Coping with Climate Stress in Eastern India: Farmers' Adoption of Stress-Tolerant Rice Varieties

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Mamta Mehar, Subash Surendaran Padmaja, and Narayan Prasad

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ABSTRACT

Cultivating stress-tolerant rice varieties (STRVs) is widely cited as a strategy of rice farmers to cope with climate-induced stresses. In India, dissemination of STRVs started in 2008 through international development initiatives, but only 5 percent of farmers have adopted it after seven years. Using a double-hurdle model, this study estimated the factors influencing simultaneous decisions on land selection and allocation for cultivating STRVs. It developed a framework for assessing the risks faced by farm households due to adverse climatic conditions vis-à-vis the decision to adopt STRVs. Results show that perceived and actual experiences of climate stress are important parameters influencing the decision to adopt STRVs. Farmers who have adopted such varieties are more likely to cultivate them on only a small portion of their land. These farmers are risk takers and very patient. The study recommends the use of a targeted approach to scale up the adoption of STRVs. Farmers affected by climate stresses should be identified and educated about the benefits of STRVs through demonstration. In addition, the accessibility of the seeds must be ensured.

Keywords: stress tolerant rice variety, double hurdle, risk and time preference

JEL codes: Q16, Q18, D81

INTRODUCTION

Over the past few decades, climate change, climate shock, and climate variability[1] have significantly and negatively affected the productivity of the agriculture sector (crops, livestock, forestry, and fisheries), hence undermining the achievement of food security

1 Climate change is defined as a "change in the state of the climate that can be identified by changes in the mean and/or variability of its properties that persists for an extended period, typically decades or longer" (IPCC 2007, 30). Climate

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to a large extent (Wheeler and von Braun 2013; FAO 2018; Ray et al. 2019). FAO (2018) estimates cereal production loss in developing countries at USD5 billion due to natural disasters that occurred between 2005 and 2016. Additionally, scientific evidence for climate change projection suggests that agricultural productivity will soon be significantly reduced, especially in countries at lower latitudes (Stevanović, Popp, and Lotze-Campen 2016). Estimates by Ray et al. (2019) suggest that recent rice yields had decreased by 0.3 percent (approx. 1.6 million tons per annum) globally, which translates to approximately 0.4 percent annual decrease in consumable food calories available from rice. Nelson et al. (2009), using IMPACT[2] modelling, predict that global rice production will decline by 12–14 percent by 2050 compared with production levels in 2000 due to climate change.

Clearly, the demand-supply gap will be widening due to population growth and production decline because of climatic variations. Floods and droughts have respectively caused submergence and soil salinity (Hassani, Azapagic, and Shokri 2020) and constrained productivity. Drought normally affects about 23 million ha of land under rice cultivation in Asia, submergence about 20 million ha, and salinity about 15 million ha (Haefele et al. 2010). Yield loss from submergence across rainfed lowlands in South Asia is estimated at about 80 kg/ha per annum on average (Dey and Upadhaya 1996). In eastern India, rice productivity in submergence-prone areas averages 0.5–0.8 tons/ha, lower than in favorable rainfed lowlands (2.0 tons/ha) and much lower than in input-intensive irrigated systems (5.0 tons/ha) (Singh et al. 2013). Such yield variation, due mainly to erratic monsoon behavior, suggests a need to focus on technological packages to improve yields by considering drought in upland rice areas and submergence in rainfed lowlands (Das and Bastia 2013; Gumma et al. 2015).

Cultivating crop varieties tolerant to climate stress is the most cited adaptation measure (Westengen and Brysting 2014). Various studies discuss other adaptation and mitigation practices, such as optimum time of planting; appropriate agricultural inputs, specifically the use of different varieties or stress-resistant crop varieties; crop rotation; crop diversification; and having crop insurance to cope with risks associated with climate stress (Bradshaw, Dolan, and Smit 2004; Mehar, Mittal, and Prasad 2016).

The climatic scenario has changed, however, and now adaptation strategies for rice depend much on improvements of crop varieties (Yamano et al. 2016). The use of STRVs alone does not fully address the issues due to climate stress; land allocation to different seed varieties needs to be considered too. Farmers often use multiple varieties of desirable traits in the same season. The varietal traits are related to consumption preferences (such as cooking quality and taste), production (such as early maturing, high-yield potential, tolerance to stress, e.g., pests and diseases, drought, and submergence), and market-related attributes (such as better processing quality and plant and grain size) (Kalinda, Tembo, and Kundashula 2014; Mehar, Yamano, and Panda 2017). This study investigated why farmers cultivate STRVs and how they allocate land.

STRESS-TOLERANT RICE VARIETIES IN SOUTH ASIA

Rice, the staple food in South Asia, is cultivated in over 60 million ha in the region, accounting for about 37.5 percent of the area planted to rice worldwide. More than 50 million South Asian households depend on rice cultivation for livelihood. The region produced slightly above

variability, beyond individual weather events, refers to variations in the mean state and other statics (such as standard deviations, statistics of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events (IPCC 2012, 257).

Climate shock or *climate extreme* is defined as the occurrence of weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable (IPCC 2012, 257). This includes natural disasters events such as drought, floods, and cyclones.

2 See https://www.ifpri.org/project/ifpri-impact-model

170 million tons of paddy (about 32% of global production) on 38 million ha of land in 2020 (FAO 2020). Rice intake provides 60–70 percent of the calorie requirement and 50–55 percent of the protein requirement (Bishwajit et al. 2013).

