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Adoption Trend of Climate-Resilient Rice Varieties in Bangladesh

Swati Nayak [1,*], Muhammad Ashraful Habib [1], Kuntal Das [1], Saidul Islam [1], Sk Mosharaf Hossain [1], Biswajit Karmakar [2], Roberto Fritsche Neto [1], Sankalp Bhosale [1], Hans Bhardwaj [1], Sudhanshu Singh [1], Mohammad Rafiqul Islam [1], Vikas Kumar Singh [1], Ajay Kohli [1], Uma S. Singh [1] and Lutful Hassan [3]

[1] International Rice Research Institute, Los Baños 4031, Laguna, Philippines; m.habib@irri.org (M.A.H.); k.das@irri.org (K.D.); saidul.islam@irri.org (S.I.); s.hossain@irri.org (S.M.H.); r.fritscheneto@irri.org (R.F.N.); s.bhosale@irri.org (S.B.); h.bhardwaj@irri.org (H.B.); sud.singh@irri.org (S.S.); mr.islam@irri.org (M.R.I.); v.k.singh@irri.org (V.K.S.); a.kohli@irri.org (A.K.); u.singh@irri.org (U.S.S.)

[2] Bangladesh Rice Research Institute, Joydebpur, Gazipur 1701, Bangladesh; biswajitbrri@gmail.com

[3] Bangladesh Agricultural University, Mymensingh 2202, Bangladesh; vc@bau.edu.bd

* Correspondence: s.nayak@irri.org; Tel.: +91-7381049124

Abstract: Rice is a major crop in Bangladesh that supports both food security and livelihoods. However, a need remains for improved productivity and adaptation to the risks associated with climate change. To accomplish this, the increased adoption of climate-resilient and high-yielding rice varieties can be beneficial. Therefore, we conducted a study in Bangladesh over three consecutive years: 2016, 2017, and 2018. The scope of the study included the major cropping season (wet), Aman. The yield advantages of climate-resilient rice varieties were evaluated and compared with those of the varieties popular with farmers. We included new stress-tolerant varieties, such as submergence-tolerant rice (BRRI dhan51 and BRRI dhan52) and drought-tolerant rice (BRRI dhan56 and BRRI dhan71), along with farmer-chosen controls, in the study. We conducted the evaluation through on-farm trials to compare the varieties in both submergence- and drought-affected environments. The seasonal trials provided measured results of yield advantages. The participating farmers were also studied over the three-year-period to capture their varietal adoption rates. We calculated both the location estimated yield advantages (LEYA) and the location observed yield advantages (LOYA). The results revealed that, under non-stress conditions, the grain yields of climate-resilient varieties were either statistically similar to or higher than those of the farmer-chosen controls. Our study also revealed a year-to-year progressive adoption rate for the introduced varieties. The study suggests that the wide-scale introduction and popularization of climate-resilient varieties can ensure higher productivity and climate risk adaptation. The close similarity between LOYA and LEYA indicated that the observational and experiential conclusions of the host farmers were similar to the scientific performance of the varieties. We also found that comparison performed through on-farm trials was a critical method for enhancing experiential learning and obtaining an accurate estimation of yield advantages.

Keywords: LOYA; LEYA; adoption; varieties; climate-resilient

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1. Introduction

Agriculture plays an important role in securing livelihoods and boosting the economic progress of a nation. The agricultural sector accounts for 19.3% of Bangladesh's GDP and is a major source of employment. Furthermore, 13.4% of this 19.3% is derived from crop production, and rice alone contributes to 46% of the total [1]. The significance of rice in Bangladesh is evident because it accounts for 91% of the total food grain production. It is a staple food for more than 99% of the population. Per capita consumption of rice is 416 g per person per day [2]. Thus, rice is at the center of the food security–environment–sustainability web in Bangladesh. This holds true for South Asia as well [3,4]. Rice covers 76% of the total crop area, of which 84.7% is cultivated with modern varieties and the remaining 15.3% with local traditional varieties [5]. Currently, rice is grown on 11.4 million hectare (ha) of land and its production is close to 34.4 million metric tons (MT) [6]. However, by 2030, the population is expected to reach 189.9 million and feeding a population of that size would require an estimated 42.5 million MT of paddy, which is equivalent to 28 million MT of milled rice [6].

Considering the current trend and projected food demand, there is a need to increase the production of major food crops significantly, especially in the regions facing severe environmental stresses [7]. Over time, compared to other food crops, rice production faces progressive limitations because of various environmental challenges. In Asia, more than 30% of the 700 million households belonging to low-income groups are located in rainfed lowlands that are being affected by environmental stressors [8], making them more vulnerable to the associated risks of food and livelihood insecurity. Among the most significant limitations on rice production are the frequent flooding in regions with high rainfall and the inundation of fields from nearby bodies of water. Statistically, at least 16% of rice production around the globe is affected by frequent submergence caused by flash floods [9,10]. In addition, it is believed that, as a long-term aftereffect of climate change (including global warming), incidences of flooding will increase, which will pose a significant threat to the sustainability of rice productivity in the future [11]. Current concerns such as sea-level rise indicate a likely increase in occurrences and intensities of extreme climatic events. Moreover, the uneven distribution of rainfall is expected to increase the frequency of flooding in several regions [12]. The rainfed tropics, where food insecurity and poverty are on the higher side, are expected to witness the most significant consequences [13,14]. Although rice is known for its physiological capacity to grow in flooded conditions, submergence for more than a week has been found to negatively affect the yield of several rice varieties [15,16].

