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Agricultural technologies for marginal and landless farmers: the case of hybrid rice cultivation in India

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Abstract Hybrid rice technology was launched in India in 1994. We analyse the farm-level data and find that the benefits of hybrid rice—and, therefore, adoption—vary by region and farmer type. Adoption is higher among farmers with inadequate water for irrigation and small landholdings and who cultivate a small percentage of their landholding with rice. Marginal and landless farmers, most of whom are subsistence farmers, cultivate hybrid rice because it yields more and provides food security for their household. These results explain why hybrid rice is more prevalent in marginal conditions of states such as Uttar Pradesh, Chhattisgarh, Gujarat—than in fertilized, irrigated, and transplanted regions.

Keywords Food security, small and marginal farmers, hybrid rice, India, technology adoption

JEL Codes Q13, Q16, Q18

Technology adoption is a domain well researched in general and in agriculture. Several factors influence technology adoption, and its level or extent differs by farmer and area, as does the impact of technology adoption. Small and marginal farmers constitute the most critical dimension of any agricultural technology or policy related to it. A farmer's decision to adopt or reject a new technology at any time is influenced by the combined effect of many factors related to the farmer's objectives and constraints (CIMMYT 1993). Technical, locational, informational, and management factors need to be considered, in particular, along with technology-related factors, while studying an individual's decision-making (Shrestha and Gopalakrishnan 1993). The pace of adoption is determined by the attributes of the technology (Bisanda et al. 1998) and the potential adopters' perceptions of the attributes.

The important attributes for agricultural technologies are yield advantage (Spielman et al. 2012) and enhanced disease resistance (Lyman and Nalley 2013). But the technology's potential in a particular region is determined by its macro- and micro-environmental factors (Gandhi and Desai 1992), leading to "location-specific profitability" (Traxler and Byerlee 1993). The land allocation decisions are influenced by irrigation (Janaiah and Hossain 2003); land type (Hossain, Janaiah, and Husain 2003); and the niche index[1] (Kshirsagar, Pandey, and Bellon 2002).

The adoption of technology in a market economy is an economic decision, show some classical works (Griliches 1957; Pannell et al. 2006). The adoption of hybrid rice is low because the return to cultivation is either poor (Janaiah 2003; Ramasamy et al. 2003) or marginally better than the traditional varieties (Pandey and Bhandari 2009). The cost of inputs influences farmers' adoption decisions (Spielman et al. 2012) and the price of outputs (Nirmala et al. 2012). Producers in locations farther away from the regional centre tend to adopt technologies later due to transport and travel

[1]Niche index is defined as one minus the sum of squares of the proportional area under k-th soil type and l-th land type and is a measure of extent of environmental variability.

costs, which increase with the distance (Rogers 1962; Sunding and Zilberman 2000). If profitability is low and, therefore, technology adoption is poor, overall profitability is enhanced by providing subsidies on technology (Chengappa, Janaiah, and Gowda 2003; Spielman et al. 2012), complementary inputs, and government procurement (Sunding and Zilberman 2000). As a result, adoption is encouraged.

The supply of technology has been considered a mechanism through which an innovation is made available to prospective adopters (Brown 1981). The availability of seeds (Singh 2000) at a reasonable price (Pandey and Bhandari 2009), along with channel decision and pricing (Brown 1981), is essential for the diffusion of new technology. The rate of adoption improves as more farmers learn about the recommended package of practices (Adesina and Zinnah 1993) and gain access to information (Boahene, Snijders, and Folmer 1999).

Adoption improves if national agricultural research centres make extension services available (Duwayri, Tran, and Nguyen 1999) and private firms promote the technology (Brown 1981). Other influences on farmers' adoption include attending a field day, being a contact farmer, being near some agricultural enterprise or research station, participating in meetings (Doss et al. 2003), individual-level learning through their own or others' experiences (Ward and Pede 2013), and social learning (Bandiera and Rasul 2006; Gandhi and Namboodiri 2006; Pannell et al. 2006).

