Chapter 4
Diffusion of Submergence-Tolerant Rice in South Asia

Takashi Yamano

Abstract Climate change is expected to increase the incidence and magnitudes of extreme weather events. To help farmers mitigate the expected impacts of extreme weather events, abiotic stress-tolerant crop varieties have been developed. The diffusions of the stress-tolerant crop varieties, however, have been limited. This chapter reviews recent studies on the adoption and impacts of the submergence-tolerant rice varieties in South Asia. Studies have identified significant benefits of those rice varieties in South Asia using various survey and analytical methods. However, farmers have problems identifying submergence-tolerant rice varieties in informal seed markets. Using DNA fingerprinting, a study found that many farmers in Bangladesh could not identify varietal names correctly. Effective public interventions are needed to help farmers in flood-prone areas adopt submergence-tolerant rice varieties.

4.1 Introduction

Climate change studies predict that the frequency and intensity of extreme weather events will continue to increase (IPCC 2018; ADB 2021). In developing countries, agriculture absorbs more than 60% of the damage and loss caused by climate-related disasters across all economic sectors (FAO 2021). In Asia, flood-prone areas are also major rice-producing areas where farmers depend on rice to support their livelihoods, and flood risks are high in rainfed areas where resource-poor farmers tend to reside. To mitigate flood-related losses in rice production, the International Rice Research Institute (IRRI) and its collaborators have developed rice varieties tolerant to submergence.[1]

[1] IRRI and other international agricultural research institutes have been developing and disseminating stress-tolerant crop varieties and other climate-smart agricultural technologies. Yamano et al. (2016) and Mishra et al. (2022) present reviews of recent agricultural technologies and their impacts among farmers in developing countries.

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Despite the benefits of stress-tolerant rice varieties, the adoption of submergence-tolerant rice varieties has been limited. Although many adoption studies on agricultural technology in developing countries exist,[2] recent studies focus on social networks and farmer-to-farmer technology extension (Takahashi et al. 2019). Because the adoption of submergence-tolerant rice varieties requires seed costs and no additional rice production knowledge, studies found information access as a major adoption constraint (Yamano et al. 2018; Veettil et al. 2021; Bairagi et al. 2021). By conducting a randomized controlled trial (RCT), Emerick and Dar (2021) show that farmer field days effectively encourage farmers to adopt submergence-tolerant rice varieties in Eastern India.

Submergence-tolerant rice varieties, or other stress-tolerant crops, exhibit few stress-tolerance traits under normal conditions. Their benefits become visible only when the specific stresses they are tolerant of occur. Thus, the adoption process of farmers and diffusions of the varieties in target areas would be different from other agricultural technologies that exhibit technological advantages under normal conditions.[3] In addition, farmers have difficulties identifying seeds of stress-tolerant rice varieties in informal seeds markets. To better understand how farmers gather information about submergence-tolerant rice varieties and examine their ability to identify rice varieties they cultivate, this paper reviews (1) studies on the adoption of submergence-rice varieties and (2) studies that use DNA fingerprinting for rice variety identification in South Asia.

4.2 Background

Rice plants respond to flooding stress through two mechanisms: (1) their ability to elongate above rising floodwater levels, which allows them to avoid complete submergence,[4] and (2) submergence tolerance through which certain rice varieties survive submergence of ten days or more, particularly through metabolic adjustment in shallow water (Xu et al. 2006; Mackill et al. 2012). In the 1990s, rice scientists found that the second mechanism of the submergence tolerance of certain rice varieties is controlled by a single major quantitative trait locus (QTL),[5] named Sub1, which

[2] Doss (2006) and Foster and Rosenzweig (2010) provide reviews.

[3] For instance, during the Green Revolution, modern rice varieties were easy to identify because they were shorter and produced significantly more grains than traditional rice varieties (David and Otsuka 1994).

[4] They are called floating rice in some areas and their genetic mechanisms have been identified (Hattori et al. 2009).

[5] Single major quantitative trait locus (QTL) is a section of DNA that correlates with variation in a phenotype.

provides tolerance to complete submergence for up to 14 days. By using marker-assisted backcrossing (MAB),[6] rice scientists successfully introgressed[7] the Sub1 QTL into Swarna (Neeraja et al. 2007). Subsequently, many Sub1 varieties[8] have been developed using popular rice varieties in target areas. Studies in agronomy and agricultural economics found that submergence-tolerant rice experiences no significant yield penalty under normal conditions but performs better under submergence than other varieties (Sarkar et al. 2006).