Farmers in South Asia have been growing five mega varieties of rice (Swarna, Samba Mahsuri, BR11, IR64, and CR1009) over a large area in the last few decades. However, these varieties are susceptible to submergence stress. In 2003, the International Rice Research Institute (IRRI) initiated a program to introduce the Sub1A gene (for flood tolerance) by marker-assisted backcrossing into these rice varieties (Septiningsih et al. 2009; Neeraja et al. 2007), as the STRVs bred from these varieties were expected to take less time to spread. Bred from Swarna (MTU 7029), Swarna-Sub1, the resulting flood- or submergence-tolerant rice variety, was approved for cultivation in India in August 2009. In the same year, IRRI also released the Shahbaghi dhan variety for cultivation in the drought-affected areas of Jharkhand and Odisha states in India. Since it has been observed that a crop may experience multiple stresses in a season, varieties of the multiple stress-tolerant green super rice have been released to mitigate these stresses (Yorobe et al. 2016). Stress-tolerant rice varieties were distributed in South Asia starting 2008 (Yamano et al. 2016), soon after the global food crisis. In India, very few varieties had been released at the time of this survey (early 2014); since then, many more varieties have been introduced.

Studies done on STRVs could be summarized into four types: experimental studies by breeders in research experiment stations or in a farmer's fields, trait preference studies, adoption studies, and impact studies. Several experimental studies show that STRVs have higher yields and chances of survival during climate stresses than traditional varieties (Bailey-Serres, Lee, and Brinton 2012; Bhowmick et al. 2014; Ismail et al. 2013; Mackill et al. 2012; Septiningsih et al. 2009; Singh et al. 2012; Singh, Mackill, and Ismail 2011). Some findings (e.g., Sarkar et al. 2009) are based on farmer's field trials, and some (e.g., Diaz et al. 1998; Mandal et al. 2009) are from farmers' participatory variety selection studies. A few studies assessed the coverage and potential benefits of STRVs at the household or community level. Yamano et al. (2015) show that STRVs were planted on 3 percent of the total land area under rice cultivation in 2013. Dar et al. (2013) discuss the welfare impact of Swarna-Sub1 on socially disadvantaged groups (Scheduled Castes and Scheduled Tribes) that own rice fields mostly in flood-prone areas in Odisha. In their randomized control trial study, Emerick et al. (2016) show that treatment farmers who were given submergence-tolerant rice seeds experienced reduced risk of flood damage, cultivated rice over a larger area, and used more inputs such as fertilizers and credit. Bairagi et al. (2018), on the other hand, explore the impact of STRVs on smallholders' income and expenditure, among others.

Emerick and Dar (2021) found that the adoption rate of farmers in treatment villages who did not attend the field days was almost identical to that of farmers in control villages. However, the rate was about 50 percent higher for attendees from treatment villages. Farmers' socioeconomic characteristics—such as gender (Mehar, Yamano, and Panda 2017), caste (Dar et al. 2013), individual risk-taking behavior (Mehar, Yamano, and Panda 2017; Ward et al. 2014; Ward, Makhija, and Spielman 2020), and self-perception or self- efficacy (Yamano et al. 2015)—influenced their decision to use stress-tolerant varieties. Yamano et al. (2018) also found that neighboring farmers who were early seed recipients influenced the decision of other farmers regarding adoption of submergence-tolerant varieties. A few studies examined the influence of information channels on adoption decisions (e.g., Veettil, Raghu, and Ashok 2021; Pede et al. 2018).

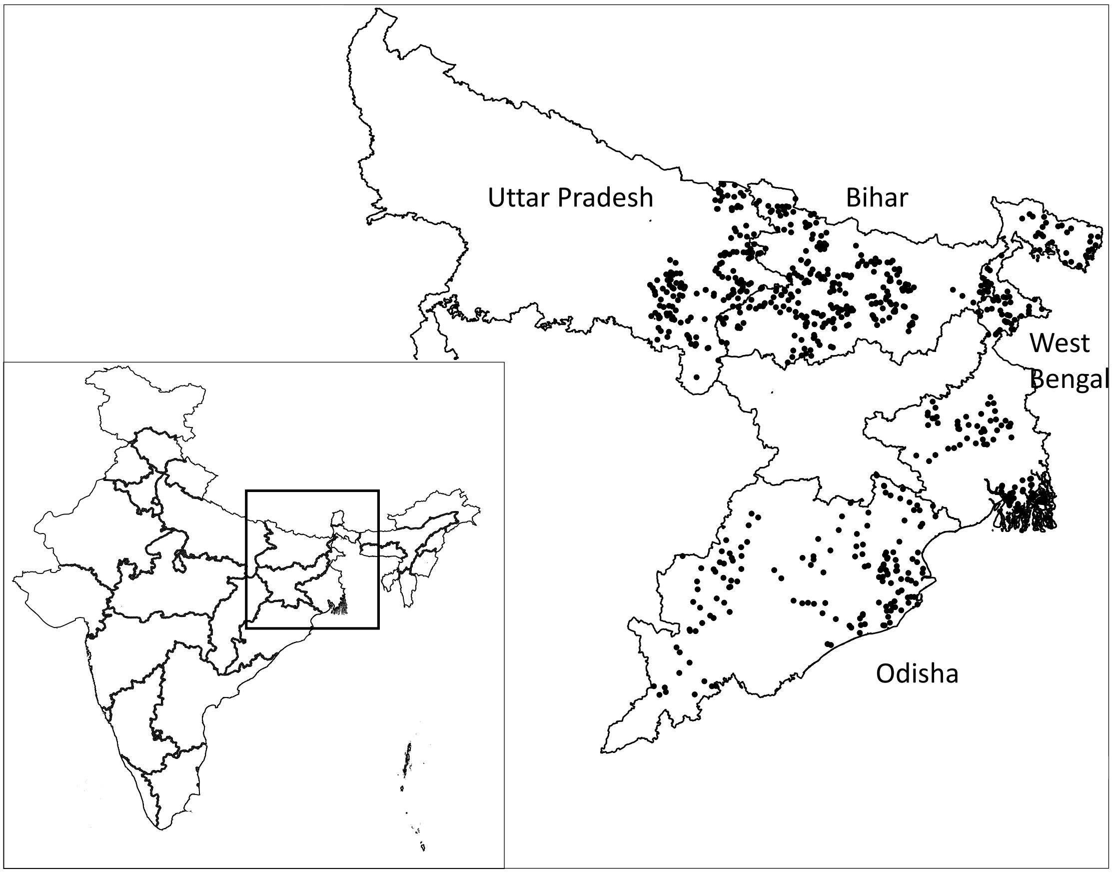
To sum up, the literature on stress-tolerant varieties investigates, among other things, the performance of the varieties in experimental plots, characteristics of farmer adopters, patterns of and constraints to adoption, and impact of these varieties on production, income, etc. However, in all these studies, adoption is considered a discrete choice, although it is also associated with a continuous indicator, i.e., the extent of adoption