Adoption decisions are also influenced by the personality of the decision-maker, such as age, gender, experience, education, and exposure to the outside world (Rogers 1962; Lin 1991; Bisanda et al. 1998; Janaiah and Hossain 2003). Farm size, ownership of cattle, and farm machinery are often taken as indicators of a farmer's economic situation. These are expected to be positively associated with the adoption of improved rice technology because of the technology's high cost.

Earlier studies (Lipton and Longhurst 1989) showed that large farmers adopted new technologies immediately, and small farmers were risk-averse and did not adopt these readily. But later studies reported the disappearance of this relation for wheat and rice (Dasgupta 1977). Although small farmers adopt late, they usually allocate a higher proportion of land to the improved varieties than do large farmers (Herdt and Garcia 1982)—the "paradox of proportions" (Lipton and Longhurst 1989). Smaller farms are likely to adopt technologies better and faster than large, well-off farmers (Ghimire, Wen-Chi, and Shrestha 2015). Farmers in drier areas are likely to benefit more from agricultural technologies in terms of food security (Murage et al. 2015).

Recent studies on hybrid rice conclude differently about the impact of landholding on adoption decisions. Some find a negative relation between landholding and adoption (Janaiah and Hossain 2003; Hossain, Janaiah, and Husain 2003; Khandker and Thakurata 2018), but Spielman et al. (2012) report a positive relation, indicating that wealthy farmers were the primary adopters. The initial investment required for an input-intensive technology such as hybrid rice might be a hurdle in adoption (Sunding and Zilberman 2000; Duwayri, Tran, and Nguyen 1999). The availability of credit is considered essential in influencing technology adoption (Lin 1991; Pandey and Bhandari 2009). The satisfaction of Indian farmers with hybrid rice, and their willingness to grow it in the future, is shaped by their perception of the technology's physical and economic benefits. Khandker and Gandhi (2018) find higher satisfaction and willingness to grow among farmers in the rain-fed and low-productivity regions.

Every new technology is associated with a package of practices, and the differences between the old and new technologies can hinder adoption (Pandey and Bhandari 2009). If farmers are completely aware of the technology, and the technology's true potential can be realized, the returns can improve. Research shows the importance of disseminating productivity-enhancing technologies among poor farmers (Shiferaw et al. 2014), and Sikhulumile (2020) reports the differential adoption of agricultural technologies by farmers and its impact on food security.

In India, hybrid rice technology adoption is essential for public policy and corporates involved in agricultural input marketing. However, the understanding of hybrid rice cultivation and its adoption in India is limited. There are very few studies on the topic, and even fewer are recent. This study uses rich empirical data from three Indian states—Uttar Pradesh (UP), Chhattisgarh, and Gujarat—to show the plausible reasons for the differential adoption of hybrid rice. We attempt to infer yield advantage patterns, profitability, and determinants of the extent of Indian farmers' adoption of hybrid rice. We also focus on the potential role of hybrid rice technology in addressing the food security of farmers' households.

This study adds to the limited literature on hybrid rice in India. Its results and conclusions are based on the data collected from three Indian states. Although these states cover different agroclimatic conditions, the results cannot be generalized to other rice-growing regions. Also, the farmers' information is entirely based on their memory of cultivating hybrid rice a few months before the survey. Hence, there is a possibility of response errors.

Methodology

The analysis in this paper is split into two parts—descriptive statistics and the ordinary least squares (OLS) regression model.

First, we tabulate the data captured during the survey using descriptive statistics. We also try to infer the underlying patterns by viewing the data along dimensions such as state, geography, level of agricultural inputs, landholding, and education.

Second, we use an OLS regression model to explain the extent of the adoption of hybrid rice. The dependent variable is the extent of adoption of hybrid rice, that is, the percentage of rice that a farmer allocates to cultivating hybrid rice. The independent variables included in the model can be divided into the farm- and farmer-specific variables, farmers' perceptions of hybrid rice cultivation, and dummy variables.

Data

The information for this study was collected using a structured farmer survey. The sample consisted of 441 farmers growing hybrid rice across UP, Chhattisgarh, and Gujarat. The questionnaire was designed, translated into local languages, and then pre-tested. The final survey was conducted between December 2012 and February 2013. We chose an opportune time for the survey to get the data from the recent kharif season and harvest. A team of four investigators was trained to conduct the interviews. All the investigators were experienced in conducting surveys in the rural regions on similar lines. The investigators were proficient in Gujarati and Hindi.