To observe the performance of Swarna-Sub1 on farmers' fields, Dar et al. (2013) conducted an RCT in Odisha, India. Half of the 128 flood-prone villages across eight blocks in Balasore and Bhadrak districts were randomly assigned to treatment in 2011. Five farmers were randomly selected in each treatment village to receive 5 kg (kg) Swarna-Sub1 seeds, which can be cultivated on 0.1–0.2 ha. The authors found that Swarna-Sub1 had an estimated 45% increase in yields over other popular rice varieties when fields were submerged for ten days. Further, in a subsequent study based on the Odisha RCT, Emerick et al. (2016) found that submergence-tolerant rice induced farmers to apply more inputs, presumably because of the reduced risks from floods.

In the most recent study coming out from a series of RCT studies from Odisha, Emerick and Dar (2021) implemented three different ways to select seed recipient farmers/demonstrators for dissemination of Swarna-Sub1 in 100 villages.[9] Then, in randomly selected 50 treatment villages, they conducted field demonstration days promoting Swarna-Sub1. The results indicated that the field days increased adoption rates by 40%. This is an encouraging result supporting the effectiveness of dissemination efforts. Their results show no differences among the three different selections of recipient farmers.

4.3 Adoption Studies of Submergence-Tolerant Rice in Bangladesh and India

To better understand how submergence–tolerant rice varieties spread among farmers, a series of adoption studies were conducted in flood-prone areas in northern Bangladesh and Eastern India (Yamano et al. 2018; Bairagi et al. 2021; Raghu et al. 2022). The three studies took different sampling strategies.

[6] After crossing two rice varieties, scientists examine DNA markers of new seeds and select ones with a set of desirable markers. After a few seasons of multiplications and selections, they complete a MAB process.

[7] Introgression is the gradual movement of genes from one species into the gene pool of another, when there is some opportunity for hybridization between them.

[8] For this reason, some studies call submergence-tolerant rice varieties with Sub1 QTL as Sub1 varieties. In this review, we use 'submergence-tolerant rice varieties' because it is a more general term, possibly including submergence-tolerant rice varieties without Sub1 QTL.

[9] The three selection processes of seed recipients included selection by village officials, by villagers in participatory selection, and by local women groups.

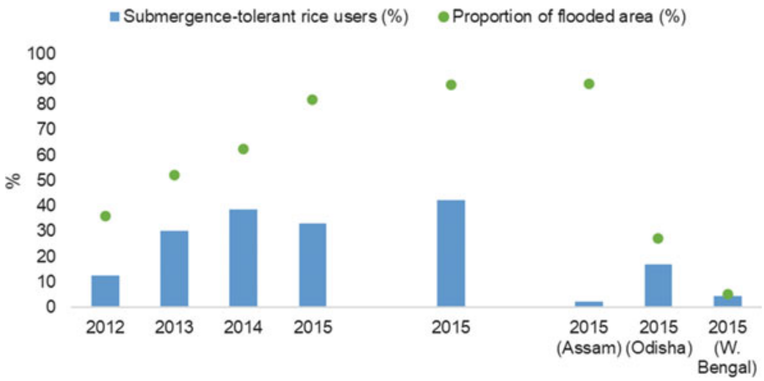

Fig. 4.1 Adoption of submergence–tolerant rice and flood experience in Bangladesh and India (Yamano et al. 2018; Bairagi et al. 2021; Raghu et al. 2022). *Notes* 465 farmers in Lalmonirhat, Kurigram, and Rangpur districts; 1,020 farmers in Gaibandha, Jamalpur, Kurigram, Lalmonirhat, Rangpur, and Sherpur districts; 1,544 farmers in Assam, 1,600 farmers in Odisha, and 1,600 farmers in West Bengal, India

Yamano et al. (2018) selected villages where submergence–tolerant varieties were distributed between 2009 and 2012. They obtained lists of villages and names of seed recipient farmers in three districts in northern Bangladesh. The authors conducted the first survey of 465 farm households in 2013, asking about the 2012 *aman* season (July–December growing season). In 2016, asking about the 2015 aman season, the authors conducted a follow-up survey, revisiting the same respondents. The results of the panel surveys are presented in Fig. 4.1.

In 2012, the adoption rate was only 12%, although 37% of the sample households experienced floods. In subsequent years, the adoption rate increased to 30% in 2013 and 39% in 2014 before declining to 32% in 2015. In 2013 and 2014, the proportions of farmers who experienced floods increased to 52 and 62%, respectively. In 2015, floods were severe. More than 80% of the sample farmers in this study reported floods in 2015.