Abiotic stresses such as droughts and floods significantly constrain rice production in Bangladesh [17]. One of the most significant recurring challenges to rice productivity in the rainfed lowlands of Southeast and South Asia is flash floods that lead to the submergence of plants for more than ten days [18]. In Bangladesh, major setbacks to the realization of potential yield are abiotic stresses such as flooding (50%), drought (20%), and salinity (30%) [19]. Drought occurs mainly due to low and erratic rainfall. The north-western part of Bangladesh is considered a drought-prone area. Approximately 5.7 million ha of rice are grown under rainfed conditions that cause substantial yield decreases. Drought affects rice crops in more than one growth stage, for example, in the post-transplantation and establishment stages (early-phase drought) or in transplanted Aman (T. Aman: rainfed lowland rice), in which the crop is affected in the reproductive stage (terminal drought), resulting in considerable yield loss. Upland rice (Aus) also suffers from drought as the crop is direct-seeded and grown under rainfed conditions [19]. Bangladesh, the seventh-most-affected country by extreme weather events, saw 191 such occurrences from 1999 to 2018 [20]. According to government assessments in 2017, about 16,000 ha of farmland were fully lost and 560,000 ha of standing crops were partially damaged. Although data based on a comprehensive evaluation of the August 2017 flood-affected food crops are unavailable, Aman rice in low-lying areas was probably the most affected [5,21]. In addition to drought, Bangladesh has the largest rainfed crop ecosystem; it too is prone to submergence [22,23]. Farmers in Bangladesh cultivate varieties such as BR10, BR11, and Swarna that have duration greater than 145 days as well as shorter duration varieties (<135 days) such as Binadhan-7, BRRI dhan39, and BRRI dhan49. These varieties are preferred because of their suitability, availability, high market value, high yield, and desired grain quality. Cultivars that are susceptible to drought and submergence suffer yield loss due to recurring climatic hazards every year [24]. With the recent innovations achieved through research in plant breeding, several climate-resilient varieties are available that can withstand climatic shocks and enable farmers to harvest a reasonable economic yield compared with conventional susceptible cultivars. Even though older varieties are capable of resisting floods to some extent, they are characterized by inferior grain quality and lower yields. Additionally, in a few regions, farmers have abandoned rice cultivation, leaving their lands fallow during the rainy season [25]. To offset the impact of submergence, the introduction of genes for submergence tolerance into high-yielding cultivars has proven to be the most impactful solution [26]. Since these flood and drought spells occur every year, a variety should possess the basic trait of climatic resiliency in addition to other agronomic qualities, including yield.

In past studies on climate-ready crops, different outcomes showed positive, negative, and even indifferent impacts of various genes integrated into different crop species [26–28]. However, a good understanding of the powerful influence of the submergence-tolerant quantitative trait locus (QTL) named *Sub1* on yield, as well as yield-related metrics in farmers' fields with no stress, is not available. Through head-to-head trials, we assessed the effects of the *Sub1* QTL integrated into various genetic backgrounds, such as BRRI dhan52 (BR11-Sub1) and BRRI dhan51 (Swarna-Sub1), on rice grain yield under non-submergence conditions in different locations over the years. Our study also evaluated drought-resilient varieties such as BRRI dhan71 and BRRI dhan56 and compared them with Binadhan-7 and BRRI dhan39 in 2018. As a unique on-farm trial method in farmers' fields, head-to-head trials were used, which allowed growers to compare submergence and drought-tolerant varieties cultivated side by side with popular cultivars of farmers' choice under their own crop management practices.

Study Objectives

i. To assess the yield gain of submergence- and drought-resilient varieties over traditionally grown varieties through on-farm trials.
ii. To understand adoption and dissemination rates of tested/introduced varieties in the concerned villages and communities.

2. Materials and Methods

Our study was conducted across three districts (Sylhet, Chapai Nawabganj, and Panchagarh) in Bangladesh during the Aman seasons of 2016 and 2017. In 2018, a total of six districts were covered for the study, each defined with a specific code name: E1 (Sylhet), E2 (Cox's Bazar), E3 (Chapai Nawabganj), E4 (Thakurgaon), E5 (Panchagarh), and E6 (Natore) (Figure 1). These regions represent different agro-ecological zones (AEZs) of Bangladesh (Table 1). The experimental materials consisted of some popular varieties of rice with traits of submergence tolerance (with *Sub1*) and drought tolerance.

In order to measure the yield advantage of new varieties over the farmer-chosen varieties, on-farm trials were established. These on-farm trials are multi-locational strip trials, in which the test varieties are grown alongside the farmer-chosen varieties in a side-by-side manner. Farmer-chosen management practices are followed for the trial sites. This provides a realistic estimation of absolute yield as well as yield advantage (or disadvantage) of a new variety under a particular ecosystem. When all the factors of crop production are kept constant, the yield advantage shown by a variety is considered to be solely expressed because of its genetic composition.

