14% less land area in China (Li et al, 2009). It helps China feed more than 60 million people every year (Spielman et al, 2012; Li et al, 2009). Therefore, hybrid rice is very important for food security in poor tropical countries with higher population and less arable land (Santiaguel and Quipot, 2012). Hybrid rice technology has attracted the attention of researchers and decision makers in many countries to break the yield ceiling of HYV rice (Hossain et al, 2003). "The Father of Hybrid Rice" Professor Yuan Longping mentioned that Bangladesh could be self-sufficient in rice if it adopted hybrid rice technology (Yuan, 2012).

Rice provides 75% of consumers' daily nutritional energy and 50% protein demand. In Bangladesh, people consume 268.5 kg/capita/year, which is at the top of the world (Mottaleb, 2020). This makes rice as the most widely grown crop in the country. It also provides livelihood to millions of poor farmers. In 2022-2023, 39.10 million tons of rice was produced from 11.64 Mha of agricultural land to feed 172.95 million people (BBS, 2023; Worldometer, 2023). In future, more rice will have to be produced to feed a growing population (1.08%/year) from shrinking land (0.4%/year) (Kabir et al, 2015). Rice production needs to increase from 40.40 to 47.20 Mt on 10.62 to 9.80 Mha of rice land to feed a population of 186-215.4 million by 2030-2050 (Kabir et al, 2015). Therefore, increasing the cultivation of hybrid rice as well as minimizing the yield gap would be a better option. Hybrid rice technology can help in boosting the country's economic development and reducing poverty.

In Bangladesh, hybrid rice research and development began in 1993 at BRRI in collaboration with the International Rice Research Institute (IRRI), with the aim of providing supplementary food to the country's growing population (Julfiquar, 2002; Rashid et al, 2011). Research was initially limited to evaluating F_1 hybrids and testing IRRI CMS and R lines. From 1996, BRRI started research on hybrid rice, which gained momentum with the formation of a working group, technical support from IRRI and financial support from the Bangladesh Agricultural Research Council (BARC). After 8 years (1993-2001) of intensive research paid off significantly and the first commercial hybrid rice, called BRRI hybrid dhan1 was released. To date, 27 rice hybrids have been locally developed (9 from the public sector and 18 from the private sector).

The results show that the use of hybrid rice did not significantly increase between 2007 and 2024 due to the limited diversity of registered hybrids (235) in terms of adaptation to adverse conditions, resistance to pests and diseases, growth duration, grain type, yield potential, cooking properties and taste etc. Currently, most hybrid rice in the country produces 2.5 tha^{-1} seeds, so the seed production

technology should be modernized to obtain a seed yield of more than 3 tha^{-1}. Research and development of hybrid rice technology in the public and private sectors is not progressing as per demand due to lack of adequate infrastructure and skilled manpower. As a result, 90% of registered hybrids are imported from China (61%), India (28%) and the Philippines (1%).

We need to develop climate smart hybrid rice that is compatible with the 17 rice types based on our ecosystems such as Favorable Boro (Short duration), Favorable Boro (Long duration), Saline Boro, Cold tolerant (Haor), Cold tolerant (Northern and Western), Healthier rice (Boro), Favorable Aman, Saline Aman, Flash flood, Drought, Tidal submergence, Healthier rice (Aman), Upland rice, T.Aus, Healthier rice (Aus), Premium quality rice, and Deepwater rice will increase the cultivated area to support the growth of hybrid rice in the country. Both in the public and private sectors, the existing facility related to the hybrid rice technology are not sufficient to conduct targeted research.

The success of a hybrid depends on the combination, adaptation and allelic interactions of the parents. Several problems such as unstable male sterility (MS), lack of cytoplasmic diversity, inherited CMS load and low productivity of the seed parent, poor grain and flower quality, biotic and abiotic stresses, hybrid sterility and marginal heterosis of indica hybrids were identified. This study will be useful for policy makers, private, public and stakeholders for better understanding the future hybrid rice research/business plans. In addition, it also processes information on; i) status of hybrid research, ii) breeding systems and methods related to hybrid rice development and production, iii) trait-specific parental line improvement, and iv) economic opportunities.

Status Of Hybrid Variety In Bangladesh

In 1998, Bangladesh was hit by a flood that lasted from July to September. At that time, the National Seed Board of Bangladesh (NSB) announced a dynamic decision to introduce hybrid seeds for cultivation in Boro season 1998-99 as part of government initiatives of "post-flood" recovery program to address the country's food shortage. Accordingly, in 1998, four private companies, including Advanced Chemical Industries (ACI) Seeds Ltd., MacDonald Bangladesh (Pvt.) Ltd. Ganzes Pevo Corporation and Mollika Seed Company were able to import four hybrid rice varieties, namely Alok 6201, Loke Nath 505 and Amorsree-1 from India and Sonar Bangla (CNSGC-6) from China. A total of about 600 tons of hybrid seeds were imported, of which 75% were Alok 6201 (Hossain et al, 2003). Currently, a total of 235 rice hybrids have been registered by the Seed Authority (SCA, 2023) since 1998. Out of 235 rice hybrids, 194 rice hybrids for Boro season (irrigated condition), 35 rice hybrids for Aman season (rainfed condition) and remaining 6 rice hybrids for Aus season (rainfed condition). Most of the hybrid varieties registered in Bangladesh are originated in China followed by India. Bangladesh has reflected the capacity in hybrid rice breeding by releasing a large number of hybrids (>11% of the total registered rice hybrids cultivars (Table 1).

Table 1. Season-wise Registered Rice Hybrids In Bangladesh Since 1998

Origin	Number of varieties	Seasons			Contribution (%)
		Aus	Aman	Boro	
Bangladesh	27	1	10	16	11.49
China	143	3	9	131	60.85
India	64	2	16	46	27.23
Philippines	1	0	0	1	0.43
Total	235	6	35	194	100
Season wise contribution (%)		2.55	14.89	82.55	100

(Source: SCA, 2024)

Recently, 73 private seed companies and three public organizations; BRRI, BADC and Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) and Non-Government Organization (NGO); Bangladesh Rural Advancement Committee (BRAC) practices hybrid technology. However, hybrid rice technologies are far from being in demand because there is not enough focus on research and development. Research and development of hybrid rice in the public and private sectors is not accelerating due to a lack of skilled labor, low infrastructure and a limited number of diverse germplasms. Eleven leading organizations each have on or above 7 registered hybrids and hold 44% of Bangladesh's hybrid rice varieties (Table 2).

Table 2. Top 11 Organizations In Bangladesh Having More Than Seven Registered Hybrid Cultivars

Organization	Nature of organization	Number of Registered hybrid rice varieties			Contribution (%) of total registered cultivars
		Own	Imported	Total	
ACI Seeds Ltd.	Private	1	7	8	3
Aftab Bahomuki Farm Ltd.	Private	0	7	7	3
Bangladesh Agricultural Development Corporation	Public	0	7	7	3
Bayer Crop Science Ltd.	Private	0	12	12	5
BRAC Seed and Agro Enterprise	NGO	8	10	18	8
Bangladesh Rice Research Institute	Public	8	0	8	3
Mahyco Bangladesh Pvt. Ltd.	Private	0	7	7	3
Partex Agro. Ltd.	Private	0	7	7	3
Supreme Seed Company	Private	1	13	14	6
Syngenta Bangladesh Ltd.	Private	0	9	9	4
Winall High-tech Seed Company Ltd.	Private	0	7	7	3
Total		18	86	104	44

(Source: SCA, 2024)

The highest number of hybrid rice varieties (26) was registered in 2020, followed by 2006 and 2015 (18 varieties each year), 2008, 2014, 2016 and 2021 (17 varieties each year). However, some of them have been achieved as popular varieties by farmers due to their short growth duration, yield, grain quality and adaptability in the diverse rice ecosystem (Table 3).

