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Hybrid Rice: Bangladesh's Failure and China's Success

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Authors' contributions

This work was accomplished by the contribution of all authors. Authors AKMKP and YZ wrote the article. Author MEU helped in literature searches and edited the draft. Author QG planned and supervised the study. All authors read and approved the final manuscript.

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ABSTRACT

Excessive population pressure and low *per capita* landholding in Bangladesh often cause food crises. Recently, the country has achieved self-sufficiency in cereals production, at a marginal level, but still needs to continue importing. Therefore, to ensure food security of the ever-increasing population, it needs to increase the per hectare food production in Bangladesh. Rice is the key crop of the country, as an estimated 75 percent of the people's caloric intake comes from rice because of the suitability of the climate for rice production and the rice-based food habits of the nation. Hybrid rice technologies can help the nation to meet the future food demand. Although the country has an overwhelming demand for rice, farmers are not significantly adopting the high-yielding hybrid varieties. On the contrary, the popularity of hybrid rice is declining among the farmers. Researchers have identified that socio-economic reasons are the main causes behind low/no adoption. This article critically analyzes the reasons behind the low-level adoption of hybrid rice in

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Bangladesh and simultaneously, examines the successful experiences of China's hybrid rice production. Finally, the study shows the future directions for hybrid rice improvements and adoption in the country.

Keywords: Adoption; agricultural extension; food security; hybridization technology; policies.

1. INTRODUCTION

Agriculture has long been playing a decisive role in the economy of Bangladesh as approximately 46.50 percent of the total labor force depends on agriculture [1], which contributes around 15.96 percent to the GDP of the country [2]. Agriculture also has an overwhelming impact on poverty reduction and overall food security of the country. The population of the country is increasing considerably. At the same time, the per capita arable land is severely decreasing. Therefore, ensuring food security of the increasing population is posing a huge challenge to the country. According to the World Bank [3], *per capita* arable land of the country is only 0.05 hectare; while the minimum per capita agricultural land requirement for food security is around 0.5 hectare [4]. Added to the farmland crisis, the country is gravely suffering from the adverse effects of climate change, which is also one of the reasons behind low production. Over the last three decades, the temperature of the country has increased significantly. It is estimated that by 2030, 2050 and 2100 the temperature may increase around 1, 1.4 and 2.4℃ respectively [5]. This is significant as an increased temperature reduces the yield of different crops [6]. Therefore, the country is in a risky situation in meeting the future challenges concerning food security. Lack of sustainable production knowledge is also reducing the overall production of the country. Furthermore, Bangladesh is the most densely populated country in the world where around 1,237.51 persons reside per square kilometer [7]. It is estimated that the population of the country will be around 222 million by 2050 [8] which is almost 1.5 times higher than the current population. To feed the additional people, the country needs hybrid crops for maximization of yield.

Although most crops have been hybridized to some extent, the main two cereal crops of the country, rice, and wheat, are still low-yield. Maize is treated as the fodder crop in Bangladesh. In Bangladesh, rice is the staple food for 150 million people of the country and it contributes 58.3 percent of value-added in agriculture [9]. Rice alone supplies 76 percent of calorie intake and 66 percent of protein requirement of the country [10]. Rice also employs around 43.6 percent labor force of the country [11,12] and provides around 9.5 shares of the GDP [13]. Rice single-handedly provides 96 percent of the cereal food for the country. Rice as a single crop covers around 81 percent of the cropped area of Bangladesh [11]. Thus, rice is called "the life of the people of Bangladesh". No obvious alternative crop can replace rice presently.