To assess the impacts of the 2015 floods, another survey was conducted in 2016 in northern Bangladesh by Bairagi et al. (2021). They covered six districts where the 2015 floods occurred. Unlike Yamano et al. (2018), their sampling did not depend on prior distributions of submergence–tolerant rice varieties. Thus, their respondents should be considered as a representative sample of flood-prone areas in northern Bangladesh. Nevertheless, they found a higher adoption rate, at 42%, than Yamano et al. (2018) did in 2015. About 90% of the surveyed households experienced floods in the 2015 aman season.

In India, a survey was conducted in flood–prone districts of three states (i.e., Assam, Odisha, and West Bengal) in 2016 (Raghu et al. 2022). There were 160 randomly selected villages in flood-prone areas in each state. From the total of 480 villages in the three states, 4,750 farm households were randomly selected. The results found that only a small number of farmers (around 2%) adopted submergence-tolerant rice varieties in Assam, although heavy floods occurred during the 2015 *kharif* season. The adoption rate was relatively high in Odisha at 16.7%, where about 27% of areas were affected by floods in 2015. On the other hand, the adoption rate in West Bengal was only 4.2%, while the proportion of flooded area was only 5%. Based on the 2015 flood information alone, it seems farmers in Assam should have been targeted more in the promotion of submergence-tolerant rice varieties.

4.3.1 Yields and Profits

All three studies discussed found yield advantages of submergence-tolerant rice over other rice under normal and submergence conditions. According to Yamano et al. (2018), in the 2012 aman season, the average yields of the flood-tolerant rice varieties were higher than their parental varieties under normal and submergence conditions (Fig. 4.2). However, the observed yield differences should not be considered causal impacts of the submergence-tolerant rice varieties. First, farmers who adopt new varieties could be progressive farmers who are more capable than other farmers. Second, Emerick et al. (2016) observed that farmers may allocate more inputs to submergence–tolerant rice varieties because of reduced risks of flood damage. Third, submergence-tolerant rice varieties could have been adopted on flood–prone plots and had a low yield because of the location.

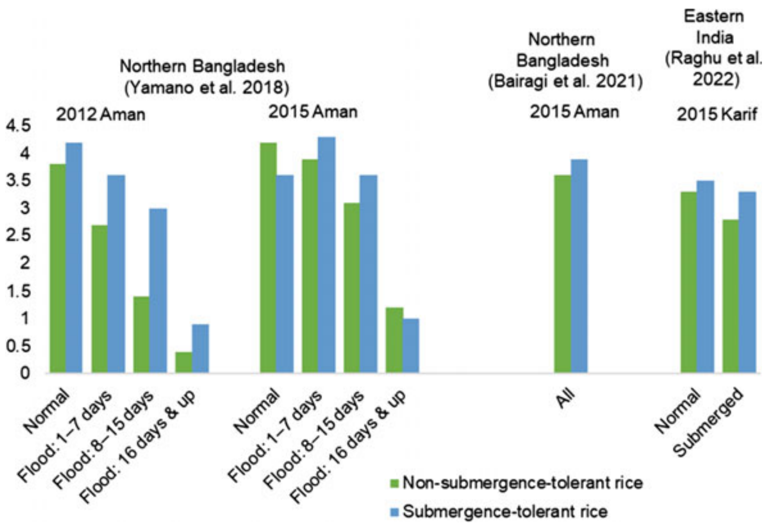

Fig. 4.2 Yields (t/ha) of submergence–tolerant varieties and other rice varieties (Yamano et al. 2018; Bairagi et al. 2021; and Raghu et al. 2022). *Note* See Fig. 4.1 for details on the study areas