(Zilberman, Zhao, and Heiman 2012), which is important in estimating effects.

STUDY AREA

The study is based on a primary survey of 6,000 households, which was part of the Rice Monitoring Survey Project conducted by IRRI in four states of eastern India (Bihar, eastern Uttar Pradesh, Odisha, and West Bengal) in early 2014 (Figure 1). The data are available in the public domain (Yamano 2014–2015).[3] These states are the major rice-growing areas in India, accounting for 43.6 percent of the country's total rice area of 43 million ha (DE&S 2014, 74). They differ in terms of agroecological zones and, therefore, also in terms of production practices and varieties grown. Approximately, half of the districts in each state were randomly selected based on the 2001 Census.[2] The number of villages in each state were capped at 150, which determined the total number of villages in each district, based on the proportion of the area under rice cultivation in the district to the total area under rice cultivation in the entire state. Thus, a total of 600 villages were selected for the four states. In each village, 10 households were randomly selected for interview. The number of households totaled 6,000, but after data cleaning and consistency check, only 5,539 households were included in the analysis.

Figure 1. Location of the surveyed villages in eastern India



Source: Authors' own

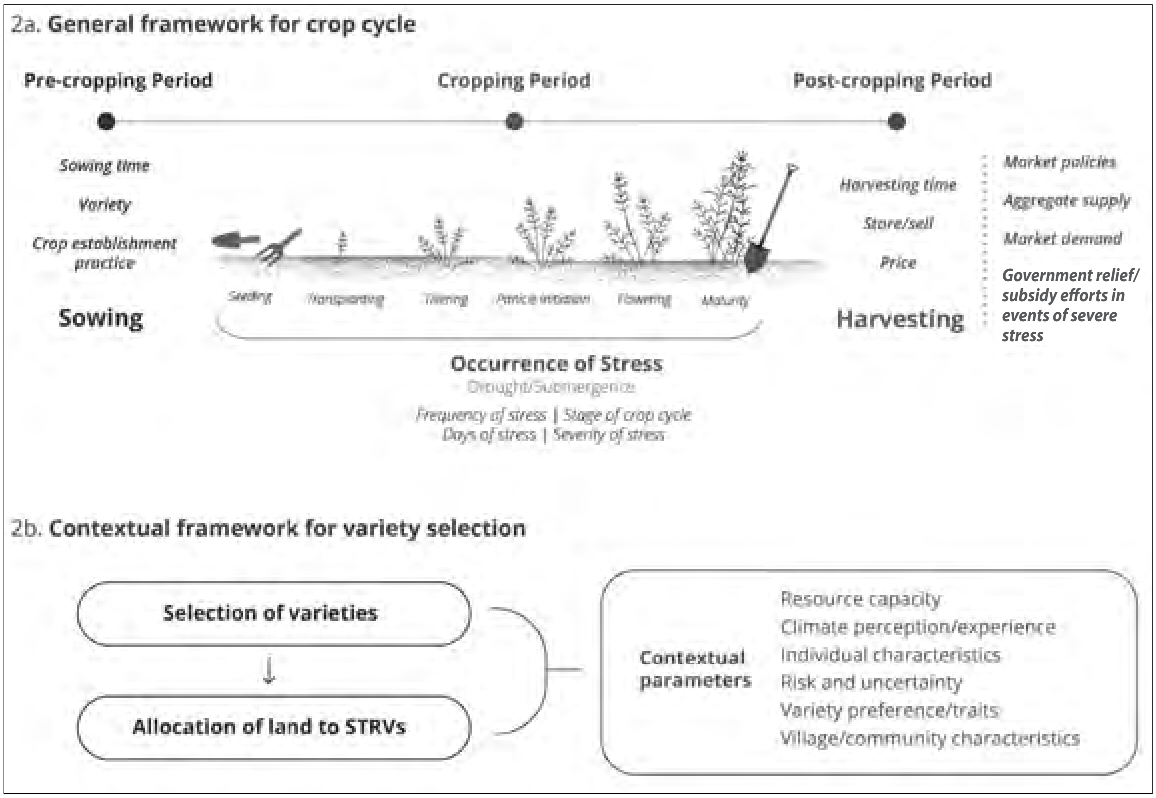
[3] See http://ricestat.irri.org/fhsd/php/panel.php