It was essential to have a mix of states with agroclimatic and ecological conditions, the extent of area under rice, productivity level, performance, and stage of adoption, in the sample to capture a more significant variation and make the study more conclusive. The states, and regions within them, were selected based on the secondary data and inputs from the experts, including the scientists involved in hybrid rice development, agricultural economists, and specialists in the private and public sectors. Our study used multistage stratified sampling similar to Bisanda et al. (1998), where the sampling was based on the importance of the technology in a particular region.

Sample profile

The study sample consists of farmers who had grown hybrid rice in at least one of the four years between 2009 and 2012 (Table 1). Overall, 441 farmers were sampled across 19 districts in three states; and 96.15%

Table 1 Summary of the sample profile

Characteristics/details of the study sites	Uttar Pradesh	Chhattisgarh	Gujarat	All three states
Number of districts	7	7	5	19
Sample size	158	149	134	441
Crop year		2012 kharif		
Percentage of sample that grew hybrid rice (2012)	96.20%	96.64%	95.52%	96.15%
Percentage of sample that grew hybrid rice (2011)	89.87%	87.25%	90.30%	89.12%
Age (years)	43.46	41.29	46.93	43.78
Education (years)	9.89	8.74	8.97	9.22
Average landholding (hectares)	2.1	3.5	2.1	2.6
Percentage of operated area planted to rice	66.70%	88.6%	79.20%	78.00%
Percentage of rice area planted to hybrid rice	66.90%	62.10%	67.80%	64.80%

of the farmers in the sample were cultivating hybrid rice at the time of the survey. On average, 78% of the landholding was under rice cultivation, indicating that most farmers were predominantly cultivating rice. Also, these farmers planted hybrid rice on 64.8% of the area cultivable with rice.

Results and discussion

We first present the descriptive statistics to infer patterns in the yield advantage of hybrid rice over open-pollinated varieties (OPV) across the three states.

Yield advantage

While the absolute level of hybrid rice yield is the highest in UP, the yield advantage is higher in Chhattisgarh and Gujarat (Table 2).

Table 2 Yield advantage of hybrid rice

State	Yield (kg per hectare)		Yield
	Hybrid	OPV	advantage
Uttar Pradesh	5799.7	5003.9	15.9%
Chhattisgarh	5791.7	4748.6	21.9%
Gujarat	5525.4	4314.7	28.0%
All three states	5726.5	4716.8	21.4%

Regions such as the northern hills in Chhattisgarh or southern hills in Gujarat are not so fertile; these are predominantly rain-fed. Their average yield is lower, but the relative advantage of hybrid rice is much more and statistically significant. Hybrid rice has a yield advantage over OPV of 43.9% in the north-eastern plains of UP, 72.7% in the northern hills of Chhattisgarh, and 38.0% in southern Gujarat.

We observe that irrigation improves yields. However, the yield gap falls as irrigation improves. The yield advantage of hybrid rice over OPVs in rainfed conditions is 36.7%, whereas it is 19.2% in partially irrigated and 13.0% in thoroughly irrigated regions. This indicates that hybrid rice is likely to have more advantages in completely rain-fed regions than partly or completely irrigated regions.

We then check whether the advantage of hybrid rice technology differs with the level of application of fertilizers. Urea or nitrogen fertilizer is used as a proxy for fertilizer usage. The yield levels are much higher when the use of nitrogen fertilizer is high, but the yield gap differential between hybrid rice and OPV rice is not significant. The yield advantage of hybrid rice technology is 41.5% under low nitrogen conditions, 14.3% under medium nitrogen conditions, and 5.6% under high nitrogen conditions.

We also note that the yield advantage varies with landholding in Uttar Pradesh. The productivity of hybrid and OPV rice is the lowest for marginal and landless farmers, but the yield advantage of hybrid rice is far more for them (24.5%) than that for large and medium farmers (11.0%) and small farmers (14.7%).