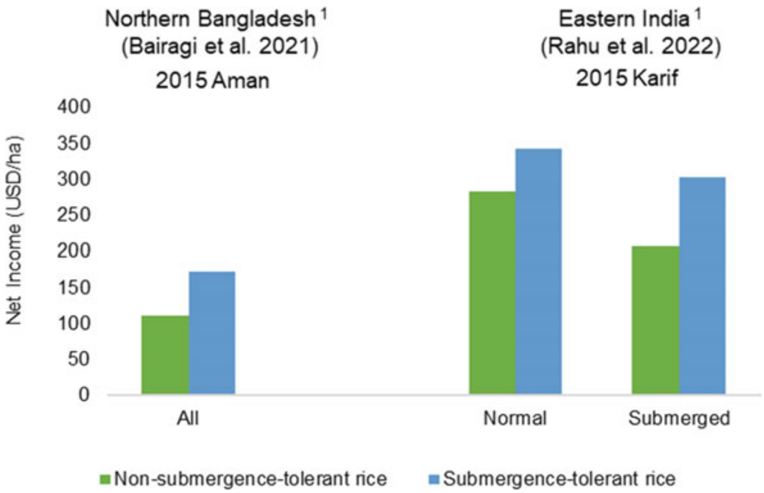

Fig. 4.3 Net income (USD/ha) from submergence-tolerant varieties and other rice (Yamano et al. 2018; Bairagi et al. 2021; and Raghu et al. 2022). *Notes* See Fig. 4.1 for details on the study areas. Exchange rates used: USD 1 = IDR 67.2; USD 1 = BDT 78.4

Both Bairagi et al. (2021) and Raghu et al. (2022) realized the selection problem and employed an endogenous switching regression (ESR) model to identify the impacts of the submergence–tolerant rice varieties on different outcomes. Both studies observed higher yields for the submergence–tolerant than other rice varieties. The results from the ESR model found yield impact as a 10.2% increase among the adopters and a 7.7% increase among the non–adopters (Bairagi et al. 2021). In India, Raghu et al. (2022) found the yield impact as a 29.6% increase among the adopters. Among non-adopters, the expected impact was 7.7%, as noted in Bairagi et al. (2021). The two studies identified larger causal impacts than the observed differences.

In addition to the production outputs, farmers consider profit or net income when they decide to adopt new agricultural technology.[10] The observed net incomes are presented in Fig. 4.3. Both studies found higher net incomes for the submergence–tolerant rice varieties than other rice varieties. The ESR model in Bairagi et al. (2021) suggested that the impact of submergence-tolerant rice varieties on net income would be 145% among adopters and 48% among non–adopters. Raghu et al. (2022) found that the average treatment effect (ATE) among adopters and non–adopters of the submergence-tolerant rice varieties on net income ranged from 31 to 60% under submergence, depending on estimation models. Under normal conditions, it would be in the range of 18–27%. These studies suggest that the expected gains in net income would be large for farmers in flood-prone areas in northern Bangladesh and India.

[10] In studies of agricultural economics, net income is usually calculated after subtracting paid-out costs from revenues, while profit is calculated by subtracting imputed own labor costs from net income.

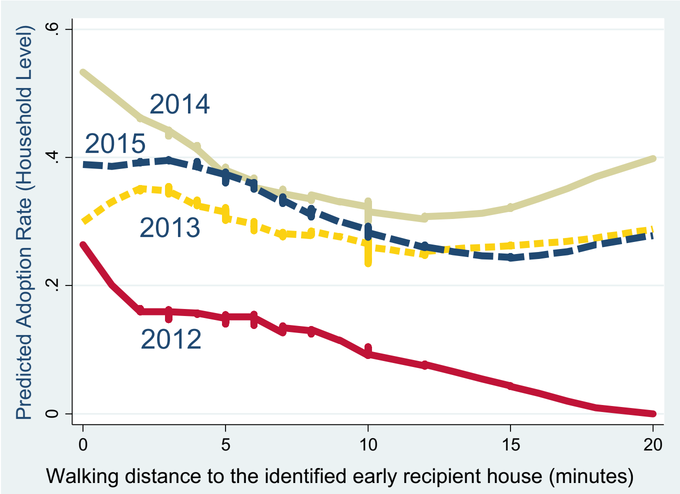

Fig. 4.4 Adoption rate of submergence-tolerant rice in terms of walking distance to the identified seed recipient's house (Yamano et al. 2018)

4.3.2 Farmer-To-Farmer Information Exchange and Adoption

To investigate how to disseminate submergence-tolerant rice varieties among farmers, Yamano et al. (2018) focused on the information and seed exchanges between seed recipient farmers and their neighbors. During the interviews, enumerators showed a list of the seed recipients in the village and asked respondents to identify one recipient that the respondent knew best. The recipient farmers tended to be recognized as progressive farmers in each village.[11] After identifying one recipient farmer, respondents were asked about the walking distance (in minutes) from the respondent's house to the identified seed recipient's house. Figure 4.4 shows the relationship between the distance to the identified recipient farmer and the adoption of the submergence-tolerant rice varieties. From the figure, the authors found that the adoption rate was higher among farmers who were located closer to the identified seed recipient.