METHODS

Conceptual Model

Farmers invest time, money, and labor in rice production; however, they cannot be certain of their yields due to weather variability from planting time to harvest. Further, their decision making is often influenced by individual capacity, capability, emotions, and other biases, which in turn affect the decision makers' risk-taking behavior. To have an idea how farmers make decisions on selecting rice varieties and allocating land to particular varieties in a particular season at the time of sowing, a conceptual framework was developed (Figure 2). The framework shows the links between farmers' characteristics and decisions on variety selection and the variety's land allocation. The decision-making mechanism has two parts: (1) a general framework that presents the crop cycle in the context of variety and (2) the contextual characteristics influencing variety selection decision and extent of variety adoption at the time of sowing. The first part portrays the usual practice of farmers to make decisions on sowing time every season, crop establishment practice, and variety to be grown. At time t_s farmers sow the variety; this may be a time horizon, as discussed earlier, since farmers often plan different timings of sowing in different plots. Harvesting is done at time t_h, which again will be a time horizon based on sowing and climate conditions at that particular time. Between ts and t_h, the crop goes through different stages—tillering, panicle initiation, flowering, and crop maturity. At time t_s the climate stresses (type, frequency, timing, severity) are unknown. There is thus an inherent risk for a chosen variety, which is related to whether climate stress occurs and

Figure 2. Conceptual framework depicting: (a) Variety outcome in general crop cycle and (b) Varietal selection decision at sowing time



Source: Adapted from Mehar (2016)

to an individual's own risk-taking behavior on adopting new practices. Moreover, since yield can be realized only at harvest stage (t_h), there is also a time preference concern by farmers on investing in adaptation strategies. A farmer has to make decisions at t_s based on imperfect knowledge and perception and considering resource constraints. Thus, more specifically, the farmer's decision will be based on the parameters given in part 2 (b) of the conceptual framework.

Empirical Model

A farmer's decision to adopt STRVs involves two separate decision processes: (1) selection decision, i.e., whether to adopt STRVs, and (2) extent of adoption, i.e., what portion of land will be planted to STRVs. It is important to test the separability hypothesis in both decisions. To do so, we apply the Benjamin test, developed to test separation hypothesis in the agricultural household model (Le 2010).

Adoption data are usually characterized by a large number of zero observations (considered non-adopters), for which a linear regression model might produce biased estimates. Studies had examined a single-decision process as a response to the censored aspect of data using a Tobit model (Adesina and Baidu-Forson 1995). However, the Tobit model does not address the sequential decision of selection and extent of adoption. In our case, zeros are actually observed outcomes, hence, the Heckman selection model (1979), as adopted in such cases (Ghimire, Huang, and Shrestha 2015; Ibrahim et al. 2009), is not adequate. To deal with the simultaneity of the technology adoption decision, a two-part or double-hurdle model is normally used (Cragg 1971; Blundell, Ham, and Meghir 1987; Wooldridge 2002). This approach was adopted by Ayele (1999) and Worku and Mekonnen (2012); Ghimire, Huang, and Shrestha (2015); and Verkaart et al. (2017).

These studies analyzed the adoption decision and demand for seeds, based on a separable household approach using the double-hurdle model to estimate the factors affecting the adoption decision and proportion of land allocated to improved maize. The assumption is that all non-technology variables affecting adoption and intensity decisions are exogenous. In the present study, multicollinearity among the variables was also tested.

The use intensity of STRVs is defined as:

$$V = \text{area under STRV (ha)}/\text{total cultivated land (ha)} \qquad (1)$$

The double-hurdle model, introduced by Cragg (1971), embodies the idea that an individual's decision on extent of participation in an activity is the result of two processes: the first hurdle, which determines whether the individual is a zero type, and the second hurdle, which determines the extent of participation, given that the individual is not a zero type (Engel and Moffatt 2014).

The first hurdle is the STRV selection decision, estimated using a probit model, as described in equation 2.

$$\text{Selection equation: } D_i^* = X_i' \beta + u_i' \qquad (2)$$

$$\text{where} \quad u_i \sim N(0,1)$$

Threshold equation: = 1 if >0 (for STRV-growing farmers)
= 0 if ≤0 (for non-STRV-growing farmers)

where D_i^* is an unobserved latent variable determining a household's decision to use STRVs; X is a vector of individual characteristics, asset endowments of farm households, household characteristics, and location (regional) variable hypothesized to affect the adoption decision; and u is the random disturbance term distributed with mean 0 and variance 1.

The second hurdle involves an outcome equation, which uses a truncated model to determine the intensity of STRVs. Few studies have tested this stage alone, using the Tobit model.

The stage uses only those farmers who have cultivated STRVs. The equations can be expressed as

$$Y_i^* = X_i'' \beta + u_i'' \text{ Where } u_i'' \sim \mathrm{N}(0, \sigma^2) \quad (3)$$

where Y_i^* is associated with the decision on proportion of total cultivated land to be allocated to STRVs. The variable coefficients in the first hurdle explain that each one-unit increase in a given variable leads to an increase in likelihood (probability) to select STRVs. The variable coefficients in the second hurdle explain how the selection variables influence the intensity of land allocation to STRVs. Further, to ascertain that the two equations are distinct and uncorrelated, it is recommended to use at least one different variable in one equation (Ghadim, Burton, and Pannell 1999).