Table 3. Frequency Of Hybrid Rice Cultivars Are Registered In Bangladesh From 1998 To 2023

Year of registration	Number of hybrids registered	Year of registration	Number of hybrids registered
1998	4	2013	1
2000	1	2014	17
2001	3	2015	18
2003	2	2016	17
2005	4	2017	2
2006	18	2018	11
2007	11	2019	1
2008	17	2020	26
2009	13	2021	17
2010	12	2022	16
2011	14	2023	1
2012	9		

(Source: SCA, 2024)

Status Of Hybrid Rice Variety Cultivation In Bangladesh

During the Boro season of 1998-1999, imported hybrid rice varieties were cultivated on approximately 23,700 hectares (Hossain et al., 2003). So far, NSB has registered a total of 235 hybrid rice varieties (SCA, 2024). The areas under hybrid rice cultivation increased continuously until 2008-2009 to 2001 and then reached a plateau until 2023 (Figure 2). The largest area (1.21 Mha) was covered with hybrid rice in 2022-2023, followed by 1.14 Mha in 2021-2022 (BBS, 2023).

Hybrid rice produced an average of 22.17% higher yield compared to irrigated Boro rice. In the 2022-23 season, hybrid rice yielded 4.75 t/ha during the Boro season, which was 15.29% higher than the average yield of HYV (4.12 t/ha) (BBS, 2023). Hybrid rice covered 1.21 Mha out of 4.85 Mha of land under Boro rice cultivation in 2022-23, which covered 24.95% of Boro rice growing area (Figure 2a-b).

During the last decade, the cultivation area of hybrid rice has not increased, although new hybrid varieties were released. Hybrid rice varieties are currently grown in 62 out of 64 districts. Hybrid rice is not grown in the Patuakhali and Borguna districts. Hybrid rice cultivation has been rapidly increased in Bagerhat district, where 83.7% of the total rice cultivation area is covered by hybrid rice varieties. Hybrid rice cultivation covers the least land area (0.35%) in Dhaka district. The largest area (58,579 ha) under hybrid rice in Sunamganj accounted for an average of 26.34% of the total rice area (0.22 Mha), followed by Mymensingh (21.73% of 56,608 ha), Noakhali (79.49% 69,847 ha). Gopalganj (75.24% of 76,727 ha of land) and Sherpur (57.60% of 88,556 ha of land). Hybrid rice varieties are cultivated on 438–49,736 ha of land, which covered 1.84–38.47% of land in other districts during Boro season (Figure 3) (BBS, 2023).

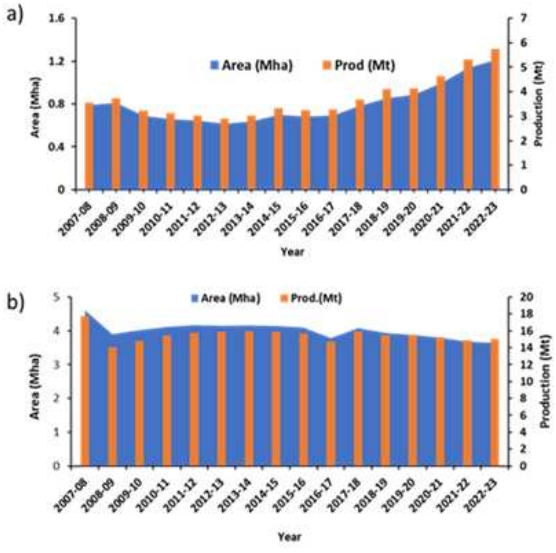

Figure 2. Comparison between hybrid and inbred rice area and production from 2007-8 to 2022-23; a) Hybrid and b) Inbred.

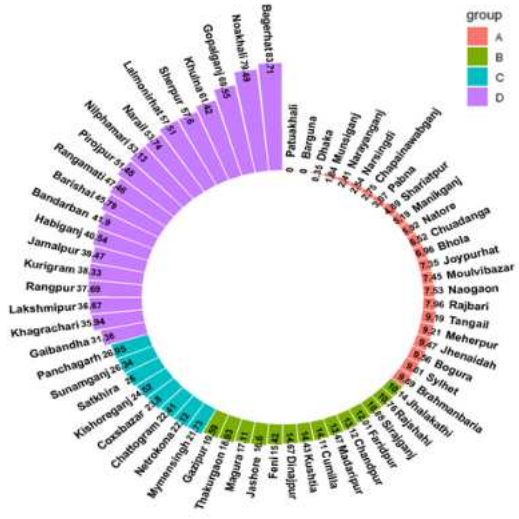

Figure 3. Percent coverage of total rice cultivation area by hybrid rice cultivation in different districts of Bangladesh in Boro season of 2021-22 (BBS, 2022).

Status of hybrid rice seed production technology in Bangladesh

Hybrid rice seed production technology is an expensive and labor-intensive technical event that depends on the characteristics of the parent, growing season, climatic conditions and expertise. Choosing a suitable location for the production of hybrid rice seeds based on climatic conditions is the main focus in obtaining economically viable hybrid rice seeds. Optimum weather conditions for hybrid seed production during flowering are; daytime 24-30°C, day-night temperature difference 8-10°C, relative humidity 70-80% with bright sunshine and moderate wind for 3-5 days, which ensures safe pollination (Sah and Joshi, 2020). In Bangladesh, suitable weather was found only during the Boro season, so hybrid rice seed production is limited to the Boro season instead of the Aus and Aman seasons. Therefore, hybrid rice seed production blocks could be expanded in areas where the aforementioned climatic conditions prevail during flowering. Currently hybrid seed production is concentrated only in Mymensingh and Bogra districts due to climatic conditions and facilities available for hybrid rice seed processing. Hybrid rice seed production is carried out by several private companies/organizations either under the supervision of contract farmers or on leased land or using both systems. Private companies produce hybrid seeds preferably through contract farmers, providing technical support and materials to minimize production costs. BRAC started hybrid rice seed production in Bangladesh in 2000-2001 using imported parental lines (lines A and R). The first hybrid rice varieties called GB-4 (Jagoron; three-line system hybrid) were produced under BRAC's pilot seed production scheme. However, the seed production was lower (about 400 kg/acre) compared to the economically viable seed production (1000-1200 kg/acre). Therefore, the production of experimental seeds was not economically viable until production technologies and technical know-how were optimized. This seed production scheme gradually evolved into a skilled workforce that was intensively trained by China, BRRI, IRRI and FAO. Then, hybrid rice seed production and production area were gradually increased and reached an economically viable level (Figure 4). Currently, most of the country's hybrid rice seed requirement is produced locally from mother lines imported from China, India and the Philippines, saving huge foreign exchange and ensuring timely availability of seeds to farmers. On the other hand, foreign seed companies, especially from China and India, are interested in producing hybrid rice seeds in Bangladesh through their Bangladeshi counterparts due to lower production costs in terms of land, labor and weather conditions. Rather, we should produce more seeds with our own varieties to save a lot of currency. It has been calculated that the production costs of hybrid rice seeds are approximately 20% lower when local parental lines are used. The performance of nationally developed registered hybrids corresponds to the better performance of seeds of exotic hybrids. The average seed yield potential of BRRI hybrids was found to be >2.50 t/ha. The development of locally produced hybrid rice seeds shows that this technology has already developed a skilled workforce that will help maintain the country's food security.