Hybrid rice provides additional yield advantage. One study found that hybrid rice can increase yield in comparison to the average inbred rice in Bangladesh [14]. This study also showed the average production of inbreed rice was around 6.03 tons rice and 4.50 tons byproduct whereas the average production of hybrid rice in the same condition was 7.76 tons rice and 5.50 tons byproducts. Initially, after the introduction of hybrid rice in Bangladesh in 1998, for nine years, the area under hybrid rice cultivation significantly increased, but latter decreased [15]. Currently, only 7.48 percent of total rice area is under hybrid cultivation in Bangladesh [2]; while China by contrast; hybrid rice covers around 57 percent of the total cultivated rice area. Thus, it comes as no surprise that China is now feeding 20 percent of the world's population from only 10 percent of the world's arable land [16]. With that being said, the focus of this study is to find out: (i) what are the reasons behind low/no adoption of hybrid rice in Bangladesh? (ii) what lessons Bangladesh can learn from China's experience of successful intensive use of hybrid rice cultivation?

2. HYBRID RICE

Hybrid rice originated from the breeding of two different parental types. In the process of hybrid seed production, two different parental strains are bred artificially and the new generation is called F_1. This improved vigor is called 'hybrid vigor' or '*heterosis'*. Hybrid vigors are generally higher in agronomic characteristics: therefore, they generally outyield their parents. Broadly speaking, hybrid rice has two advantages: i) advantage in terms of high yields in comparison to inbred varieties and; ii) advantage in terms of economic profitability due to higher total sales

(more rice to sell) for the almost the same capital investment [17].

FAO [18] declared 2004 as International Rice Year. FAO has been encouraged hybrid rice production. In a report, FAO [18] mentions that hybrid rice can meet food security of the needs of the world because: i) hybrid rice can produce at least 15-20 percent higher yield in comparison to inbred rice; ii) around the world, the demand for rice is increasing day-by-day as a staple food; iii) HYVs are showing a declining trends of yields worldwide, so hybrid rice is needed to fill the gap and meet the future food security goals. FAO, IRRI, ADB, and UNDP are supporting the improvement of the hybrid rice varieties to meet world food security needs [18].

Hybrid rice was developed in China during the year 1964 by Professor Longping Yuan [19], who is often called "the father of hybrid rice". Yuan first found the natural male sterile in *indica* rice. He did not get the restore line: later, in 1970, his colleague Professor Li found pollen abortive material from a wild rice variety named *Oriza rufipogon.* The wild variety was the donor of cytoplasmic male sterility (CMS) to develop an effective line for CMS [20]. In China, the average yield of hybrid rice is about 7500 kg/hm^2 and the additional production from hybrid rice can feed more than 70 million people of China [16]. Currently, China has developed super-hybrid rice varieties, which are even more productive than hybrid rice. China currently is studying third-phase hybrid rice to produce a target yield of 13.5 ton/hm^2 [16].

3. CURRENT STATUS OF HYBRID RICE IN BANGLADESH

The *per capita* arable land of the country was 0.173 hectare in 1961, whereas the last estimation, in 2013, It was only 0.048 hectare [3] showed in Fig. 1. In this condition, it is doubtful that the country can meet the food security goal without increasing adoption of hybrid rice. Despite that fact, the adoption rate of hybrid rice in Bangladesh is not increasing satisfactorily.

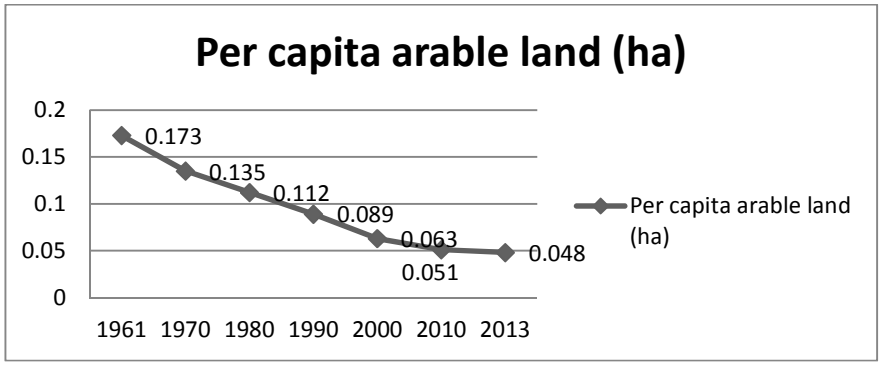

Fig. 1. Per capita arable land procession with time
Source: Authors' Calculation, data from World Bank [3]