The approach taken by this study is to include individual characteristics, family equity, and social status characteristics with controlling state-level effects. The variables are adapted from agricultural technology adoption literature. Demographic factors such as age are empirically found to be positively related to adoption of new technology (Zegeye, Tadesse, and Tesfaye 2001; Engel-Warnick, Escobal, and Laszlo 2006; Samal et al. 2011; Akpan, Nkanta, and Essien 2012). Other factors such as gender, family size, and caste have been assessed in some studies (Sain and Martinez 1999; Yesuf 2004; Dar et al. 2013; Mehar, Yamano, and Panda 2017). An important feature of the family is its equity position in society. Three indices were used to define these: agricultural wealth index, non-agricultural wealth index, and tropical livestock unit. The wealth indices were constructed using principal component analysis (PCA), which covers a range of variables on ownership of agricultural assets (including plow sets, carts, duster, chaff cutter, sprayer, diesel pumps, wheelbarrows, thrasher, power tiller, trolley, tractors) and non-agricultural assets (including bicycle, radio, TV, DVD players, mobile phones, two wheelers, four wheelers, refrigerators, coolers, electric fan, computers). Tropical livestock unit was calculated using the number of livestock owned by the household and the conversion factor (refer supplementary appendix).

Other factors of interest in the present study are the risk aversion attitude of farmers and their patience. The role of these farmers especially in the adoption and intensity decision of agricultural technology is discussed, with particular emphasis on variety adoption decision. In Ethiopia, Knight, Weir, and Woldehanna (2003) used a hypothetical question to classify farmers by their aversion to risk; they found that risk aversion is related to lower levels of technology adoption. In China, Liu (2007), who conducted lotteries with pair-wise choices to elicit preferences, found that risk-averse farmers are slower to adopt new cotton varieties. Binswanger (1980; 1981) found that Indian farmers exhibit decreasing absolute risk aversion as well as increasing partial relative risk aversion. That is, farmers are more reluctant to engage in risky behavior the lower their wealth levels and the greater the payoff for a specific lottery. Both risk- and time-preference values were derived from experimental games (Appendix Table 1).

RESULTS AND DISCUSSIONS

Farmers and Farm Characteristics

The respondents interviewed were primarily responsible for rice farming management in the surveyed household (Table 1). Their average age is 48 years, which is close to the national average (50 years) (Mo A&FW 2016). Less than 5 percent of the respondents are female. The average family size (seven members) in the surveyed states is higher than the national average (five members). Caste-wise distribution shows that 28 percent of them belong to other backward caste and 37 percent to Scheduled Castes or Scheduled Tribes.

In the Kharif season (starts in June and ends in October), farmers in the region cultivate rice in 80 percent of the land, on the average. About 92 percent of them carry out manual transplanting. Most households are marginal or small-scale farmers with an average farm size of 1.75 ha.

Table 1. Basic descriptive statistics of respondents (N = 5,539)

Variable	Basic Description	Mean (Standard Deviation)
Individual characteristics		
Age	Age of respondents (years)	47.79 (12.79)
Gender	Dummy=1, if female respondent, 0 otherwise (reference or base category: male respondent)	4.13 (0.20)
Risk aversion	Constant partial risk aversion coefficient (measured in a separate experimental study)	0.33 (0.12)
Time discount rate	Subjective discount rate (measured in a separate experimental study)	6.47 (1.81)
Household-related characteristics		
Other backward caste (OBC)	Dummy=1, if the household belongs to OBC, 0 otherwise (reference or base category is general caste)	0.28 (0.45)
Schedule Caste & Schedule Tribe (SC & ST)	Dummy=1, if the household belongs to SC or ST, 0 otherwise (reference or base category is general caste)	0.37 (0.48)
Family size	Number of family members in a household	7.72 (4.7)
Landless household	Farm household with no land ownership	0.02 (0.14)
Land size	Size of cultivated area (ha)	1.75 (4.60)
Agricultural wealth index	Composite index for agricultural assets owned	0.012 (1.01)
Non-agricultural wealth index	Composite index for non-agricultural assets owned	0.004 (1.00)
Tropical livestock unit	Composite index for livestock holdings	3.93 (3.68)

Note: The respondents were the prime decision-makers in rice farming in their respective families.

The risk and patience level of the farmers were estimated using experimental games. Compared with non-adopters of STRVs, both men and women adopters are relatively more risk-taking and patient (Figures 3 and 4). Moreover, the overall similarity of the shape and median weight differences in the violin plots of the male adopters and non-adopters is evident in both figures, whereas those of the female adopters and non-adopters are quite different.

Climate Experience of Farmers

Farmers were asked about their perception of climate stress and actual experiences (Table 2). The results show that the majority of farmers agreed that drought has worsened over the past five years. Around 70 percent reported experiencing drought at least once in the past five years. Similarly, 50 percent of the farmers reported experiencing submergence, while only 8 percent have encountered salinity.

We measured cultivation of varieties in two ways: selection and extent of adoption. The selection parameter is defined as the percentage of farmers growing at least one STRV of the predefined category at a specific time. About 67 percent of the surveyed farmers were cultivating modern varieties, which covered 65 percent of the total cultivated area (Table 3). Only 5 percent of the farmers reported they were growing STRVs, which covered around 3 percent of the area.