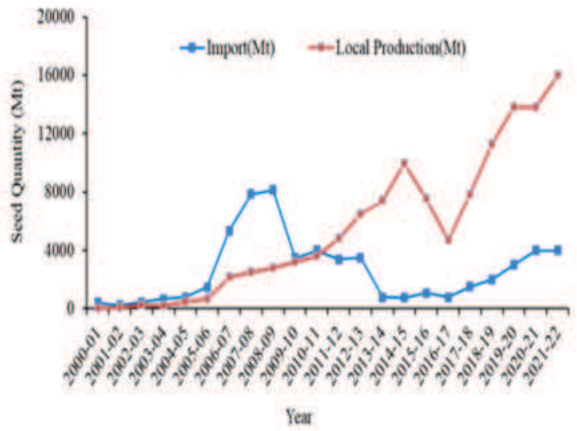

Figure 4. Hybrid rice seeds import and local production from 2001 to 2021.
(Source: DAE and Private Company 2022)

Major Limitations For Expanding Of Hybrid Rice In Bangladesh

Hybrid rice varieties are quickly adopted by farmers, but we could not extend existing hybrid varieties to the whole country due to the following expected limitations:

1) Rice quality after parboiling is one of the most popular characteristics for acceptance of certain products at the farmer level,

especially the amylose content. Varieties with relatively high amylose content (>25%) and non-sticky parameters are always preferred among the people of Bangladesh. In addition, medium bold to slender grain size is another preference to the consumers. Most registered hybrid varieties did not meet the above criteria.

2) Most of the hybrid varieties registered in Bangladesh are introduced and cultivated in the favorable rice ecosystem, which covered only four of the 17 rice types in Bangladesh. In terms of land cover, hybrids use 1.21 Mha of cultivated rice land in Boro season in the 2022-2023. Therefore, hybrid varieties could not be introduced in a large part of the country.

3) Hybrid rice varieties are registered either locally or nationally or both. However, the marketing of site-specific varieties is not controlled and farmers are misled by choosing the right varieties for cultivation and yields that are less than the potential of these varieties. The seed packets lack cultivation instructions for farmers, so that farmers are unable to provide adequate care during biotic, abiotic stresses and natural disasters.

4) The price of rice grains is relatively lower for hybrids than for native grains due to low amylose content. In addition, mills encourage negative grain quality publicity because they buy grain from farmers at low prices and mills have not labeled hybrid varieties in their marketing.

5) Lack of registered hybrid varieties for Aman and Aus seasons, because development of hybrid varieties for these two seasons has not been at a remarkable rate.

6) Most hybrid varieties are depleted in nature and prone to biotic and abiotic stress compared to inbred mega varieties.

Research And Development Of Hybrid Rice Technology In Bangladesh

Bangladesh Rice Research Institute (BRRI)

The Bangladesh Rice Research Institute (BRRI) is a monoculture research institute under the National Agricultural Research System, mandated since 1970 to develop modern rice varieties adapted to the diverse agricultural ecosystems of the country. Research and development of hybrid rice technology began at BRRI in 1993, collaboration with the International Rice Research Institute (IRRI) was aimed at providing additional food for the country's growing population (Julfiquar, 2002; Rashid et al, 2011). Research was initially limited to evaluating F_1 hybrids and testing IRRI CMS and R lines. From 1996, hybrid rice research gained momentum at BRRI with the formation of a working group, technical support from IRRI and financial support from the Bangladesh Agricultural Research Council (BARC). At that time, BRRI's hybrid rice research program was supported by a contract research sub-project of the Agricultural Research Management Project (ARMP) funded by the World Bank and coordinated by BARC. BRRI's hybrid rice research and development (R&D) program was further strengthened when two Chinese scientists worked closely with BRRI scientists for several months in 1997-1998, assisting in seed production and hybrid rice processing under the Technical Cooperation Project (TCP) funded by Food and Agriculture Organization (FAO). At the same time, three other Chinese hybrid rice experts started working with BRRI under the Technical Cooperation for Developing Countries (TCDC) with financial support from FAO. Later, BRRI's hybrid rice program was further strengthened through the IRRI-ADB project launched in 1998. As part of the project, some Indian consultants visited Bangladesh to prepare a hybrid rice program and a long-term master plan. During this time, a number of BRRI scientists and staff of Bangladesh Agricultural Development Corporation (BADC) trained at home and abroad in hybrid rice breeding and seed production technology. Again, BRRI receives financial support through the Poverty Alleviation Rice Research Assistance Project (PETRRA) to continue hybrid rice research in 2002 under the title "Bangladesh Hybrid Rice Research and Development". After that, a 5-years hybrid rice project, Government of Bangladesh has approved the USD 1 million project "Bangladesh Hybrid Rice Research and Development" to provide financial support for hybrid rice research in the country. This project started in July 2005 and ended in June 2011. After completion of GOB, BRRI established the Hybrid Rice Research Division to strengthen hybrid rice research to develop locally accepted hybrid rice varieties and prioritize consumer preferences. A two-year China-Bangladesh technical cooperation project titled "Strengthening Hybrid Rice Research and Development in Bangladesh" was carried out at BRRI from July 2016 to June 2018. Meanwhile, BRRI has developed quite a few basic hybrid lines (A, B and R) that were used in the development of heterotic rice hybrids. The first promising restoration line BR 827-35-2-1-1-1R was identified in 1995 and the first CMS line BRRI1A was developed in 2000. National released the BRRI hybrid dhan1 as the first public hybrid rice variety approved by national seed board in 2001 for commercial cultivation in two regions of the country. With few opportunities to share the best parental materials from China, India and the Philippines, BRRI researchers began developing their own parental materials to promote hybrid rice cultivation in the country. With this objective in mind, BRRI seasonally developed 146 potential CMS lines using various cyto-sources and 248 improved restorer lines to further develop hybrid rice varieties with high yield and good cooking quality (BRRI Annual Report, 2023). Since 2001, BRRI has faced several constraints in developing and releasing 8 rice hybrids for commercial cultivation, of which 5 are registered for Boro season and two for T. Aman season and one for T. Aus season. Boro hybrid rice cultivars have an average yield potential of more than 8.5 tha^{-1}, while 6.5 t ha^{-1} or more in T. Aman and T. Aus hybrid rice varieties (Table 4).