[11] Yamano et al. (2015) conducted surveys in 50 villages in Uttar Pradesh and Odisha, India, where demonstrations of Swarna–Sub1 took place. They found that the seed recipient farmers had higher scores on self-perception toward adoption of new agricultural technologies than the representative farmers. Farmers from scheduled castes, female farmers, and less educated farmers had low scores on self–perception.

4.3.3 Seed Sources

In the survey region, government agencies and non-government organizations (NGOs) have promoted submergence-tolerant rice varieties since 2009. At the same time, private seed dealers are also involved in seed production multiplications and sales. Figure 4.5 shows the proportions of the main seed sources of submergence-tolerant rice seeds among the adopters in Yamano et al. (2018). In 2012, 56% of the users used their own seeds from the previous season. In the same year, about 25% of the users obtained seeds from other farmers, and another 16% obtained seeds from NGOs; no farmer obtained seeds from shops or dealers in 2012. In 2013, however, farmers bought the seeds at local shops and dealers. The proportion of users who bought the seeds increased to 26% in 2013 and 40% in 2015. In the same period, the proportion of users who obtained the seeds from the government and NGOs declined to 21% in 2015. In 2015, the private seed sector became the largest seed source of the submergence-tolerant rice varieties.

The seed information sources in Fig. 4.5 relied on farmers' identification of rice varieties. There are no mechanisms to verify seed identity in the informal seed markets and farmer-to-farmer seed exchanges. Thus, farmers' poor ability to identify rice variety names has been the main limitation of these adoption studies, and this has been addressed in studies using DNA fingerprinting, as discussed in Sect. 4.4.

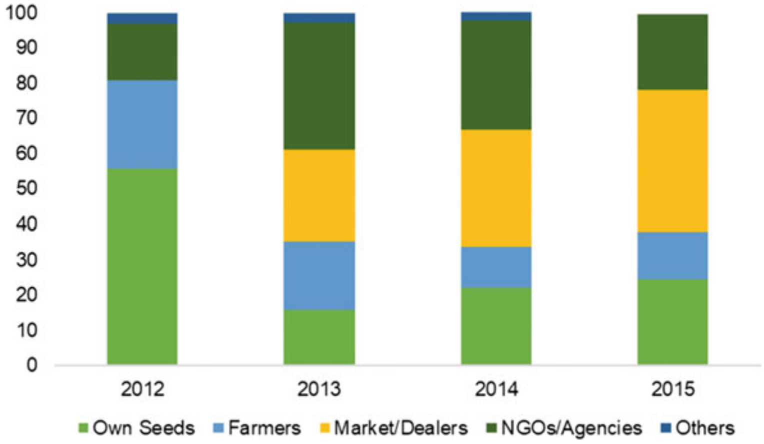

Fig. 4.5 Seed sources of submergence-tolerant rice varieties in 2012–2015 in northern Bangladesh (Yamano et al. 2018)

4.4 DNA Fingerprinting of Farmers' Seed Samples

Realizing farmers' poor ability to identify rice variety names, researchers often grouped rice varieties (Estudillo and Otsuka 2006). When detailed survey data on variety adoptions were absent, studies relied on experts (Tsusaka et al. 2015). Without reliable area estimates under different rice varieties, rice breeders and policymakers are left with little guidance in understanding farmers' preferred rice varieties.

To obtain accurate information on the varietal identification of crops produced by farmers, some studies have used DNA fingerprinting, which has become available and affordable. It has been applied to track the adoption of wheat (Gade et al. 2021) and rice (Kretzschmar et al. 2018) varieties. These studies collected seeds or leaves from farmers' fields. Then, genome-wide markers, such as single nucleotide polymorphisms (SNPs), were used to identify the sample varieties against a reference library of existing varieties.

In the case of submergence-tolerant rice varieties, varietal identification is even more difficult because they are designed to possess characteristics of one of their parent varieties. The only difference is the presence of the Sub1 QTL in Sub1 varieties. DNA fingerprinting was conducted on rice seeds collected from major rice-producing areas of Bangladesh to investigate the issue. The main results are summarized in Yamano et al. (2017) and Kretzschmar et al. (2018).