This method generates evidence on whether to promote a variety or not. The sites selected for our study were located in the regions prone to abiotic stress. The selection of farmers for the trials was accomplished through different partners from the national agricultural research and extension system, representing diverse AEZs. We compared the yield and yield-contributing characteristics of introduced and farmer-chosen varieties extensively. In addition to scientific measurement of yield and related parameters, we assessed varietal adoption through rapid and participatory rural appraisals (PRAs) using focus group discussions (FGDs) and field days. PRAs were organized in the participating villages in the subsequent year of varietal introduction in order to measure adoption. We measured the speed of varietal dissemination by calculating the seed dissemination ratio for three consecutive years:

$$\text{Dissemination ratio} = [(A) - (B)]/(A)]$$

where A = number of farmers who had taken seeds from original trial farmers and had cultivated the variety and B = number of farmers who participated in the original trials.

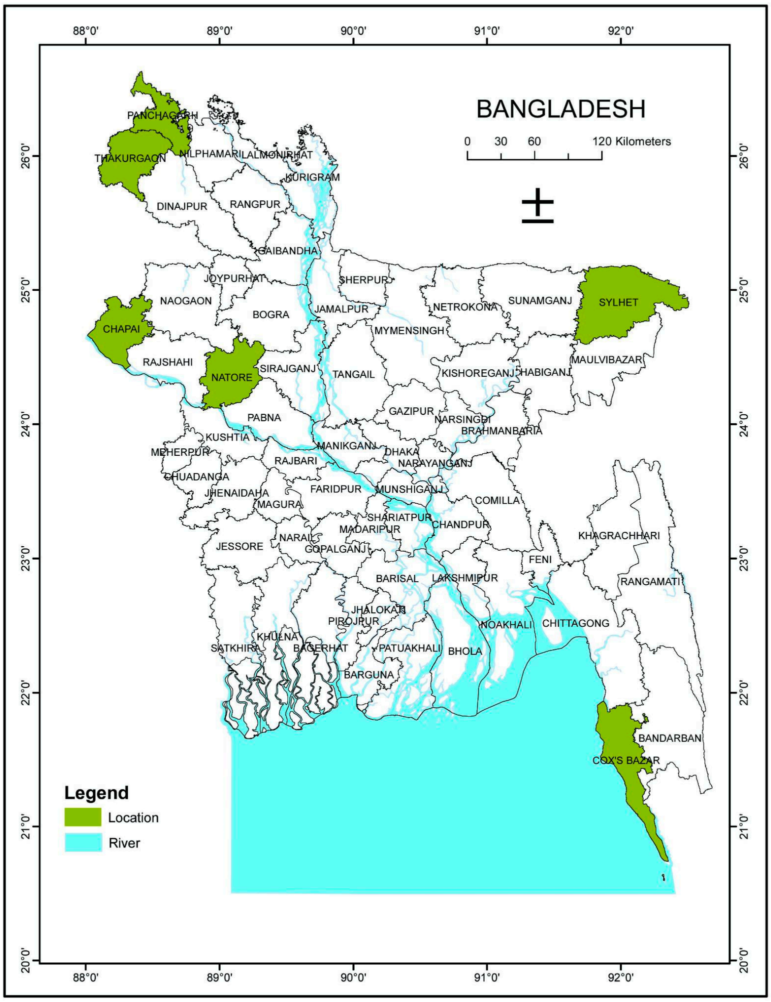

Figure 1. Study areas in Bangladesh.

Table 1. Description of selected study sites (districts), AEZs, and the predominant climatic parmeters.

Name of District	Environment Code	AEZ (Agro-Ecological Zone)	Climatic Parameters			
			Temperature (°C)		Rainfall (mm)	Humidity (%)
			Min.	Max.	Average	Average
Sylhet	E1	Eastern Surma-Kushiyara Floodplain	20.8	31.5	158.7	67.9
Cox's Bazar	E2	Chittagong Coastal Plains Northern and Eastern Hill	22.0	31.1	142.7	71.0
Chapai Nawabganj	E3	High Ganges River Floodplain High Barind Tract	16.7	30.7	120.7	80.0
Thakurgaon	E4	Old Himalayan Piedmont Plain	21.9	31.5	148.6	65.1
Panchagarh	E5	Old Himalayan Piedmont Plain	22.9	32.9	155.0	67.9
Natore	E6	High Ganges River Floodplain	23.6	33.4	97.7	60.8

Source: Available online: http://www.bmd.gov.bd (accessed on 23 March 2022).

Four farmer-chosen popular cultivars, BRRI dhan39, BR11, Binadhan-7, and Swarna, alongside submergence-tolerant varieties BRRI dhan52 (BR11-Sub1) and BRRI dhan51 (Swarna-Sub1), as well as the new drought-tolerant cultivars BRRI dhan56 and BRRI dhan71 were considered for the study (Appendix A). These varieties were developed by two premier institutes, the Bangladesh Rice Research Institute (BRRI) and Bangladesh Institute of Nuclear Agriculture (BINA). During the on-farm trials, two varieties representing near isogenic lines (NILs) were evaluated and compared. Purposefully, the study was conducted at sites that are prone to flood to evaluate the possible positive or negative effects of the *Sub1* QTL. However, most of the trials did not experience significant abiotic stress. This gave us the opportunity to evaluate the performance of varieties even under non-stress conditions.