Table 4. Salient Features Of BRRI Developed Hybrid Rice Varieties

Variety Name	Year of released	Season	Grain type	Growth duration (days)	Amylose content (%)	Average Yield potential (tha^{-1})	Recommended regions
BRRI hybrid dhan1	2001	Boro	MS	160	27	8.5	Jashore, Barisal
BRRI hybrid dhan2	2008	Boro	MB	145	23.5	8.0	Dhaka, Cumilla, Jashore and Rajshahi
BRRI hybrid dhan3	2009	Boro	MB	145	23.0	9.0	Cumilla and Rajshahi
BRRI hybrid dhan4	2010	T Aman	S	118	22.5	6.5	Mymensingh and Cumilla
BRRI hybrid dhan5	2016	Boro	MS	144	23.4	9.0	All regions
BRRI hybrid dhan6	2017	T Aman	S	115	24.0	6.5	Dhaka, Chattagram and Khulna
BRRI hybrid dhan7	2020	Aus	S	110	23.0	7.0	Chattagram, Khulna and Rangpur
BRRI hybrid dhan8	2022	Boro	LS	148	23.3	11.0	Dhaka, Chattagram and Rangpur

Note: MS = Medium slender, MB = Medium bold, S = Slender, LS = Long slender, T.Aman = Transplant Aman, T. Aus = Transplant Aus. [Source: https://brri.portal.gov.bd/, visited on 02/05/2024]

As part of technological expansion, BRRI has provided a small number of parental lines (A and R lines) and F_1 seeds of registered hybrids free of charge to interested parties (e.g. BRRI R/S and DAE, BRRI staff, private seed companies, farmers etc.) to produce hybrid seeds and popularize BRRI hybrids among farmers in the country (Figure 5). BRRI also conducted an intensive training program for hybrid seed growers, Department of Agriculture Extension (DAE) staff, BRRI research staff and farmers on hybrid rice seed production and cultivation technology to increase the country's rice production (BRRI Annual Report, 2013-14 to 2022-23).

PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr

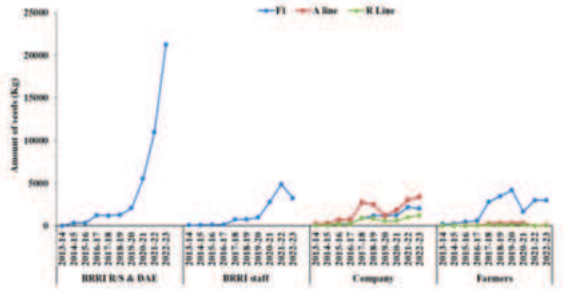

Figure 5. Distribution of parental lines and hybrid seeds of BRRI released rice hybrid varieties among the stakeholders for seed production and cultivation.

Performance Of BRRI Hybrid Rice Varieties

During Boro season 2019-2020, 60 demonstration trials were conducted in 20 regions in different districts, consisting of 17 BRRI hybrid dhan3 and 43 trials of BRRI hybrid dhan5. Average yield of BRRI hybrid dhan3 was 9.26 tha^{-1} while highest yield was observed at 11 tha^{-1} at two locations viz. Madhabpur in Habigonj and Brahmanpara in Cumilla districts followed by Parshuram in Feni (10.80 tha^{-1}) and sadar in Gopalgonj district (10.60 tha^{-1}). The lowest yield potential (7.30 tha^{-1}) was Madan upazilla in Netrokona. BRRI hybrid dhan5 yield ranged from 7.5 to 11.17 tha^{-1} where maximum yield was found in Keshobpur upazilla of Jashore district followed by Moksudpur (11.16 tha^{-1}), Kotalipara (10.86 tha^{-1}) and Tongipara in Gopalgonj district (10.75 tha^{-1}). The highest average yield (10.47tha^{-1}) of BRRI hybrid dhan5 was measured in five demonstrations in Gopalgonj district and lower result was observed in Sylhet district where average yield was (8.06 tha^{-1}). BRRI hybrid dhan3 (8.0 tha^{-1}) and BRRI hybrid dhan5 (8.55 tha^{-1}) yielded 33% and 43% more than BRRI dhan67 at Mongla in Bagerhat district. BRRI hybrid dhan5 showed a yield potential of 9.0 tha^{-1} in Kaokhali upazilla of Rangamati district which was 38% higher than BRRI dhan88 (Figure 6).

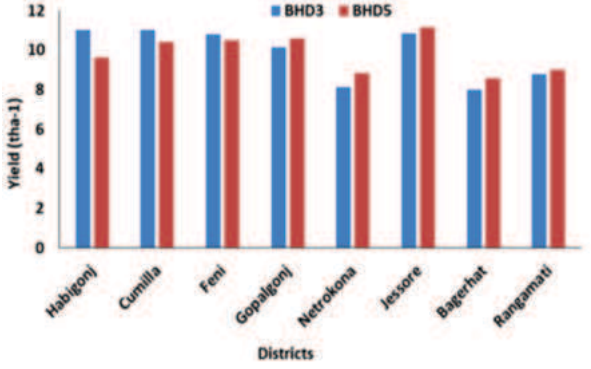

Figure 6. Performance of BRRI hybrid varieties (BRRI hybrid dhan3 and BRRI hybrid dhan5) are observed under 60 trials in different districts during Boro 2019-20.

A comparative trial was conducted by using 11 hybrids (6 hybrids from BRRI and 5 from private sectors) with salinity tolerant check inbred variety BRRI dhan67 at three locations of saline prone area of Satkhira district. None of the tested entries were survived at kaligonj due to rapid increase of water salinity level (from 9 to 25.86 dS/m) at reproductive stage. Although all the tested genotypes performed well in Debhata (<5 dS/m during full growth period) followed by Assasuni (<7 dS/m at full growth stages) due to lower water salinity compared to Kaligonj (Figure 7). BRRI hybrid dhan5 showed high yield potentiality 8.4 tha^{-1} in Debhata followed by Assasuni (8.06 tha^{-1}) which was 10 to 48% higher than popular exotic hybrids like IT, Janokraj, Heera, Tejgold, SL-8 and check variety BRRI dhan67. BRRI hybrid dhan3 and BRRI hybrid dhan6 also performed 7 to 37% and 0.5 to 29% higher yield than the check variety, respectively (Table 5). Therefore, it is suggested that BRRI hybrid dhan3, BRRI hybrid dhan5 and BRRI hybrid dhan6 can be cultivated profitably in areas where water salinity level of the paddy field remains <7 dS/m during full growth period (BRRI Annual Report, 2019-2020). In Aus season, BRRI hybrid dhan7 showed the highest yield potentiality 7.20 tha^{-1} in Gopalgonj sadar during 2020 (A keynote presentation on progress report 2019-2020 of BRRI regional station Gopalgonj).