Figure 3. Estimated risk preference of users

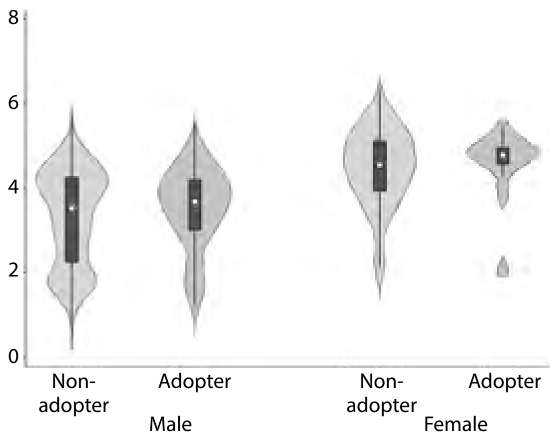
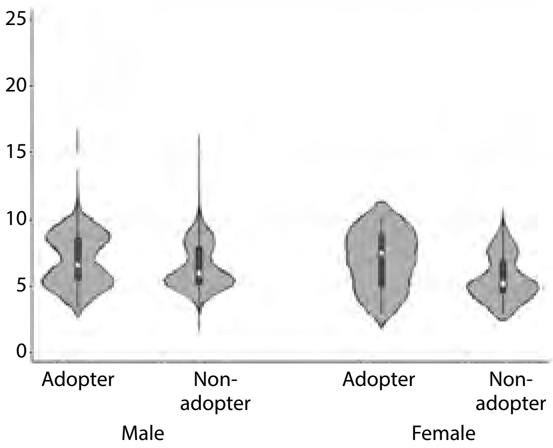


Figure 4. Estimated time preference of users



The distribution by state shows Odisha having the highest percentage (78%) of farmers growing modern varieties, covering 54 percent of the total area cultivated by the surveyed farmers (Table 3). Farmers in Bihar and eastern Uttar Pradesh mostly planted hybrid varieties. Most farmers were unaware of the varieties they were growing; we categorized them as "unclassified." Odisha (10%) and West Bengal (12%) had the highest share of areas planted to traditional varieties. Only a small percentage of farmers cultivated STRVs, and most of them were in Odisha (7.5% of farmers, 3% of cultivated area). Percentage-wise, eastern Uttar Pradesh had the highest area covered (8%) and percentage of farmers (8%).

The surveyed farmers cultivated seven stress-resistant varieties in Kharif 2013; most of them used Swarna Sub1. The highest concentrations of STRV-growing farmers were in Odisha, eastern Uttar Pradesh, and West Bengal.This may be due to the seed distribution efforts of IRRI and the National Food Security Mission over the past few years. IR 64 Sub1 was found to be cultivated mostly by farmers in Bihar, eastern Uttar Pradesh, and West Bengal. Samba Sub1, also a submergence variety, was observed to be cultivated only in eastern Uttar Pradesh.

Table 2. Farmers' perception and experience of climate stresses

	Submergence	Salinity	Drought
Perception that climate change has worsened over the years			
Strongly disagree	31.43	66.74	13.85
Disagree	19.76	20.97	15.03
Neither disagree nor agree	4.73	3.85	4.10
Agree	33.98	6.74	43.50
Strongly agree	10.10	1.70	23.52
Experience (in last 5 years)			
None	51.37	92.27	30.82
1 year	16.00	2.02	12.10
2 years	19.44	3.63	23.81
3 years	7.62	1.01	20.48
4 years	3.83	0.27	7.97
5 years	1.73	0.79	4.82

Table 3. Coverage of rice varieties by major categories across states

State	Stress-Tolerant Rice Variety	Modern Variety	Hybrid	Traditional Variety	Unclassified
Unit: % of cultivated areas in the state					
Bihar	0.67	49.97	16.72	4.48	28.16
Odisha	3.10	53.84	2.00	10.19	16.07
Eastern Uttar Pradesh	7.77	49.08	10.56	4.44	10.27
West Bengal	2.36	65.20	0.13	12.91	16.94
Total	**3.12**	**57.98**	**9.83**	**8.02**	**21.05**
Unit: % of farmers in the state					
Bihar	2.73	51.37	22.99	5.16	22.61
Odisha	7.44	78.11	4.24	17.58	28.08
Eastern Uttar Pradesh	4.65	69.86	17.94	6.61	17.21
West Bengal	3.38	68.67	0.48	20.50	24.36
Total	**4.62**	**67.31**	**11.07**	**12.70**	**23.14**

Note: Farmers reported growing more than one variety; hence, row sum of % of farmers is more than 100.

Among the drought-resistant varieties, NDR 97 was used mostly by farmers in eastern Uttar Pradesh. To determine how farmers choose a variety, it is important to understand the sources of seeds. Farmers purchased almost all varieties from different sources (Table 4). They purchased Samba Sub1 (released in 2013) from the market. The seed dealer gave farmers free lottery tickets as an incentive, but whether such incentives encouraged them to buy these seeds was not investigated. About 25 percent of farmers indicated that they may not be growing NDR97 in the next season because of its low profit margin due to low market demand. CSR-36, being inland salinity-tolerant, has a yield advantage of 1.06 ton/ha in sodic soils (IRRI 2014). Farmers in Karamanga village of Jagatsinghapur district in coastal Odisha were cultivating this variety, but they were not aware of its saline-tolerant trait. They were growing it because CSR-36 fetches a better price than any other variety. Despite this price advantage, the farmers grew it on only a portion of their land due to lack of adequate quantity of seeds for their use.

Results from the Double-Hurdle Model

Using the double-hurdle model, we estimated the correlation of farmers' characteristics with STRV adoption (Table 4). The log likelihood ratio (-1356) and overall chi-square test (120.95) confirm the reliability of the model. The results suggest that *ceteris paribus*, the probability that respondents will select STRVs is positive and significant and that the respondents who decided to cultivate STRVs are likely to cultivate them on only a small portion of their land. This may be due to various reasons. One is the uncertainty of whether or not climate events will occur the following season, hence, the farmers prefer to cultivate varieties that satisfy other preferences on a larger area of their land. Another is that farmers may not be fully aware of the availability and benefits of STRVs, or seeds are not available in adequate quantities.