The authors conducted cross-section surveys of 3,000 households in Bangladesh, 1,500 households each in 2014 and 2015,[12] and collected seed samples from almost 20% of the sample households. In total, 1,380 seed samples were collected from 544 farmers in Bangladesh. Later, the seeds were planted in individual pots, and their leaves were collected in individual plastic bags. The plastic bags were sent from Bangladesh to the IRRI Headquarters located in Los Baños, Laguna, Philippines. Instead of rice seeds, leaves were used to extract DNA because it was considered easier and more accurate to extract DNA from leaves than seeds. The genotyping of the farmer and breeder seed samples was conducted using Illumina Infinium 6 K SNP chips. Out of over 6,000 DNA data points, about 4,000 data points were used to genotype farmers' seeds.

The results of the varietal identification are presented in Fig. 4.6. The most popular rice variety in Bangladesh was Swarna, developed in the 1980s in India. Interestingly, Swarna was never officially released in Bangladesh. Thus, farmers probably smuggled Swarna across the border between the two countries. Figure 4.6 also shows the levels of DNA matches between the samples from farmers and the ones in the reference library. Not all samples were identified as 100% matches of those in the reference library. In fact, old rice varieties tended to have low levels of DNA matches. This may be because rice may lose DNA purity over time.

Note that new varieties developed in or after 2007 tended to have 100% matches. About 5% of the sample were identified as BR11-Sub1, while just over 1% were

[12] The surveys covered all rice–producing areas, not only in northern Bangladesh, so that the surveys were representative of rice–producing areas in Bangladesh.

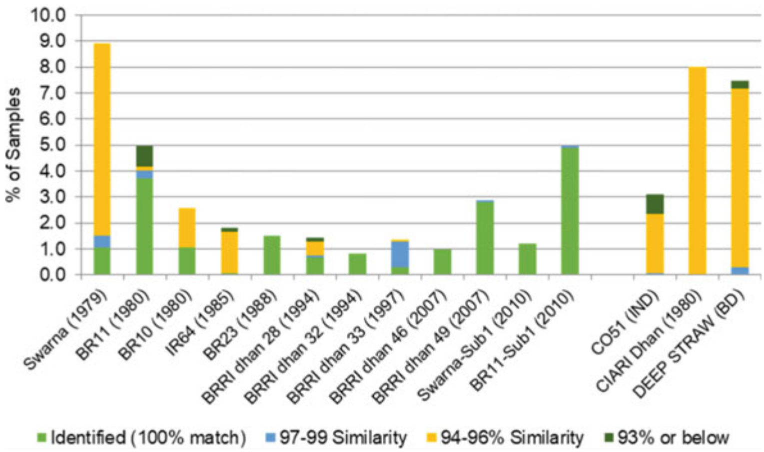

Fig. 4.6 DNA fingerprinting identification of rice varieties in Bangladesh (Yamano et al. 2017)

identified as Swarna-Sub1. Thus, DNA fingerprinting confirms that Sub1 varieties have been disseminated in Bangladesh.

Note that new varieties developed in or after 2007 tended to have 100% matches. About 5% of the sample were identified as BR11-Sub1, while just over 1% were identified as Swarna-Sub1. Thus, DNA fingerprinting confirms that Sub1 varieties have been disseminated in Bangladesh.

Regarding the farmers' ability to identify rice varieties to cultivate, Yamano et al. (2017) found that they identified newer varieties more accurately. Table 4.1 compares the identification of varieties by farmers and DNA fingerprinting. For this analysis, the authors used strict DNA identification (i.e., 99–100% accuracy with the best match in the reference library). Because old varieties were poorly identified by DNA fingerprinting, the proportions of correct identifications tend to be small.

For BR11–Sub1, farmers' identifications were 72% accurate. This means that 72% of the 50 seed samples they reported as BR11–Sub1 were actually BR11–Sub1, according to DNA fingerprinting. DNA fingerprinting found 64 samples as BR11–Sub1, suggesting that some farmers reported BR11–Sub1 under different names. The results indicated that farmer identifications would underestimate the adoption or area coverages of BR11-Sub1. For Swarna–Sub1, the results indicated that farmers tended to over–identify Swarn–Sub1, leading to overestimations of Swarna-Sub1 adoptions and area coverages.[13]

The DNA fingerprinting results are interesting and have implications for adoption studies of new varieties of rice and other crops. But DNA fingerprinting studies are few. As DNA fingerprinting becomes widely available at low costs, the technology is expected to be applied to adoption studies and to monitoring seed food supply chains, food safety, or nutrition studies.

[13] More results from the same samples are reported in Kretzschmar et al. (2018).