Statistical Analysis

We calculated the yield advantage and expressed it as the percentage change in yield of the new cultivar over its farmer-chosen/popular check variety in a particular environment. The location observed yield advantage (LOYA) and location estimated yield advantage (LEYA) from the mean location of the farmer variety were calculated using the following equation:

$$\text{Location observed yield advantage (\%)} = [(Z - Y)/Y] \times 100$$

where Z = test/new variety and Y = farmer-chosen variety.

$$\text{Location estimated yield advantage (\%)} = [(Z - YL)/YL] \times 100$$

where Z = test/new variety and YL = all-location mean of farmer-chosen variety.

We assessed the varietal adoption percentages by evaluating farmers' qualitative responses in the subsequent year after varietal introduction. The farmers in the participating villages took part in a series of FGDs and field days. The responses were recorded from the total farmers present on the day of the PRA.

$$\text{Adoption (\%)} = [(P/TP)] \times 100$$

where P = number of farmer participants who had cultivated the new varieties in the subsequent year and TP = total number of farmer participants in the PRA.

To determine the statistical significance of the deviation, we computed Tukey's honestly significant difference (HSD) [29] using IBM SPSS 16 software.

3. Results and Discussion

3.1. Comparison of Grain Yield of BRRI dhan52 and BR11

In all of the trials conducted in E1 (Sylhet) and E2 (Cox's Bazar), BRRI dhan52 (Sub1 version of BR11) produced statistically higher grain yield than the farmer-chosen variety BR11, as shown in Figure 2 and Table 2. For BRRI dhan52, the observed average yields were 4.47 t ha^{-1} and 5.40 t ha^{-1} in Sylhet and Cox's Bazar, respectively, which were higher than the 3.72 t ha^{-1} and 4.90 t ha^{-1} recorded for BR11 at the respective locations. LOYA and LEYA for BRRI dhan52 were 49.42% and 11.11% in Sylhet and Cox's Bazar, respectively (Figure 3).

The adoption rates of BRRI dhan52 in the areas of Gowainghat and Kanaighat of Sylhet during the three consecutive years (2017 to 2019) were 22%, 28%, and 38% and 17%, 24%, and 44%, respectively (Table 3). During the same period, the seed dissemination ratios were 5, 6, and 8 and 3, 5, and 1 in Gowainghat and Kanaighat, respectively (Figure 4).

The boxplots (Figure 5) indicate a narrow distribution base for the varietal yield. However, there were many outliers, as evident in Figure 5. This is because several trials in the Gowainghat region of Sylhet faced certain amounts of abiotic stress. Under those levels of stress, the farmer-chosen varieties failed to maintain yield stability and the yields observed were close to zero. For BRRI dhan52, as shown in the boxplots (Figure 5), average yield in Cox's Bazar was higher than in Sylhet. The median was higher for Cox's Bazar as well as the lower quartile (Q1) being greater than the upper quartile (Q3) of Sylhet.

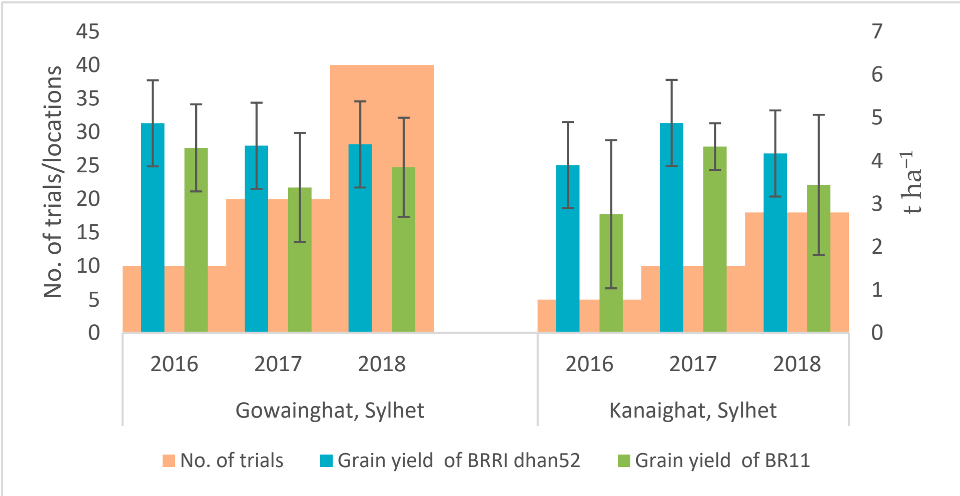

Figure 2. Comparisons of grain yields (t ha^{-1}) of BRRI dhan52 (BR11-Sub1) and BR11 evaluated during the wet seasons of 2016, 2017, and 2018.

Table 2. Parametric comparisons of new and existing rice varieties in evaluated trials during the wet season of 2018 in Bangladesh.

Location	Environment	No. of Trials	Variety Name	Maturity	Observed Yield (t ha^{-1})	LOYA (%)	LEYA (%)
Sylhet	E1	58	BRRI dhan52 BR11	132.60 b 134.78 a	4.47 a 3.72 b	49.42	20.25
Cox's Bazar	E2	23	BRRI dhan52 BR11	132.00 b 134.04 a	5.40 a 4.90 b	11.11	10.21
Chapai Nawabganj	E3	30	BRRI dhan51 Swarna	135.90 a 135.83 a	5.33 a 4.67 b	14.93	14.12
Thakurgaon	E4	15	BRRI dhan56 Binadhan-7	94.80 b 102.47 a	4.19 a 3.57 b	17.67	17.34
Panchagarh	E5	15	BRRI dhan56 Binadhan-7	97.27 b 100.87 a	3.66 a 3.44 b	6.56	6.38
Natore-1	E6	10	BRRI dhan56 BRRI dhan39	105.30 b 109.10 a	5.55 a 5.37 b	3.37	3.35
Natore-2		10	BRRI dhan71 Binadhan-7	115.20 a 104.60 b	5.48 a 5.31 b	3.30	3.20

a, b letters correspond to least significance of means for a specific parameter.