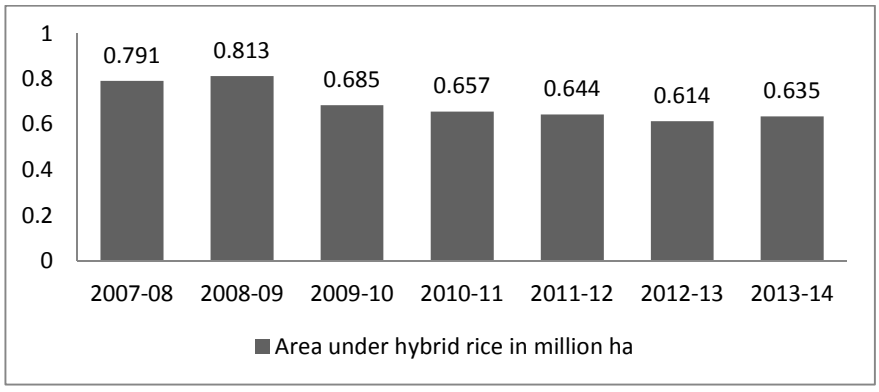

Fig. 2. Recent trends of hybrid rice cultivation over years
Source: [22]

Hybrid rice was introduced in Bangladesh in 1998 by the Ministry of Agriculture [21]. In 1999, four hybrid varieties were cultivated in the country: three of which came from India and one from China. Initially, due to high yield performance, it got a huge popularity. In nine years, from 1998-99 to 2007-08, hybrid rice area increased dramatically (about 4263 %). However, in 2008-09 it decreased around seven percent than the previous year [15] and has continues since then. In 2013-14 total rice areas were 11.8 million hectare in Bangladesh [21]. In the same year, hybrid rice area was only 0.63 million hectare (but it had been around 0.8 million hectares in the year 2007-08 [22]. While, hybrid rice can produce yield at minimum 15-20 percent higher than improved HYVs, the hybrids are not popular in Bangladesh (Fig. 2).

4. REASONS FOR REJECTION OF HYBRID RICE BY BANGLADESHIS

The hybridization of rice can be a suitable option to meet the food security of developing countries in Asia where rice is the main staple food [23]. Hybrid rice technology can even make Bangladesh a rice-exporting country [24]. As *per capita* land holding is low in Bangladesh, hybridization may possibly be the effective technology to cope with the current situation.

Initially, Bangladeshi farmers adopted hybrid rice willingly, as an innovation but it quickly lost its popularity. Researches have shown the following problems with cultivating hybrid rice in Bangladesh: (i) high cost of seed production, (ii) low seed quality, (iii) poor management skills [25,26,27]. Other significant reasons behind declining adoption of hybrid rice in Bangladesh are described below.

4.1 Low Institutional Capacity/Policy

In Bangladesh, the quality of hybrid seeds does not meet the internationally agreed standard. There are some possible explanations for this, i) the Bangladesh Seed Certification Agency (SCA) is not sufficiently qualified to assure the seed quality of hybrid rice, ii) the hybrid rice division of the Bangladesh Rice Research Institute (BRRI) has been suffering from inadequate personnel in terms of quality and quantity. At present, 119 hybrid varieties are available in Bangladesh. Of the available hybrid rice verities, BRRI released only four varieties. The rest of the varieties have been imported from China, India, and the Philippines by private companies and NGOs [28]. This figure proved the limited capability of BRRI in hybrid rice research. Imported varieties are not well tested for the applicability to the field conditions of Bangladesh. Therefore, the results are not significant in most of the cases. Furthermore, 95 percent of hybrid rice seed is imported by private companies which are more so interested in immediate profit rather than research and development. NGOs and private companies are also suffering due to lack of expert breeders. The price of imported hybrid seed is very much higher than the State-provided seed. Farmers lose interest in hybrid rice cultivation when they get poor outcomes even after investing significantly. Mottaleb et al. [28] found that low availability of trusted seed dealers, poor infrastructures such as roads and highways, informal loan unavailability and inadequate irrigation facilities are responsible for the low adoption of hybrid rice in Bangladesh.