Age shows a positive and significant effect on the decision to adopt STRVs, indicating that older farmers are more likely to adopt these varieties. On the other hand, Zilberman, Zhao, and Heiman (2012) argue that younger producers are more likely to adopt new technologies because they

Table 4. Results from double hurdle model using maximum likelihood estimation

Variable		1st Hurdle (Probit)		2nd Hurdle (Tobit)	
		Coefficient	Standard error	Coefficient	Standard error
Age (years)		0.11**	0.04	–0.07	0.05
Gender (dummy, female=1, ref.: male)		3.78**	0.91	–2.40	1.86
Risk aversion		–42.21*	0.78	42.16**	19.65
Time discount rate		–0.91	0.12	3.63*	1.02
Caste (dummy=1 for SC/ST, ref.: general caste)		0.59	0.50	–0.11	0.56
Caste (dummy=1 for OBC, ref.: general caste)		0.71	0.48	0.19	0.49
Family size (no.)		0.09***	0.05	–0.21*	0.05
Landless (dummy=1 if no ownership)		4.69	3.56	–3.53*	1.24
Farm size (ha)		0.05	0.12	0.06	0.11
Agricultural wealth index		–1.09	0.34	1.88*	0.49
Non-agricultural wealth index		1.59	1.18	–4.87*	1.36
Tropical livestock unit (index)		–0.42*	0.14	0.38**	0.17
Drought experience (at least once in last 5 years)		0.22	0.20	–0.85*	0.23
Submergence experience (at least once in last 5 years)		0.20	0.14	–0.67*	0.16
Bihar (dummy, ref.: West Bengal)		–10.14**	4.16	6.39	5.33
Odisha (dummy, ref.: West Bengal)		3.76	2.84	–12.60*	3.75
Eastern Uttar Pradesh (dummy, ref.: West Bengal)		–4.12	1.89	5.06**	2.64
Constant		10.48***	6.25	–30.13*	9.69
Number of observations		5523			
Log likelihood		–1356			
Chi-square	Overall	120.95*			
	Hurdle or probit equation	54.75*			
	Above or tobit equation	121.06*			

*, **, and *** represent statistical significance at 1%, 5%, and 10% levels, respectively

have lower cognitive cost and longer planning horizon.

Gender is positively and significantly associated with the selection decision; it is negatively but not significantly associated with extent of adoption decision. The positive coefficient suggests that women are more likely than men to have an adoption plan for STRV. This supports the argument that men and women have different preferences for varieties (Mehar, Yamano, and Panda 2017). Along these lines, Paris et al. (2008) argue that "ignoring women's indigenous knowledge and preferences for rice varieties may lead to slow adoption of new varieties." Thus, scientists and scholars have had increasing efforts to consider gender-differentiated perception and requirements for crop traits in stress-tolerant breeding programs, and these are not limited to rice but for other crops as well, such as maize and potato (Gebre et al. 2019; Gillian et al. 2013). New crop varieties are intended to benefit a wide range of producers, but empirical studies reveal that women farmers' adoption of agricultural technologies, including new varieties associated with increased crop yields, is relatively low (Peterman, Behrman, and Quisumbing 2010).

The households' caste categories were found not to significantly influence any of the decisions. Dar et al. (2013), in an earlier study exploring the relationship between caste and adoption of STRVs, found that low caste groups had higher benefits from Swarna Sub1. They argue that farming households from these castes usually have land in areas prone to floods. Also, stress-prone regions have received priority in the dissemination of STRVs, thus seeds have been provided freely or at subsidized prices in these areas. In this study, no significant relationship was observed between caste categories and adoption of STRVs.

Family size is positively and significantly associated with the selection decision; however, farm households with larger family size are less likely to adopt the STRVs on a larger cultivation area. One reason is that they may be cultivating multiple varieties that promise high yield, desirable cooking traits, and more fodder compared with the STRVs.

The effect of farmers' risk attitudes and preference for time (given the time lag between sowing and harvesting) on their adoption decision was explored. It was found that risk preference and time preference are negatively and significantly associated with STRV selection, but positively with extent of adoption decision. This implies that individuals who are patient and risk-taking are more likely to adopt climate mitigating strategies. These results are similar to those of Smale, Just, and Leathers (1994), who report that risk perceptions of maize growers in Malawi influenced both probability and intensity of adoption of new maize varieties. Similarly, Feder (1980) and Just and Zilberman (1988) found that the intensity of technology adoption depends on the degree of risk aversion. With respect to time preference, Duflo, Kremer, and Robinson (2009) found that present bias, not impatience, prevents farmers from adopting fertilizers.

Farm ownership and family asset endowment are also important factors influencing the decision to adopt new technologies. Our results show that the decision to adopt STRVs is not influenced by farm size and agricultural and non-agricultural wealth indices. However, the agricultural wealth index is positively associated with the extent of adoption decisions. This may go with the argument that agricultural assets, *ceteris paribus*, are more likely to increase with increasing farming practice as the latter may result in increased farm productivity and thus capacity to buy more assets, and vice versa (Mmbando et al. 2021). Farmers with improved tropical livestock units are less likely to use STRVs, but those who adopt them are more likely to cultivate them on a larger land area. Several studies (Deressa et al. 2009; Shiferaw and Tesfaye 2006; Temesgen, Yehualashet, and Rajan 2014) show varying effects (both positive and negative) of livestock ownership on adoption of new agricultural technology. Our study also found that landless farmers (tenants) are less likely to grow STRVs in a larger area. Often, landless farmers, who lease lands for crop cultivation, are neglected by agricultural programs or schemes, which often target farmers who own land. Yegbemey et al. (2013) asserts that institutional arrangements and land rights are important for climate change adaptation.