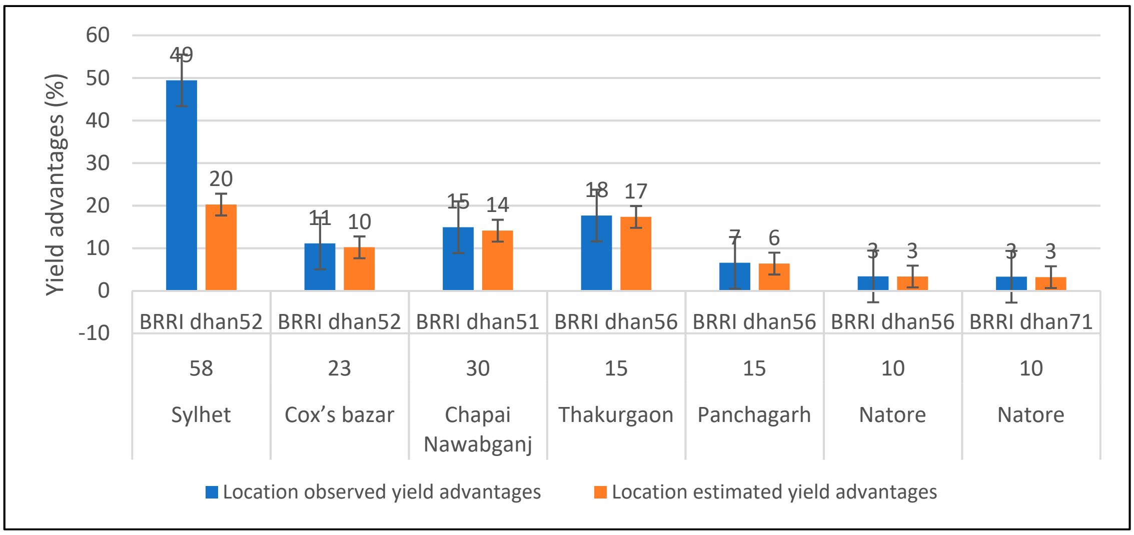

Figure 3. Comparison of LOYA and LEYA of new rice varieties over existing ones at different locations.

Table 3. Adoption rate (%) during 2017, 2018, and 2019 of BRRI dhan51, BRRI dhan52, and BRRI dhan71.

Location	Variety Name	Introduction Year	Number of Trials	Total Participants Attending PRA	Participants in PRA Who Had Actually Cultivated the Variety	Adoption Year	Adoption Rate (%)
Gowainghat, Sylhet	BRRI dhan52	2016	10	250	55	2017	22
		2017	20	500	139	2018	28
		2018	40	1,000	377	2019	38
Kanaighat, Sylhet		2016	5	125	21	2017	17
		2017	10	250	59	2018	24
		2018	18	500	218	2019	44
Sadar, Chapai Nawabganj	BRRI dhan51	2016	5	125	27	2017	22
		2017	10	250	73	2018	29
		2018	15	375	110	2019	29
Gomastapur, Chapai Nawabganj		2016	5	125	19	2017	15
		2017	10	250	67	2018	27
		2018	15	375	197	2019	53
Boda, Panchagarh	BRRI dhan71	2016	2	50	28	2017	56
		2017	3	75	53	2018	71
		2018	5	125	117	2019	94
Sadar, Panchagarh		2016	2	50	32	2017	64
		2017	3	75	59	2018	79
		2018	5	125	120	2019	96
Atwari, Panchagarh		2016	2	50	27	2017	54
		2017	3	75	56	2018	75
		2018	5	125	119	2019	95
Total BRRI dhan51 adoption %							29.17
Total BRRI dhan52 adoption %							28.83
Total BRRI dhan71 adoption %							76.00