4.2 Poor Cultivation Facilities for Farmers

Hybrid rice cultivation highly depends on irrigation facilities. Although Bangladesh has developed a wide range of irrigation facilities for HYVs rice over the last two decades, still has a huge shortage in these sectors. Irrigation water shortage during *boro* rice [29] and diesel fuel crises for water pumps [30] are the reasons for the serious shortfall of rice yields.

4.3 Low Technological Know-how

Another significant reason behind low adoption of hybrid rice is the low-level of technological know-how among farmers. No training program is planned to increase the knowledge of hybrid rice farmers of Bangladesh. Even the extension workers lack sound knowledge of hybrid rice production. Salam et al. [14] found that HYV farmers have some basic knowledge in input use and crop management but, in the case of hybrid rice, about 98 percent farmers do not have adequate knowledge in hybrid rice production. There is some evidence that, while some farmers keep hybrid seeds for the next year, some other experienced farmers choose to cultivate hybrid rice anymore.

4.4 Poor Seed Quality

The seed and agricultural inputs business is a season-based business. It is very common in Bangladesh that during the seasons (*Aus, Amon and Boro),* many traders open their temporary shops and sell the seeds. If the buyers stop buying those seeds, the weak monitoring systems allow traders to sell low-quality seeds to

cut their losses. They provide wrong information to the farmers and, when farmers get low yields, they can only bear the loss. Furthermore, farmers in Bangladesh have low capabilities and low-level awareness. Culturally, they tend to be impatient; thus, expecting big revenue in a short time. Any loss discourages them quickly and motivates them to stop their current course of action in search of alternatives. Most of the farmers are illiterate. They have below average social status and little influence in the society. They cannot take any action against the dealer or seed companies. Simply, they remain dissatisfied and discontinue the adoption.

4.5 Poor Infrastructure

A poor infrastructure facility is another reason behind low adoption of hybrid rice. Paved roads can contribute hybrid rice adoption in two ways [28]: i) decreasing the transportation cost of inputs and outputs to the nearby market; ii) increasing the information flow and visits of extension agents.

4.6 Food Habit of the People

Bangladeshi people eat flaky rice, not the sticky rice common in China and other Asian countries. If the cooked rice becomes sticky, it is normally thought that the cook is not expert. Therefore, women usually insist that their husbands do not to buy hybrid rice. Cooked hybrid rice does keep good without refrigeration for a long time like HYV rice does. In rural areas of Bangladesh, however, women usually cook before lunch and keep this rice all day, eating it for lunch, dinner and tiffin. No one can afford a refrigerator: they merely cover the food and leave it sit in the tropical humidity on the table. In the end, many rural families found that their hybrid rice was inedible before dinner for this reason, they did not want to buy it or grow it again.

4.7 Other Significant Factors

Shah et al. [31] found that farmers' educational level, annual income of the farm family; transport facilities and farmers' attitude towards hybrid rice were the important determinants for adoption of hybrid rice in Bangladesh. It is obvious that education broadens the outlook of a person. Farmers in Bangladesh generally have a very low level of education. They have low understanding of technological information regarding hybrid rice technologies. Farmers with high income can take more risk than the farmers having low-income level. Similar results were also obtained in different other sectors in Bangladesh through Sarker et al. [32] (organic farming); Kabir et al. [33] (Biogas plants).

Rashid et al. [15] identified some constraints on hybrid rice adoption in Bangladesh, such as: i) non-availability of suitable varieties in *Aman* and *Aus* rice seasons; ii) rumors about hybrid rice; iii) low selling price of hybrid rice compared to the inbred rice varieties; iv) farmers' problems in selling hybrid rice in the markets iv) limited land availability for hybrid rice in *boro* season.