Table 4.1 Farmers' identifications of rice variety names in Bangladesh

Variety	Farmer identification	DNA identified 99–100%	Correctly identified by farmers	Direction of area estimate bias
	(A)	(B)	(C)	(D)
	Number	Number	%	
Swarna	177	14	5.6	Overestimation (A > B)
BR11	69	49	31.9	Overestimation (A > B)
BR10	30	14	13.3	Overestimation (A > B)
IR64	0	1	0	Small bias
BR23	22	20	0	Small bias
BRRI dhan 28	8	9	0	Small bias
BRRI dhan 32	8	11	0	Small bias
BRRI dhan 33	15	4	0	Overestimation (A > B)
BRRI dhan 46	4	13	100	Underestimation (A < B)
BRRI dhan 49	47	37	57.4	Overestimation (A > B)
BR11–Sub1	50	64	72.0	Underestimation (A < B)
Swarna–Sub1	49	16	14.3	Overestimation (A > B)

Source Yamano et al. (2017)

4.5 Conclusion

This chap reviewed recent studies on the adoption and impacts of submergence-tolerant rice varieties in South Asia. Rice scientists have identified a gene component that provides tolerance to complete submergence for up to 14 days in the 1990s. Since then, many submergence-tolerant rice varieties have been developed and disseminated in flood-prone areas in Asia. Yet, adoption studies found that the adoption levels of the submergence-tolerant rice varieties are lower than expected in flood-prone areas in Bangladesh and India, leaving potential gains from mitigated flood damage in these areas. There are several policy recommendations to realize the gains.

First, effective information campaigns may help farmers adopt submergence-tolerant rice varieties in flood-prone areas. One panel data study found that submergence experience in the previous year increased the adoption of submergence-tolerant rice varieties in the following year in northern Bangladesh. Other adoption studies have found that increased access to information about submergence-tolerant rice varieties would increase adoption among farmers. Thus, information campaigns should be better targeted to areas where floods frequently occur so that farmers can observe the benefits of the submergence-tolerant rice varieties.

Second, better seed quality monitoring systems need to be in place. It is difficult for farmers to monitor the quality and names of the varieties of rice seeds that they buy and grow. Without accurately knowing the characteristics of their rice varieties, they cannot benefit fully from their rice production. DNA fingerprinting technology is becoming available at low costs. Public monitoring may help seed supply chains maintain seed quality.

The review in this chap suggests large potential gains from submergence-tolerant rice varieties in flood-prone areas in South Asia. Frequent floods also occur in areas outside of South Asia, and submergence-tolerant rice varieties suitable for such areas have been developed. More studies should be conducted to examine the diffusion of such varieties outside of South Asia.

4.6 Recollections of Professor Keijiro Otsuka

Otsuka sensei and I graduated from the same department at Hokkaido University, Japan, although, of course, he did so several decades before me. Because my teacher was a friend of Otsuka sensei, we received a proofread version of his Oxford University book with Hayami sensei. After reading the book, I immediately decided to follow them. Some years later, I joined GRIPS and was fortunate enough to start the RePEAT project with Otsuka sensei. We spent many days traveling to rural villages in Ethiopia, Kenya, and Uganda, endlessly talking about farmers' problems, analyzing data, and publishing papers. Otsuka sensei's energy and sincere attitude toward work pushed me to work hard. I cannot say enough to express my gratitude for his mentorship.

References

ADB (Asian Development Bank) (2021) Transforming agriculture in Asia. In: Asian Developing Outlook Update 2021. Asian Development Bank, Manila

Bairagi S, Bhandari H, Das SK, Mohanty S (2021) Flood-tolerant rice improves climate resilience, profitability, and household consumption in Bangladesh. Food Policy 105:102183

Dar MH, de Janvry A, Emerick K, Raitzer D, Sadoulet E (2013) Flood-tolerant rice reduces yield variability and raises expected yield, differentially benefiting socially disadvantaged groups. Science Report 3:3315

David CC, Otsuka K (1994) Modern rice technology and income distribution in Asia. Lynne Rienner Publishers, Boulder, Colorado

Doss CR (2006) Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. Agr Econ 34(3):207–219

Emerick K, Dar MH (2021) Farmer field days and demonstrator selection for increasing technology adoption. Rev Econ Stat 103(4):680–693

Emerick K, de Janvry A, Sadoulet E, Dar MH (2016) Technological innovations, downside risk, and the modernization of agriculture. Am Econ Rev 106:1537–1561

Estudillo JP, Otsuka K (2006) Lessons from three decades of Green Revolution in the Philippines. Dev Econ 44(2):123–148