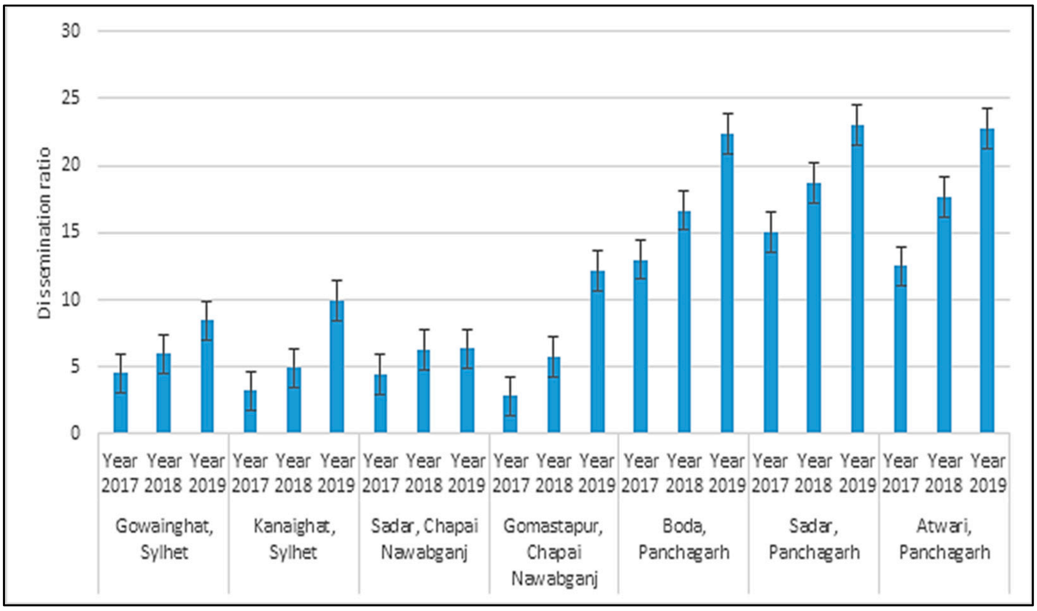

Figure 4. Comparison of seed dissemination ratio during three years (2017, 2018, and 2019).

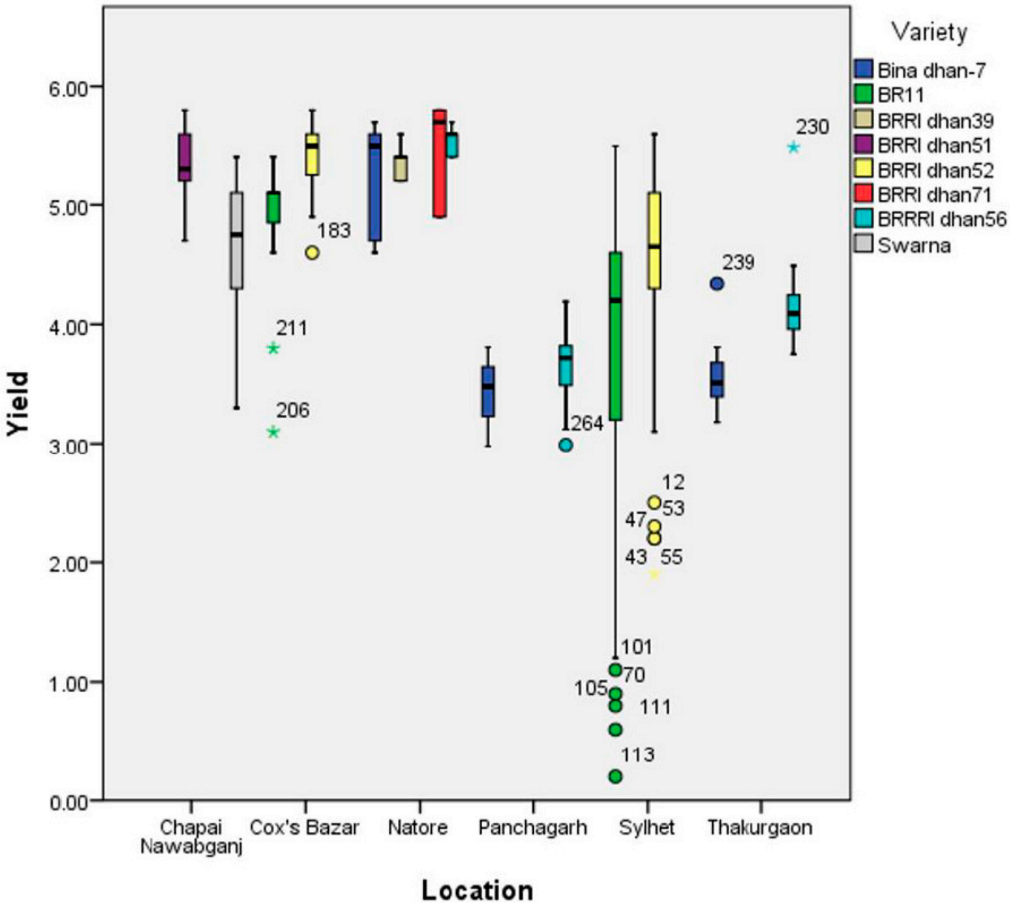

Figure 5. BRRI dhan51, BRRI dhan52, BRRI dhan56, and BRRI dhan71 yield range (t ha^{-1}), deviation, and prediction in a trial in Chapai Nawabganj, Cox's Bazar, Natore, Sylhet, and Thakurgaon districts.

3.2. Comparison of Grain Yield of BRRI dhan51 (Swarna-Sub1) and Swarna

During the wet seasons of 2016 and 2018, we observed that BRR1 dhan51 (Sub1 version of Swarna) had higher grain yield than Swarna in Chapai Nawabganj. Thirty trials were conducted in this environment (E3). Although the results for maturity were statistically similar, BRRI dhan51 significantly outyielded Swarna (Figure 6). During the wet season of 2018, BRRI dhan51 yielded 5.33 t ha^{-1}, whereas Swarna recorded a yield of 4.67 t ha^{-1}. In the same year, LOYA and LEYA of BRRI dhan51 were 14.91% and 14.12%, respectively (Table 2 and Figure 4). Thus, it was evident that the yield of BRRI dhan51 was significantly higher than that of Swarna under non-submergence (non-stress) conditions.