Table 5. Performance (yield Increase In %) Of BRRI Hybrid Rice Compared To Popular Exotic Hybrids From Private Sector And Inbred Check Variety During Boro 2019-20

Location 1	**Yield increase (%) of BRRI hybrids over checks in Assasuni**								
Assasuni									
BRRI hybrids	Yield (tha^{-1})	Checks	Yield (tha^{-1})	Janokraj	Heera	Tejgold	SL-8	BRRI dhan67	IT
BHD 2	6.82	Janokraj	5.90	15.59	1.04	19.44	23.33	25.60	16.58
BHD 3	7.19	Heera	6.75	21.86	6.52	25.92	30.02	32.41	22.91
BHD 4	5.83	Tejgold	5.71	-1.19	-13.63	2.10	5.42	7.37	-0.34
BHD 5	8.06	SL-8	5.53	36.61	19.41	41.16	45.75	48.43	37.78
BHD 6	6.74	BRRI dhan67	5.43	14.24	-0.15	18.04	21.88	24.13	15.21
BHD 7	5.95	IT	5.85	0.85	-11.85	4.20	7.59	9.58	1.71
Location 2	**Yield increase (%) of BRRI hybrids over checks in Debhata**								
Debhata									
BRRI hybrids	Yield (tha^{-1})	Checks	Yield (tha^{-1})	Janokraj	Heera	Tejgold	SL-8	BRRI dhan67	IT
BHD 2	7.46	Janokraj	6.70	11.34	-2.48	15.30	18.23	25.59	10.03
BHD 3	8.15	Heera	7.65	21.64	6.54	25.97	29.16	37.21	20.21
BHD 4	6.38	Tejgold	6.47	-4.78	-16.6	-1.39	1.11	7.41	-5.90
BHD 5	8.40	SL-8	6.31	25.37	9.80	29.83	33.12	41.41	23.89
BHD 6	7.68	BRRI dhan67	5.94	14.63	0.39	18.70	21.71	29.29	13.27
BHD 7	6.44	IT	6.78	-3.88	-15.82	-0.46	2.06	8.42	-5.01

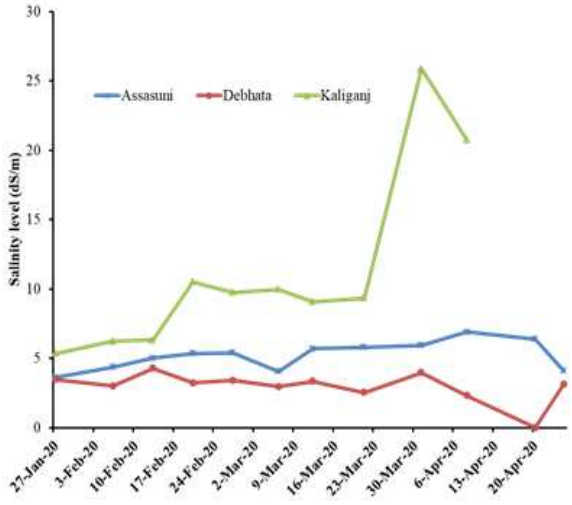

Figure 7. Water salinity levels of different experimental plots at Asasuni, Kaliganj, Debhata in Satkhira in Boro 2019-20.

Hybrid Rice Research In Universities Of The Country

There are seven public agricultural universities in the country such as Bangladesh Agricultural University (BAU), Sher-e-Bangla Agricultural University (SBAU), Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Sylhet Agricultural University (SAU), Khulna Agricultural University (KAU), Habiganj Agricultural University (HAU) and Kurigram Agricultural University (KrAU). In

addition, within the faculty of agriculture; bachelors, masters and doctoral degrees are offered by two public universities of science and technology; Patuakhal Science and Technology University (PSTU) and Hajee Mohammad Danesh Science and Technology University (HMDSTU), one department called Agronomy and Agricultural Extension of Rajshahi University and department of agricultural Technology of Khulna University. In addition, three selected private universities; International University of Business, Agriculture and Technology (IUBAT), EXIM Bank Agricultural University, Bangladesh (EBAUB) and Daffodil International University (DIU) offered degrees in agricultural sciences. In total, approximately 1,800 agriculture graduates join our national workforce upon graduation. But these graduates have little knowledge of hybrid rice technology. Because hybrid rice technology in university masters and postgraduate studies is not sufficient theoretically or practically due to lack of relevant research and lack of funds. Therefore, the research and development achievements of hybrid rice in agricultural universities are very limited. Only BSMRAU developed a hybrid rice variety with mild aroma which was registered with NSB in 2016 for cultivation across the country as BU Sugandhi hybrid dhan1 (SCA, 2020).

Research in private sectors

The seed wing of the Ministry of Agriculture of the Republic of Bangladesh in association with 73 private sector seed companies and a NGO is involved in the production, import and marketing of hybrid rice seeds. However, they contribute very little to hybrid rice research due to high cost implication and low skilled manpower. Only eight private organizations like ACI Seeds Ltd., ACI formulation Ltd., BRAC Seed and Agro Enterprise, Getco Agro Vision Ltd., Lal Teer Seed Ltd., Mitali Agro Seeds Industries, Sabuj Bangla Agro Ltd. and Supreme Seed Company Ltd. developed hybrid rice varieties on their own research (Table 6). BRAC has initiated hybrid rice marketing and research since 2001 in collaboration with IRRI. In 2022-2023, twenty-four private seed companies produced 11,753 tons of hybrid rice seeds (F_1) using 15,428 acres of land based on parental lines (A and R lines) imported from China, India, and the Philippines (Bangladesh Seed Association, 2023). National seed policy must provide 'crop insurance' for hybrid rice seed production to sustain this nascent seed industry.

Table 6. Locally Developed Hybrid Rice Varieties In Private sector/NGO from 1998-2023

Private Company	Variety name	Year of released	Season	Growth duration (days)	Average yield potential (tha^{-1})	Recommended regions
ACI Seeds Ltd.	ACI hybrid dhan16	2022	Aman	118	6.06	All regions
ACI formulation Ltd.	ACI formulation hybrid dhan4	2021	Boro	146	8.40	Chattagram, Khulna and Rangpur
BRAC Seed and Agro Enterprise	BW001 (Jagoron3)	2006	Boro	133	6.00	Mymensingh, Cumilla and Jashore
	BRAC5 (Shakti2)	2009	Boro	147	8.60	Dhaka, Mymensingh, Cumilla, Jashore and Rangpur
	BRAC6 (Shakti3)	2009	Boro	148	8.30	Cumilla, Jashore and Rangpur
	BRAC hybrid dhan10 (Mukti1)	2014	Aman	108	6.00	Mymensingh, Chattagram, Rajshahi and Jashore
	BRAC hybrid dhan12	2015	Boro	143	8.10	Mymensingh, Chattagram, Khulna and Rajshahi
	BRAC hybrid dhan17	2021	Boro	142	8.50	All regions
	BRAC hybrid dhan18	2021	Aman	122	6.68	All regions
	BRAC hybrid dhan20	2022	Aman	115	6.08	All regions
Getco Agrovision Ltd.	Getco Agro Vision Hybrid dhan5 (Rupashi Bangla2)	2015	Boro	147	7.75	Dhaka and Chattagram
Lal Teer Seed Ltd.	Lal Teer hybrid dhan1	2020	Aman	119	6.70	Dhaka, Chattagram and Khulna
	Lal Teer hybrid dhan2	2020	Aman	118	5.90	Chattagram, Barishal and Khulna
	Lal Teer hybrid dhan3	2022	Boro	142	7.80	Chattagram, Khulna and Rangpur
Mitali Agro Seeds Industries.	Mitali Hybrid Dhan3 (SHD1018)	2020	Boro	142	7.80	Chattagram, Khulna and Rangpur
	Mitali hybrid dhan4(SHD1390)	2021	Boro	141	8.50	Chattagram, Khulna and Rangpur
Sabuj Bangla Agro Ltd.	Sabuj bangla hybrid dhan1	2015	Boro	145	7.25	Chattagram and Rajshahi
Supreme Seed Company	Heera14	2022	Aman	122	5.77	All regions