FAO (Food and Agriculture Organization of the United Nations) (2021) The impact of disasters and crises on agriculture and food security: 2021. FAO, Rome

Foster AD, Rosenzweig MR (1995) Learning by doing and learning from others: human capital and technical changes in agriculture. J Polit Econ 103:1176–1209

Gade P, Alam MA, Barma NCD, Majumder R, Garapaty R, Paranjape VD, Killian A, Vijayaraghavan K, Kabir MR, Hakim MA, Islam MZ, Hossain MM, Rahman MM, Rahman M, Khan MAA, Islam MR, Hasan MM, Amin MF, Acevedo M (2021) Assessment of wheat variety adoption in Bangladesh through DNA fingerprinting. Crop Sci 61:3564–3577

Hattori Y, Nagai K, Furukawa S, Song XJ, Kawano R, Sakakibara H, Wu J, Matsumoto T, Yoshimura A, Kitano H, Matsuoka M (2009) The ethylene response factors SNORKEL 1 and SNORKEL 2 allow rice to adapt to deep water. Nature 460(7258):1026–1030

IPCC (Intergovernmental Panel on Climate Change) (2018) 2018 Global warming of 1.5°C: an IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. IPCC, Geneva, Switzerland

Kretzschmar T, Mbanjo EGN, Magalit GA, Dwiyanti MS, Habib MA, Diaz MG, Hernandez J, Huelgas Z, Malabayabas ML, Das SK, Yamano T (2018) DNA fingerprinting at farm level maps rice biodiversity across Bangladesh and reveals regional variety preferences. Sci Rep-UK 8:31490

Mackill DJ, Ismail AM, Singh US, Labios RV, Paris TR (2012) Development and rapid adoption of submergence-tolerant (Sub1) rice varieties. Adv Agron 115:299–352

Mishra A, Pede VO, Arouna A, Labarta R, Andrade R, Veettil PC, Bhandari H, Laborte AG, Balie J, Bouman B (2022) Helping feed the world with rice innovations: CGIAR research adoption and socioeconomic impact on farmers. Glob Food Secur-Agr 33:100628

Neeraja C, Maghirang-Rodriguez R, Pamplona A, Heuer S, Collard B, Septiningsih E et al (2007) A marker-assisted backcross approach for developing submergence-tolerant rice cultivars. Theor Appl Gen 115:767–776

Raghu PT, Veettil PC, Das S (2022) Smallholder adoption to flood risks: adoption and impact of Swarna-Sub1 in Eastern India. Environ Challenges 7:100480

Sarkar RK, Reddy JN, Sharma SG, Ismail AM (2006) Physiological basis of submergence tolerance in rice and implications for crop improvement. Curr Sci India 91:899–906

Takahashi K, Muraoka R, Otsuka K (2019) Technology adoption, impact, and extension in developing countries' agriculture: A review of the recent literature. Agri Econ 51:31–45

Tsusaka T, Velasco ML, Yamano T, Pandey S (2015) Expert elicitation for assessing agricultural technology adoption: the case of improved rice varieties in South Asian countries. Asian J Agr Dev 12(1):19–34

Veettil PC, Raghu PT, Ashok A (2021) Information quality, adoption of climate-smart varieties and their economic impact in flood-risk areas. Environ Dev Econ 25:45–68

Xu K, Xia X, Fukao T, Canlas P, Maghirang-Rodriguez R, Heuer S (2006) SUB1A is an ethylene response factor-like gene that confers submergence tolerance to rice. Nature 442:705–708

Yamano T, Rajendran S, Malabayabas ML (2015) Farmers' self-perception toward agricultural technology adoption: evidence on adoption of submergence-tolerant rice in Eastern India. J Econ Soc Dev 17(2):260–274

Yamano T, Malabayabas ML, Habib MA, Das SK (2018) Neighbors follow early adopters under stress: panel data analysis of submergence-tolerant rice in northern Bangladesh. Agr Econ 49(3):313–323

Yamano T, Arouna A, Labarta RA, Huelgas ZM, Mohanty S (2016) Adoption and impacts of international rice research technologies. Global Food Secur 8(1):1–8

Yamano, T, Huelgas, Z, Habib, MA, Das, SK, Malabayabas, ML, Kretzschmar, T, Cariño, G, Reveche, MY (2017) DNA fingerprinting for variety identification and its implications to area estimate and adoption studies: case of submergence-tolerant rice in Bangladesh. Paper presented at the 9th ASAE International Conference, Bangkok, pp 11–13 s