On the contrary, Ward et al. [34] found that the social network is extremely important in the adoption of hybrid rice in Bangladesh. For example, a network with less distance between hybrid adopters is extremely significant for a large number of adopters, if they are far away from the farmer. They found that network effect is more effective than that of the interaction with agriculture extension officers. Therefore, extension officer's contact does not play a significant role in adopting hybrid rice [34]. This is because farmers rely more on their peers and relatives than the extension offices [35]. Azad et al. [26] found that high price of hybrid seed; low cooking quality and high incidence of diseases and insects infestations compared with inbred rice varieties limit farmers in hybrid rice production in Bangladesh.

5. CHINA'S SUCCESS IN HYBRID RICE DISSEMINATION

Chinese hybrid rice breeding and large-scale cultivation have achieved a significant yield increases and progress in modern agricultural science. This has not only opened up a new method for rice production worldwide, but also greatly enriched the genetic breeding and high-yielding rice cultivation theories and practices. China's hybrid rice research started late in comparison with that of Japan and the United States. Despite poor research funds, equipment and other research resources, China got its achievements more rapidly and efficiently. Therefore, the secret of enormous success in adoption and production of hybrid rice in China has become a matter of discussion.

5.1 Extensive Researches on Hybrid Rice

Of course, the technological breakthrough is the main reason behind China's success in hybrid rice. After successful achievements from Professor Yuan and Li in the 1960s, a nationwide screening of restorer lines and widespread collaborative researches were carried out. In 1973 Guangxi College of Agriculture selected

Trailing no.1, IR24 and IR26 restorer [36] for hybridization (International Rice Research Institute (IRRI) developed varieties are called shortly as IR). From 1980 to 1985, the College investigated rice varieties in 13 counties of Guangxi, Hunan and Jiangxi [37]. The Chinese Ministry of Agriculture (CMOA) has been providing a lot of support to the researchers since the 1970s. In continuation of the program, CMOA organized a Super Hybrid Rice Symposium in 1996, where scientists all over China planned, designed and solved the existing problems of hybrid rice, as well as fixed the future targets [38]. China has formed some stable breeding base throughout the country. In Sichuan Province, they have the largest hybrid rice seed production base. In Hunan Province, the country has the largest base in hybrid rice breeding. Similarly, Beijing, Hainan, Hunan and Zhejiang Provinces have established the basis of the National Hybrid Rice Research Center. Special *indica* hybrid rice and *japonica* hybrid rice cultivation base has matured into two major rice-growing areas in north and south. China not only achieved success in hybrid rice development but also solved wide ranges of production problems. By 2020, China has planned to increase total rice production and yield up to 35 and 32 per cent, respectively, maintaining the existing rice area of 31.57 million hectares [39]. In this regard, China has highly concentrated research on hybrid rice. Breeders in China not only maintain the yield advantage of hybrid rice, but also improve the quality and adaptability. In 2012 they produced more than 500 million tons of rice, which is a new record of grain production in China [38]. Extensive research helps China attain their goal well in advance. State of the art agricultural engineering has also boosted the development and production of hybrid rice in China.

5.2 Government Policies

Among the factors that influence the extensive development of hybrid rice in China, government policies are playing a significant role. Research has found that over the past 50 years, China's grain production fluctuation and evolution of government policies have a strong relation [40]. Therefore, the agricultural policy on food production has a significant impact on the positive extension of hybrid rice. Because of the significance of hybrid rice for food security, research and promotion of hybrid rice continue to receive priority from Government. In China, Government initially subsidizes hybrid rice seed production abundantly to get an affordable and high-quality seed supply for farmers [41]. In addition, farmers get access to subsidized fertilizer, pesticides and other inputs [42]. Renowned scientists were the coordinators of the hybrid rice program in China and full-time researchers got engaged in hybrid research and seed production. Over the last 40 years, China has developed more than 1000 parental line and 300 large-scale commercial hybrid varieties [43]. The government supported Yuan Longping's scientific experiments to solve the specific problems of different projects and collaborative research on hybrid rice. Based on the successful demonstration, the government started promotion of hybrid rice development as an important measure of China's grain production.