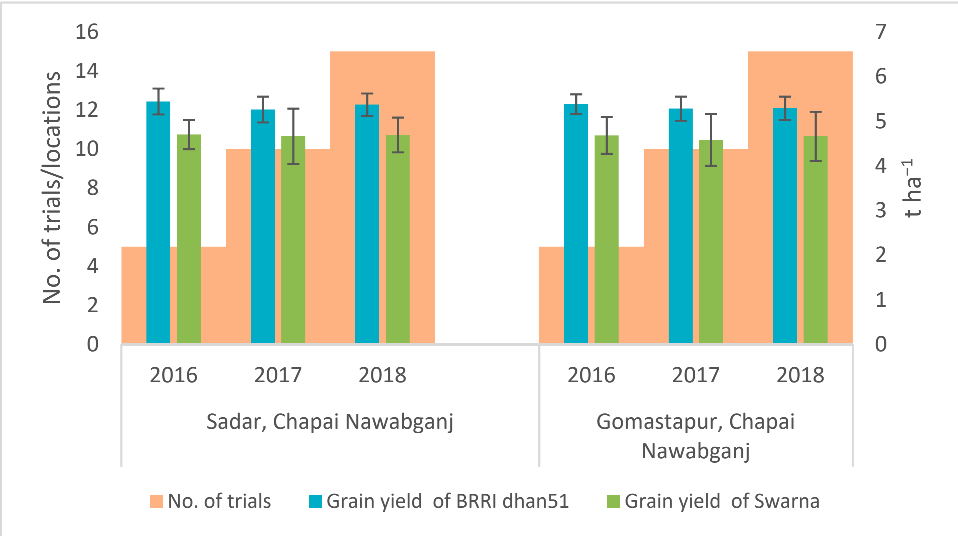

Figure 6. Comparisons of grain yields (t ha^{-1}) of BRRI dhan51 and Swarna evaluated during the wet seasons of 2016, 2017, and 2018.

The adoption rates of BRRI dhan51 during the period of 2017 to 2019 were 22%, 29%, and 29% in Sadar and 15%, 27%, and 53% in Gomastapur locations of Chapai Nawabganj (Table 3). During that period, the seed dissemination ratios were 4, 6, and 6 in Sadar and 3, 6, and 8 in Gomastapur (Figure 3).

3.3. Comparison of Grain Yield of BRRI dhan56 with That of Binadhan-7 and BRRI dhan39

In 2018, the trials conducted in Natore, Thakurgaon, and Panchagarh districts showed that BRRI dhan56 had significantly higher grain yield than the check varieties. To compare BRRI dhan56 and Binadhan-7, trials were carried out with 15 farmers in two locations (Panchagarh and Thakurgaon). The observed grain yields of BRRI dhan56 were 3.66 t ha^{-1} and 4.19 t ha^{-1}, whereas Binadhan-7 yielded 3.44 t ha^{-1} and 3.57 t ha^{-1} in Panchagarh and Thakurgaon, respectively (Table 2). BRRI dhan56 outyielded Binadhan-7 in both locations (Table 2). In 2018, the LOYA values of BRRI dhan56 were 6.56% and 17.67% in Panchagarh and Thakurgaon, respectively, which were close to the respective LEYA values of 6.38% and 17.34% (Table 2).

The yields of BRRI dhan56 and BRRI dhan39 were compared with those of 10 farmers from Natore district. The yield of BRRI dhan56 (5.55 t ha^{-1}) was higher than that of BRRI dhan39 (5.37 t ha^{-1}). A similar outcome was observed for the LOYA and LEYA of BRRI dhan56 in Natore-1, with values of 3.35% and 3.37%, respectively (Table 2 and Figure 4). The boxplots (Figure 5) indicate that the yield distribution was normal for Thakurgaon, negatively skewed (moderately) for Panchagarh, and positively skewed (extremely) for Natore-1. Hence, yield variability was less to moderate in Panchagarh and Thakurgoan but quite high in Natore district.

3.4. Comparison of Grain Yield of BRRI dhan71 and Binadhan-7

BRRI dhan71 showed significantly higher yield than Binadhan-7 in every on-farm trial being conducted (Table 2). During the wet season of 2018, grain yields of BRRI dhan71 and Binadhan-7 were recorded as 5.48 t ha^{-1} and 5.31 t ha^{-1}, respectively. In addition, during the same period, LOYA and LEYA values for BRRI dhan71 were calculated to be 3.30% and 3.20%, respectively (Table 2 and Figure 4). Therefore, BRRI dhan71 performed better in terms of yield as evident with the gain over its counterpart cultivar Binadhan-7. The boxplot (Figure 5) shows a highly negative yield distribution for BRRI dhan71, which implies high variability in yield in the test area.

The adoption rates of BRRI dhan71 during the three consecutive years (2017 to 2019) were 56%, 71%, and 94% in Boda; 64%, 79%, and 96% in Sadar; and 54%, 75%, and 95% in Atwari of Panchagarh district (Table 3). During that period, the seed dissemination ratios were 14, 16, and 22 in Boda; 15, 17, and 22 in Sadar; and 12, 17, and 21 in Atwari (Figure 3).