Farmers who have experienced climate stress in previous years are more likely to adopt mitigation strategies. This is also confirmed in the results of Yamano et al. (2018), which show that if an entire rice area is submerged, the adoption of the STRVs in Bangladesh would have increased by 83 percent the following year. Emerick et al. (2016), in a randomized control trial study in which they distributed seeds of Swarna-Sub1 to treatment farmers, found that farmers' experience of climate events influence their awareness of this specific variety. In contrast, our study found that farmers who have experienced stress (submergence or drought) in the past five years are less likely to grow STRVs in a larger area. A possible reason for this is that since STRVs have so far been disseminated in a few zones only, the surveyed farmers who were experiencing stress may not have been aware of STRVs or these may have not been available to them. Studies (e.g., Yamano et al. 2018 and Emerick et al. 2016) have found that having experienced submergence encourages farmers to adopt submergence-tolerant rice varieties. Farmers who have experienced climate stress in previous years are more likely to adopt mitigation strategies.

This present study also investigated the state-level effects. Results show that farmers in Bihar are less likely to select STRVs compared with farmers in West Bengal. Moreover, comparing farmers in

Odisha and in eastern Uttar Pradesh, the former are more likely to adopt STRVs, but less likely to cultivate them in a large area. In contrast, eastern Uttar Pradesh farmers are less likely to adopt, but those who do are more likely to cultivate them in a larger area. This may be because they have slightly bigger landholdings than Odisha farmers. However, the effect of the limited availability and reach of seeds under different projects cannot be ignored.

CONCLUSION

This study looked into STRV adoption, including its extent, as a climate mitigation strategy in eastern India. STRVs have been promoted as a mitigation strategy of programs by international, national, and local organizations in the past few decades. To boost rice production in eastern India, the government has implemented projects such as the National Food Security Mission and Bringing the Green Revolution in Eastern India. Considering that the government and other seed distribution agencies have been distributing seeds to farmers since 2008, STRV seed distribution and use are expected to be scaled up in the coming years. While adoption of new technology usually takes decades, the literature shows evidence that strategies such as proper seed dissemination along with gender-inclusive strategies and timely availability of seeds can reduce the timeframe of adoption. Adoption of a technology depends on its effectiveness and on sharing knowledge and information about technologies on a wider scale. We found that farmers' risk aversion is a key variable influencing the adoption of STRVs. Risk-averse farmers are less likely to adopt STRVs, but those who adopt are more likely to grow them in a large area. This result implies that bundling STRVs with risk mitigation strategies could help increase their adoption. Ward et al. (2014) put forward the idea of bundling insurance (a risk-mitigation strategy) and drought-tolerant paddy in Odisha. They found that farmers were willing to pay more for drought-tolerant paddy rice even under normal conditions.

Rice production is vital to meet the food requirements of people in India and abroad. Large areas prone to climate stress need to use STRVs to address national and global food security. There are two ways to achieve this: one is to encourage farmers to adopt STRVs, and the other is to encourage farmers to increase the areas they allocate to STRV cultivation. Adoption of STRVs in a larger area in individual farms could bring personal benefits to farmers. A recent study by Raghu, Veettil, and Das (2022) shows that adoption of Swarna-Sub1 in eastern India could increase yields by 19 percent and income by 48 percent. Earlier, Dar et al. (2013) showed that adoption of Swarna-Sub1 could increase the yields by 45 percent even when the rice plants get submerged for up to nine days. The livelihoods of many small and marginal farmers are affected drastically in adverse climate scenarios because they lack access to resources. Kyle et al. (2016) show that adopting Swarna-Sub1 could lead to a 14 percent increase in yield and 43 percent overall gains from crowding in inputs used. Hence, a targeted intervention focusing on making seed available to farmers in high-risk regions to increase the acreage is a viable strategy.

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APPENDIX

Calculation of Agriculture Wealth Index and Non-agriculture Wealth Index

Two wealth indices based on agricultural and non-agricultural assets were constructed separately. PCA was used to assign the indicator weights.

Factor analysis process has been used as follows:

- Standardized (normalized) the indicator variables, then calculated factor loadings. Finally, for each household, the indicator values were multiplied by the loadings and summed to produce the household's index value. In this process, only the first of the factors produced was used to represent the index.
- The persons were then ordered by the score (ranked), and the distribution was divided into three terciles (i.e., groups representing the poorest, middle, and wealthiest thirds of the sample households for further analysis).

The variables or assets (i.e., owned) that were found to be meaningful wealth indicators based on the PCA for agriculture wealth index were: plough set, cart, duster, chaff cutter, sprayer, diesel pump, wheelbarrow, thresher, power tiller, trolley, and tractor. Similarly, the assets used for non-agriculture wealth index were bicycle, radio, TV, DVD player, mobile phone, two-wheeler, four-wheeler, refrigerator, cooler, electric fan, and computer.

Calculation of tropical livestock unit (TLU)

The TLU was calculated using the numbers of livestock owned by the household with the conversion factor mentioned in Appendix Table 1 below:

Appendix Table 1. Conversion Factor used to estimate Tropical Livestock Unit

Livestock Type	Weight
Buffalo	1.60
Cows	1.25
Heifers/Calves	0.50
Bullocks	2.00
Goats	0.10
Sheep	0.10
Chicken	0.01
Pigs	2.00
Ducks	0.01