In 1975, the State Council made the decision to grow and promote the rapid expansion of hybrid rice. The State invested enormous manpower, material and financial resources on breeding and seed production to overcome the difficulties. State 'seed law', 'achievement transformation', 'variety rights ordinance' and other laws and policies also protect the development of hybrid rice.

5.3 Agricultural Technology Extension

After establishment of the People's Republic of China in 1949, the Government introduced a wide range of policies and administrative pronouncements to implement the nationwide Agricultural Technology Extension (ATE). By the mid-1950s, a complete ATE system was established in the country [44]. Now, China has the world's most extensive agricultural technology extension system. A large number of Provincial-level scientific and technical personnel have been moved to rural areas, for training farmers' groups on seed production, plant protection, soil and fertilizer management. The experimental plots, demonstration fields, site meetings and other face-to-face technical communication programs help to disseminate hybrid rice technologies to farmers. China now has the worlds' largest extension system in agriculture. In 2006 China has around 787,000 extension workers who provided their services to 637,000 villages [45]. On an average, one extension worker is supporting only 283 farm households [46]. Public extension workers in China offer their services in all remote areas thought the country [47]. High-level professional training on hybrid rice, farmers' involvement in agricultural co-operatives, and sufficient technical assistance in the field are important factors in changing the farmers' adoption behavior. A

survey done by Chen et al. [48] showed that, in Hunan and Zhejiang Provinces, the farmers participating in rice planting technology training were more involved in rice cultivation and got the higher yields. Wide use of the internet also has a significant economic impact on increasing Chinese farmers' income [49]. Thus, Chinese hybrid farmers are getting benefit from e-commerce and internet use. The internet services of farmers' co-operatives provide a wide range of information on government subsidies, rice cultivation technologies, market information and many other issues which reduce the social and natural risks in agricultural production.

5.4 Improved Input Facilities

Large numbers of public-private partnership (PPP) activities are providing their advisory services at country-level and input supports [45]. Creating a positive attitude towards hybrid rice has a significant economic impact on its adoption.

5.5 Strong Input Monitoring Systems

Strict seed quality management and monitoring is an important factor for the development of Chinese hybrid rice. To promote seed industry, China's new amendment of seed policies in 2015 has reduced the number of crops subject to variety registration requirements from 28 to 5. However, the crops that still need to be registered are rice, wheat, corn, cotton and soybean [50]. Therefore, the hybrid rice varieties are still under strong monitoring. Sound policies and regulations help farmers get higher achievements. This set of policies and regulations include the special laws, the relevant laws, administrative regulations, departmental rules, local regulations, normative documents, national standards and other components. "Seed law of People's Republic of China" is the core support whereas each province sets own regulations, such as "Guangxi Zhuang Autonomous Region seed regulations" and so on. Before 2006, the majority of Chinese seed companies were state-owned enterprises but in 2006, Chinese government promulgated the "State Council on the reform and strengthening of seed market supervision view" where there are provisions for seed business [51]. With the progress of privatization, a fairer and responsive seed quality supervision system has been formed. Government implemented the administrative licensing system for hybrid rice seed production and the authority maintains the quality. Hybrid seed companies must satisfy the specific requirements, for isolation and incubation conditions, the testing facilities, involvement of professional testing technicians and other conditions. Hybrid rice seed companies must have at least two inspectors and more than three professional hybrid seed workers who must pass the examination held at provincial level administrative departments of agriculture. Hybrid rice seed should have processing; grading and packaging, along with traceability label, and have detailed specific provisions on the label color, content, formats and so on.