4. Conclusions and Recommendations

This study had two major objectives. The first was to evaluate the yield advantages (or disadvantages) for the introduced climate-resilient varieties against the farmer-grown varieties under farmer management practices. The second objective was to understand the informal dissemination and adoption rates for the new varieties in the regions where they were introduced. The study has clearly demonstrated the yield superiority of some of the new submergence and drought-tolerant varieties vis-à-vis the farmer-chosen varieties, even under non-stress conditions. A similar study conducted in India through a randomized control trial in 2012 and 2013 had included one drought-tolerant variety, Sahabhagi Dhan. That study had affirmed as high as a 1.3 t ha^{-1} yield loss happening under severe drought. However, that study was not able to generate enough evidence for the yield advantage of the drought-tolerant variety [30]. Our study has been able to generate substantial evidence for multiple new drought-tolerant varieties developed in Bangladesh. Our study demonstrated the overall yield advantages of drought-tolerant varieties BRRI dhan56 and BRRI dhan71. Similar trends observed across LOYA and LEYA values also affirm these results. The average LOYA value of BRRI dhan56 was 6.56% and 17.67% in Panchagarh and Thakurgaon, respectively, which was close to the respective LEYA values of 6.38% and 17.34%. The LOYA and LEYA values of BRRI dhan56 in Natore-1 were 3.35% and 3.37%. The LOYA and LEYA values for BRRI dhan71 were 3.30% and 3.20%, respectively (Table 2 and Figure 4).

A previous study conducted on flood-tolerant rice variety Swarna-Sub1 in India showed that the variety decreases yield variability and provides yield advantages under flooding and no yield penalty under non-flood conditions [23]. Our current study has further included two new *Sub1* varieties, BRRI dhan51 and BRRI dhan52. In addition, our study suggests the yield superiority of both drought- and flood-tolerant germplasm even under non-stress conditions. The average yield advantages of BRRI dhan56, BRRI dhan71, BRRI dhan51, and BRRI dhan52 were 4.87%, 3.20%, 14.12%, and 10.21%, respectively (Table 2). The tolerant varieties with *Sub1* could survive complete submergence, in contrast with farmer varieties, and this can be attributed to the minimum shoot elongation of tolerant varieties underwater to reserve energy resources for maintenance of metabolism and for use during the recovery phase after the water recedes [15,31].

These newly developed varieties also strongly indicate the impact of breeding programs led by institutions such as BRRI and BINA being able to provide climate-resilient rice varieties with high genetic gain potential. One of the major arguments regarding the limited acceptance of climate-resilient varieties in various countries has been their inability to compete with farmer-chosen varieties under non-stress conditions and failing to considerably influence adoption behavior. However, superior germplasm providing assured and visible yield advantages has tremendous potential to change the scenario of varietal replacement.

Our study also established the higher adoption potential of the new resilient varieties. The new varieties were also significantly disseminated and adopted in the subsequent years after their introduction through on-farm trials. This can be credited to the superior performance of the varieties but also indicate how the learnings and awareness have not been limited to only the host farmers who participated in the on-farm trials. The multiple PRA events organized in the same villages affirmed the rapid dissemination of farm-saved seeds through a community network and adoption of the varieties by neighbor farmers. The adoption rate varied from 15% to 96%, with the average adoption rate of BRRI dhan51, BRRI dhan52, and BRRI dhan71 being 29.13%, 28.83%, and 76%, respectively.

Since the adoption rate in our study was also highly satisfactory within the participating villages, it is recommended to promote these varieties on a large scale with assured availability and supply of good-quality labeled seeds through public and private extension and delivery networks.

The adoption of stress-tolerant versions of popular rice cultivars can enable farming communities to mitigate the current and future challenges of recurrent flooding and drought in Bangladesh. This remains critical to maintain and increase the rice production rate of the country to match the demand of the growing population. Therefore, it is imperative to appropriately position these climate-resilient or stress-tolerant varieties against the popular non-stress-tolerant varieties. This also calls for targeted public-private-community partnerships in seed systems to accelerate the supply of early-generation as well as commercial and good-quality seed for faster varietal turnover.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Physiological Characteristics of the Varieties (Test Varieties and Farmer Checks) Used in This Study.

Name of Variety	Physiological Characteristics					
	Maturity (days)	Plant Height (cm)	1000-Grain wt. (g)	Yield Potential (t ha^{-1})	Grain Type	Abiotic Stress Tolerance Feature
BRRI dhan71	114–117	107–108	24.0	5.5	Medium slender & bold	Tolerates up to 21–28 days without rainfall at reproductive stage
BRRI dhan56	105–110	115	23.6	4.5–5.0	Long bold	Able to tolerate 10–12 days without rainfall at reproductive stage
BRRI dhan52	140–145 (normal conditions) 155–160 (14 days' submergence)	116	27.0	4.5–5.0 (normal conditions) 4.0–4.5 (10–12 days' submergence)	Medium bold	Able to tolerate up to 10–12 days of fully submerged conditions
BRRI dhan51	140–145 (normal conditions) 155–160 (14 days' submergence)	90	20.4	4.5–5.0 (normal conditions) 4.0–4.5 (10–15 days' submergence)	Medium slender and crystal white	Able to tolerate up to 10–15 days of fully submerged conditions
BRRI dhan39	120	106	20.4	4.5	Long slender	NA
BR11	145	115	25.7	5.5	Medium bold	NA
Binadhan-7	115–120	95	24.9	4.5–5.0	Medium slender	NA
Swarna	140–145	95	21.0	4.0–4.5	Medium slender	NA

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