Source: Seed certification agency (SCA), 2024

Table 7: Scenario Of Hybrid Rice Production With 0.044 t ha^{-1}year^{-1} Increment Rate In Different Seasons To Fulfill The Target By 2030, 2040 And 2050 In The Decreasing Trend Of Rice Land

Year	Season	Land (Mha)	Rice	Area Coverage (Mha)	Production (Mt)	Clean rice Production (t ha^{-1})	Paddy production (t ha^{-1})
2030	Aus	1.02	Hybrid	0.25	0.85	3.40	5.23
			Inbred	0.77	2.22	2.88	4.43
	Aman	5.17	Hybrid	0.90	3.24	3.60	5.54
			Inbred	4.27	13.02	3.05	4.69

	Boro	4.43	Hybrid	1.27	6.85	5.39	8.29
			Inbred	3.16	14.22	4.50	6.92
	Total	10.62	Hybrid	2.42	10.94	4.13 (Av.)	6.35 (Av.)
			Inbred	8.20	29.46	3.48 (Av.)	5.35 (Av.)
	Average	-	-	-	-	**3.81**	**5.85**
2040	Aus	0.98	Hybrid	0.25	0.96	3.84	5.91
			Inbred	0.73	2.42	3.32	5.11
	Aman	4.97	Hybrid	1.18	4.77	4.04	6.22
			Inbred	3.79	13.23	3.49	5.37
	Boro	4.25	Hybrid	1.60	9.33	5.83	8.97
			Inbred	2.65	13.09	4.94	7.60
	Total	10.20	Hybrid	3.03	15.06	4.57 (Av.)	6.78 (Av.)
			Inbred	7.17	28.74	3.92 (Av.)	5.78 (Av.)
	Average	-	-	-	-	**4.25**	**6.28**
2050	Aus	0.94	Hybrid	0.30	1.28	4.28	6.58
			Inbred	0.64	2.41	3.76	5.78
	Aman	4.77	Hybrid	1.50	6.72	4.48	6.89
			Inbred	3.27	12.85	3.93	6.05
	Boro	4.09	Hybrid	2.17	13.61	6.27	9.65
			Inbred	1.92	10.33	5.38	8.28
	Total	9.80	Hybrid	3.97	21.61	5.01 (Av.)	7.71 (Av.)
			Inbred	5.83	25.59	4.36 (Av.)	6.70 (Av.)
	Average	-	-	-	-	**4.69**	**7.27**

Hybrid rice variety evaluation and registration system in Bangladesh

Specific policies and guidelines for evaluation and registration of hybrid rice varieties were first introduced at the 40th NSB meeting in 1998. Under the original guidelines, organizations are allowed to import hybrid rice seeds for commercial cultivation for three consecutive years during the Boro season. The original guidelines were later revised and amended at the 52nd NSB meeting in 2003 under the title "Procedure for Evaluation and Registration of Hybrid Rice Varieties, 2003". Under this revised arrangement, organizations were allowed to import hybrid rice seeds for commercial cultivation within five years. It was noted that the condition approved in 2003 to allow importation of F_1 hybrid rice seeds for 5 years was changed to 8 years at the 60th NSB meeting in 2006. The procedure for evaluation and registration of hybrid rice was last reviewed and revised at the 88th meeting of the NSB in 2016. According to the revised guidelines in 2016, organizations are allowed to import F_1 seeds no more than 6 years after registration, and at the same time, organizations need to strengthen their hybrid production capacity under local conditions by using imported parental lines. Imported or locally developed hybrid accessions can be registered for and cultivation, achieving on average 20% higher yield compared to standard control varieties (popular HYV rice varieties) 2-years on-farm and station-based trials in six during recommended areas and must to achieve the targeted higher yield at least in five locations for getting tag of countrywide marketing. Otherwise, the organization is allowed to market hybrid rice seeds in a certain approved area. For the first time, when submitting hybrid to the SCA, organizations are proposed to submit the molecular data of each application together with the result of a one-year field evaluation. The latest change in the procedure for evaluation and registration of hybrid rice varieties was made at the 100th meeting of the NSB in 2019. Some corrections were made in the evaluation process, in which BRRI hybrid dhan5 and BRRI hybrid dhan6 were recommended as standard control varieties instead of popular HYV rice variety in Boro season and T. Aman season, respectively; but in T. Aus season the % heterosis is checked by using a before HYV rice variety.

Why BRRI hybrids are not popularizing compare to other hybrids?

Compared to native varieties, hybrid rice technology required special expertise in parental line development, parental line maintenance and seed production. It needs more skilled manpower and modern facilities to conduct research and development; such as development of parental lines and hybrid varieties, evaluation of developed materials, standardization of seed production techniques, establishment of modern breeding and storage facilities, trained hybrid rice seed traders, entrepreneurs, development of a sustainable marketing channel, improved promotional activities for the marketing and presentation of hybrid rice seeds, and establishing contacts with foreign organizations to share information and materials. Each activity is linked to the success of hybrid rice technology for popularizing the variety in the field of farmers. Therefore, it is quite difficult to develop a standard platform for large-scale expansion of hybrid rice across the country by a specific research organization like BRRI.

Hybrid rice division of BRRI is conducting research and development activities in a small scale since 1993 with limited facilities and manpower. Meanwhile, BRRI developed eight potential hybrid rice varieties, but they didn't attain popularity to the farmers due to scarce implementation of interlinked hybrid rice development activities. Bangladesh Agricultural Development Council (BADC) is the public organization, which is involved in multiplication and distribution of seeds of the registered cultivars from public organization and using exotic parental materials and directly imported hybrid seeds. But they have given more attention to produce hybrid rice seeds using their own register exotic parental materials than BRRI parental lines. On the other hand, some small seed companies with inadequate facilities are interested to make ties with BRRI for hybrid rice parents to produce limited amount of hybrid rice seeds. But these are not enough to expand BRRI hybrid rice technologies significantly. As a result, during last a decade expansion of BRRI hybrid rice varieties was not significantly increased. It's a great short fall in popularizing BRRI hybrid varieties to the farmers. Farmers are always wavering to cultivate BRRI hybrid cultivars, whereas they are very much encouraged to cultivate inbreds of BRRI without any hesitations.

In addition, shortage of required volume of seeds of the parental lines to BADC and companies also limited the popularity of BRRI released hybrids. Therefore, government should take initiative to establish a hybrid rice research institute having all sorts of modern facilities for conducting demand based hybrid rice varieties for the producers and farmers.