5.6 Role of Mass Media

Finally, the mass media in the promotion of hybrid rice technologies has also been efficiently utilized in China. The mass media have the special characteristics of long-lasting, multi-form frequency. National, provincial, city, district, county newspapers published various technical brochures, field blackboards, posters, radio propaganda etc. to encourage farmers to use hybrid rice.

6. CONCLUSIONS AND FUTURE RECOMMENDATIONS

In Bangladesh, there is no specific set of regulations for seed companies (for example, laboratory facilities and technical staff requirements). The government should thus fix standards for the companies. Each company must appoint quality breeders. Also, quality assessment of the breeders can also be introduced.

On the other hand, hybrid rice research in Bangladesh has been limited by lack of experts and quality researchers. To develop high-quality research personnel, Bangladesh can arrange some collaborative research with China. Bangladesh should start its own Centre for Hybrid Rice Research. this would also demand policy support such as integrated hybrid rice development policy, which must include: i) Special research program for identification of local CMS and R lines and a well-funded Centre for Hybrid Rice Research in general. ii) Effective regulation of seed companies to maintain consistent quality and affordable price, iii) A marketing policy that grants subsidy based seeds, iv) Extensive human resource development in hybrid rice among both researchers and extension officers. Here specific focus should be made on the introduction of hybrid-based Farmer's Field Schools (FFSs).

v) Ensuring a high wholesale price for hybrid rice, to assure sufficiency of income for the farmers selling rice to middlemen, or state income guarantees for hybrid rice farmers. In essence, hybrid rice should be treated as a "strategic crop" in Bangladesh.

Well-developed research on hybrid rice is crucial for future. Bangladesh needs a nationwide search of parental strains which can develop their own parental line for hybrid rice varieties development. For this reasons, storing of existing local varieties is extremely important. BRRI is needed to conduct a field-level survey, with help from the Department of Agricultural Extension (DAE), to identify the existing breeds of rice throughout the nation. Currently, BRRI's hybrid rice division has been suffering from lack of isolated area for hybridization, inadequate manpower, low budget etc. Subsequently, BRRI can conduct more of its research in collaboration with private organizations. A large budget for this kind of research is required, as one of the examples of what the Centre for Hybrid Rice Research needs to develop. The backbone of China's success in hybrid rice was this kind of huge State investment in research of this sort.

Bangladeshi hybrid rice farmers are suffering from low wholesale price for hybrid rice. This is because hybrid rice is bowl-shaped, sticky and quickly perishable when cooked. Therefore, high-level research is needed to overcome these problems, such as by increasing the amylase content in hybrid rice. Furthermore, well-structured market systems, with minimum intervention of middlemen, are needed. The farmer ought to be able to sell directly to the market as much as possible: This raises issues of investment in transport, communication and market linkages to provide buyers for the farmers' product. Therefore, another alternative is for Government to buy hybrid rice from the farmers directly and sell it directly to consumers. The 2008 caretaker Government's "fair price rice shops" could be a model for this.

Other challenges such as in Bangladeshi farmers inability to buy hybrid rice seeds could be solved introducing subsidy-based seed procurement. For this, existing fertilizer subsidy systems can be taken as a model. In addition, seeds can be supplied to farmer's cooperatives as some sort of encouragement to farmers' cooperatives would tend to make the transition to hybrid rice easier and more effective. Hybrid rice-based FFS can be a cooperative where farmers can learn the intricacies of hybrid rice production technologies and be assisted with technical advices such as marketing.

Lack of knowledge about hybrid rice is another problem in hybrid rice dissemination. Therefore, farmer's attitudes towards hybrid rice are not positive and many rumors on hybrid rice remain among the farmers. Extensive awareness campaigns, methods and results demonstration should be included in the extension systems. The mass media can play a role in fixing though extensive awareness campaign, as well as method and result demonstration should be included in extension system. Additionally, an educational and awareness-building campaign for farmers is highly recommended. However, above all a well-structured seed policy with good provision to protect the farmer's rights, good infrastructure, farm-level mechanization, and quality extension services are very important to increase the adoption of hybrid rice in Bangladesh.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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