Prospect Of Hybrid Rice In Bangladesh

Rice security in Bangladesh is not only important for economic but also for social and political stability (Nath, 2015). It is also considered synonymous with food security, just like other rice growing countries (Brolley, 2015). Bangladesh produced 39.10 million tons of rice from 11.64 million hectares of agricultural land to feed 172.95 million people in 2023 (BBS, 2023; Worldometer, 2023). The current increasing production rate is 0.034 tha^{-1} $year^{-1}$ (average during 2008-23). However, we need to increase rice production to meet the needs of an ever-growing population from a 0.4 percent annual reduction in cultivated land (The daily Prothom Alo, 2015). The total population is projected to be 186, 201.6 and 215.4 million at the end of 2030, 2040 and 2050, respectively, with an average annual growth rate of 0.83% (Kabir et al., 2015). As a result, 40.40, 43.80 and 47.20 million with a surplus of more than 2 tons rice production are needed in 2030, 2040 and 2050, respectively from 10.62, 10.2 and 9.8 million hectares of rice land (Kabir et al., 2015). An important challenge for farmers, agriculturalists and scientists is to achieve goals for mitigating the various obstacles that arise from resource depletion (land, labor, soil health and water) and the vulnerability of nature (cold, salinity, drought, flood and heat). Therefore, interventions such as; accelerating genetic growth, limiting the introduction of late varieties in the field and reducing the yield gap can help sustainable rice production.

The average production of hybrid rice varieties was 4.71 Mt/ha in 2009-2023, which was 23% higher than inbred rice varieties Boro season (BBS, 2023). Currently, farmers are also trying to grow hybrid rice varieties on a small scale during T. Aus and T. Aman seasons, but such information is not publicly available in the BBS. Hybrid rice varieties gave 20-23% higher average yield in T. Aman and T. Aus seasons than native varieties. With the increase in yield (0.034 tha^{-1}/year), we could reach our projected goal for 2030 and 2040, introducing 63% and 71% of rice land, respectively with hybrid varieties. But our projected goal of 2050 is not achievable even if we adopt 100% rice land with current hybrid varieties. To achieve the goal, the projected average rice yield must be increased at 0.044 tha^{-1} $year^{-1}$ which will be 29.41% more of the current averaged yield by 2050.

Considering the current expansion rate of land covered with hybrid rice, hybrid rice area coverage will be expanded up to 22.79%, 29.71% and 40.51% of the total rice growing land in 2030, 2040 and 2050 respectively from where 27.07%, 34.38% and 45.79% of our targeted national yield will be achieved which will be 19.12%, 17.14% and 15.58% more than the yield of inbred rice for the equal area of hybrid rice. To achieve this target, hybrid rice production should be increased on average 33.12%. Finally hybrid rice production should be reached from 3.40-3.84-4.28, 3.60-4.04-4.48 and 5.39-5.83-6.27 tha^{-1} in Aus, T. Aman and Boro seasons, respectively by 2030, 2040 and 2050. Whereas, the inbred rice production should be increased from 2.88-3.32-3.76, 3.05-3.49-3.93 and 4.50-4.94-5.38 tha^{-1} in Aus, T. Aman and Boro seasons, respectively by 2030, 2040 and 2050. Currently, registered cultivars of hybrids are suitable for cultivation only in five rice types, out of 17 (Rabbi et al, 2020). There are huge scopes in conducting rice ecosystem specific research for developing hybrid rice cultivars adapted to all 17 ecosystems. Based on current increment rate of rice production we need to hybrid coverage 2.42 Mha to 3.97 Mha of land within 2030 to 2050, respectively for fulfillment of the predicted target by 2050 (Table 7).

Simultaneously, we need to modernize hybrid rice seed production policy to keep available F_1 seeds with reasonable cost for farmers. The amount of required hybrid seeds was 18150 mt in 2022 which will be almost 2 (36300 mt) to 3.3 (59550 mt) times higher in 2030 and in 2050 respectively. So, to produce these required seeds need to establish proper infrastructure for seed production, processing, storing, marketing channel and skilled manpower. It is estimated that if we can produce our required seeds domestically using own facilities then nation can save at least 23% production cost which is usually spent for parental lines importation and as royalty in each year. On the other hand, skilled manpower will be developed besides creation of employment opportunity, fertilizers, insecticides, and essential chemicals for hybrid rice seed production like GA_3, alcohol, Bactericide industries will be flourished in the country. As a result, we will be able to available hybrid seeds to our farmers with comparatively lower price. Otherwise, our food security will be vulnerable.

Responsibility Of BRRI

Though it is hard for BRRI to fulfill the national demand on hybrid rice technology in the future based on the present status. But BRRI should only invest more in this technology as a National Rice Research Institute. Therefore, BRRI must focus on strengthening research and development of hybrid rice that prioritizes the use of local germplasm, available sources and exotic materials to develop high-yielding hybrids adapted to the diverse environments of the country (various stresses). However, the existing infrastructure and manpower are not sufficient to make targeted research a success. Therefore, BRRI should immediately prepare an initiative for the establishment of a hybrid rice research center project as well as the establishment of an institute that will create a comfortable working environment for the development of target-based new hybrids with all kinds of possibilities. Because, there is little room to ignore BRRI's responsibilities to ensure the country's future food security. We know that private organizations have less interest in developing modern hybrid research facilities with large investments. In this case, the government can start to set up relevant facilities in public spaces or help private organizations or public-private partnerships or domestic foreign organizations to strengthen research and development to develop suitable consumer and ecological hybrid rice varieties to ensure the future food of the country. Otherwise, our dependence on foreign hybrid rice technology will increase day by day, making our rice production target vulnerable, weakening our country's future food security until 2050.

Strategies For Expansion Of Hybrid Rice Cultivars In Bangladesh

i) Hybrid rice research should be strengthened by emphasizing multi-stress tolerant climate-smart varieties, preferably high yields with biotic and abiotic stress tolerance, and grain quality through public-private collaboration.
ii) Providing incentives to successful hybrid rice breeders, farmers and extension workers to inspire their motivation in hybrid rice research, production and distribution and to secure breeders' intellectual property rights.
iii) Adaptation of management practices focused on maximum yields with low inputs.
iv) Establishment of a Cooperative Hybrid Rice Research Institute/Center where researchers from various fields of public and private organizations collaborate to share germplasm and knowledge for the development of potential rice hybrids.
v) Proper implementation of seed regulations for registration of hybrid rice varieties is necessary to avoid duplication of varieties.
vi) Formation of an effective monitoring group of public and private sector experts on hybrid rice seed production and marketing to ensure availability of quality seeds to farmers at reasonable cost and time.
vii) Labeling of the hybrid seed package must clearly state the regional and other necessary information so that farmers can select the correct variety for cultivation.
viii) Development of compensation mechanism/crop insurance to protect farmers' output and preserve their interest in growing hybrid rice.
ix) Provide government support for commercial hybrid rice seed to ensure adequate supply of affordable and high quality hybrid rice seed to farmers. Farmers should receive subsidies for fertilizers, pesticides and irrigation, like the Chinese model (Li et al., 2009).
x) Information related to seasonal land area and hybrid rice cultivation and seed production should be regularly published in BBS to assess the demand for hybrid rice to maintain the food security of the country.
xi) To attract the attention of consumers, appropriate measures should be taken to maintain the brand of hybrid rice as other inbred rice from rice mills to retailers.
xii) BRRI can make an agreement with BADC or with other seed companies for parental lines multiplication of the BRRI released hybrids as per demand of the seed growers of the country.
xiii) To maintain the country's food security, we must start a research and development program for the two-lines hybrid system and conduct a comprehensive study in the northern and northeastern regions of the country, especially in Rangpur, Dinajpur and Habiganj regions to find suitable weather conditions for successful multiplication of parental lines.
xiv) According to the need-based utilization of rice, transgenic rice (CRISPR/Cas9) research facilities should be strengthened like other rice-growing countries.

CONCLUSIONS

Bangladesh faces the twin pressures of population growth and shrinking arable land, as well as unexpected natural disasters. It is estimated that the country's agricultural land has decreased by an average of 0.4% per year due to urbanization and natural disasters. At the same time, the population of Bangladesh will be increased from 172.95 million in 2023 to 215.40 million by 2050. So to feed the growing population, we need to produce 0.51 percent, 0.83 percent and 0.77 percent more rice every year in 2020-2030, 2030-2040 and 2040-2050, respectively. Rapid adoption of hybrid technology in large-scale rice production would help achieve this goal. Although a small number of hybrids have gained popularity among the 235 registered hybrids, their diversity is narrow in terms of adaptation in adverse climatic conditions, resistance to pests and diseases, duration of growth, type of grain, yield potential, cooking characteristics etc. There is a great opportunity to develop high-yielding hybrid rice varieties using all possible technologies. We need to develop climate smart hybrid rice targeting 17 rice types of rice based on our ecosystems. Both in the public and private sectors, the existing facilities related to the hybrid rice technology are not sufficient for conducting targeted research. Therefore, BRRI should prepare a long-term project of public-private partnership (domestic or exotic) to establish a National Hybrid Rice Research Institute/Centre with all facilities to develop hybrid rice varieties based on consumer preferences for sustaining the country's food security.

REFERENCES

1. Azad MAS, Mustafi BA, Hossain M. 2008. Hybrid rice: Economic assessment of a promising technology for sustainable food grain production in Bangladesh. AARES 52nd Annual conference, Rydges Lakeside, Canberra, Australia.

2. BBS (Bangladesh Bureau of Statistics). 2022. Statistical Yearbook Bangladesh. Ministry of Planning, Government of the People's Republic of Bangladesh, Sher-E-Bangla Nagar, Bangladesh.
3. BBS (Bangladesh Bureau of Statistics). 2023. Statistical Yearbook Bangladesh. Ministry of Planning, Government of the People's Republic of Bangladesh, Sher-E-Bangla Nagar, Bangladesh.
4. Brolley M. 2015. Rice security is food security for much of the world. Rice Today. International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila, Philippines. PP. 30-32.
5. BRRI (Bangladesh Rice Research Institute). 2014. Annual Report 2013-14. pp. 50.
6. BRRI (Bangladesh Rice Research Institute). 2015. Annual Report 2014-15. pp. 49.
7. BRRI (Bangladesh Rice Research Institute). 2016. Annual Report 2015-16. pp. 49.
8. BRRI (Bangladesh Rice Research Institute). 2017. Annual Report 2016-17. pp. 56.
9. BRRI (Bangladesh Rice Research Institute). 2018. Annual Report 2017-18. pp. 63.
10. BRRI (Bangladesh Rice Research Institute). 2019. Annual Report 2018-19. pp. 56.
11. BRRI (Bangladesh Rice Research Institute). 2020. Annual Report 2019-20. pp. 56.
12. BRRI (Bangladesh Rice Research Institute). 2021. Annual Report 2020-21. pp. 74.
13. BRRI (Bangladesh Rice Research Institute). 2022. Annual Report 2021-22. pp. 83.
14. BRRI (Bangladesh Rice Research Institute). 2022. Annual Report 2022-23. pp. 103.
15. Bangladesh Rice Research Institute. 2024. https://brri.portal.gov.bd/ (visited on 2 May 2024).
16. Hossain M, Janaiah A, Husain M. 2003. Hybrid Rice in Bangladesh: Farm-Level Performance. Economic and political weekly, 38(25): 2517-2522.
17. Julfiquar AW. 2002. Hybrid Rice Research and Development in Bangladesh: Hybrid Rice for Food Security, Poverty Alleviation and Environmental Protection. Hanoi, Vietnam, pp. 235-245.
18. Kabir MS, Salam MU, Chowdhury A, Rahman NMF, Iftekharuddaula KM, Rahman MS, Rashid MH, Dipti SS, Islam A, Latif MA, Islam AKMS, Hossain MM, Nessa B, Ansari TH, Ali MA, Biswas JK. 2015. Rice Vision for Bangladesh: 2050 and Beyond. Bangladesh Rice J, 19 (2): 1-18.
19. Li J, Xin Y, Yuan LP. 2009. Hybrid Rice Technology Development: Ensuring China's Food Security. IFPRI Discussion Paper: 00918 (Millions Fed: Proven Successes in Agricultural Development. 2020).
20. Mottaleb KA. 2020. Why hybrid rice is not gaining popularity in Bangladesh. 24th December, the Financial Express, Bangladesh.
21. Nath NC. 2015. Food security in Bangladesh: Status, challenges and strategic policy options. Paper presented at 19th Biennial Conference of the Bangladesh Economic Association (BAE), held on 8-10 January, 2015, Dhaka, Bangladesh.
22. Rabbi SMHA, Biswas PL, Rashid ESMH, Iftekharuddaula KM, Rahman NMF, Rahman MS, Sarkar MAR, Mamun MAA, Salam MU, Kabir MS. 2020. Increasing Rice Yield through Targeting Genetic Potentials by Rice Types. Bangladesh Rice J, 24(2): 67-82.
23. Rashid HA, Julfiquar AW, Ali S. 2011. A study on hybrid rice in Bangladesh: History, impact and current status of hybrid rice research, development and delivery in Bangladesh. A study report submitted to International Food Policy Research Institute. pp. 114-118.
24. Sah SN, Joshi BK. 2020. Hybrid Rice Seed Production Manual. Book. pp. 27.
25. Santiaguel AF, Quipot LM. 2012. Hybrids Head for the Tropics. Rice Today, 11(3): 40-41.
26. Seed Certification Agency (SCA). 2020. List of registered hybrid rice varieties publish on website. https://sca.gov.bd/ (visited on 25 December 2020).
27. Seed Certification Agency (SCA). 2023. List of registered hybrid rice varieties publish on website. https://sca.gov.bd/ (visited on 24 December 2023).
28. Seed Certification Agency (SCA). 2024. List of registered hybrid rice varieties publish on website. https://sca.gov.bd/ (visited on 24 April 2024).
29. Singh AK, Kumar B, Baghel RS, Singh RB. 2009. Sustainability of Hybrid Rice Technology vis-a-vis Inbred Rice in Uttar Pradesh. Indian Res J Ext Edu, 9(2): 22–25.
30. Spielman D, Kolady D, Ward P, Rashid H, Gulati K. 2012. Public Expenditures, Private Incentives, and Technology Adoption: The Economics of Hybrid Rice in South Asia. IFPRI discussion paper 01233. Environment and Production Technology Division.
31. The Daily Prothom Alo. 2015. Jomi komleo chal utpadon bereche tin goon (Rice production has increased by three times in spite of decreased land). http://prothom-alo.com/bangladesh/article/ 658390, (Accessed on 18 October, 2015) (in Bangla).
32. Worldometer. 2024. https://www.worldometers.info/world-population/bangladesh-population (visited on 25/05/2024).
33. Yuan LP. 2012. Q & A with the Father of Hybrid Rice. Rice Today, 11(3): 42-43.