The data on farmer education indicates that illiterate farmers gain more (37.4%) from hybrid rice cultivation than farmers who are educated up to high school (18.3%) or graduation (26.2%). Overall, the data indicates that it is much more beneficial in terms of yield advantage to grow hybrid rice in rain-fed and less fertilized regions. At the same time, the yield advantage of hybrid rice is higher for marginal and landless farmers and less educated farmers than for educated farmers and for farmers with large landholdings.

Cost of cultivation

The cost of cultivation for hybrid and OPV varieties varies by state and the landholding (Table 3). In general, hybrid rice cultivation costs more per hectare. This gap is the largest in Gujarat (19.4%), next in Uttar Pradesh (17.1%), and the smallest in Chhattisgarh (6.1%), but the difference is significant only in UP and Gujarat. In all three states, the cost of seeds and fertilizers was higher for hybrid rice than for OPV. The cost of manure and insecticides was higher for hybrids in Gujarat and UP. The cost of irrigation and labour used for hybrid and OPV rice is not significantly different in any state, but the cost of seeds and fertilizers is higher in all three states.

The cost of cultivation per hectare of hybrid and OPV varieties is the highest for small and marginal farmers and the least for large farmers (Table 4). The difference in cost of cultivation is the highest for large farmers (18.1%) and lowest for medium farmers (12.9%). The cost of seeds and fertilizers is higher for hybrid rice than OPV for all farmers.

Manure for hybrid rice costs small and marginal farmers more than OPV rice, but large and medium

Table 3 Costs of inputs for hybrid and OPV rice cultivation by state (INR per ha)

	Uttar Pradesh			Chhattisgarh			Gujarat		
Input	HR	OPV	% Difference	HR	OPV	% Difference	HR	OPV	% Difference
Seed	2956.8	973.1	203.9***	3367.0	1690.1	99.2***	3373.3	955.6	253.0***
Manure	2553.1	1982.5	28.8ns	2478.4	2698.6	–8.2ns	6491.4	4991.6	30.0*
Fertilizer	7090.4	5682.3	24.8***	6095.9	5296.1	15.1*	6699.7	4257.9	57.3***
Insecticide	1151.1	804.9	43.0*	2309.6	2476.3	–6.7ns	1576.3	1317.4	19.7ns
Irrigation	4976.7	4355.6	14.3ns	1704.7	1645.8	3.6ns	3633.7	3971.8	–8.5ns
Labour	13,021.4	12,899.2	0.9ns	9900.8	10,177.3	–2.7ns	13,062.8	12,545.8	4.1ns
Total	39,759.4	33,967.4	17.1***	32,097.1	30,263.5	6.1ns	42,412.7	35,520.0	19.4***

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%, Miscellaneous costs calculated but not mentioned here.

Table 4 Costs of inputs for hybrid and OPV rice by landholding (INR per ha)

	Large			Medium			Small and marginal		
Input	HR	OPV	Difference	HR	OPV	Difference	HR	OPV	Difference
Seed	3072.5	1192.7	157.6***	3185.7	1338.9	137.9***	3271.4	1230.6	165.8***
Manure	2964.2	2981.5	–0.6ns	3305.4	3397.7	–2.7ns	4135.8	3249.9	27.3ns
Fertilizer	6768.3	5017.0	34.9***	6252.5	5237.4	19.4**	6836.3	5905.6	15.8***
Pesticide	2012.4	1980.7	1.6ns	1829.5	1282.8	42.6ns	1509.3	1701.2	–11.3ns
Irrigation	3320.8	3348.4	–0.8ns	3032.9	3066.9	–1.1ns	3573.9	3457.3	3.4ns
Labour	12,035.8	11,812.3	1.9ns	11,753.1	11,448.1	2.7ns	12,120.7	11,717.8	3.4ns
Total	37,115.6	31,415.9	18.1*	37,149.3	32,900.6	12.9*	38,686.8	33,427.8	15.7***

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%, Miscellaneous costs calculated but not mentioned here.

farmers incur less cost. Compared to large and medium farmers, small and marginal farmers spend less on pesticides for hybrid rice than on OPV, but these differences are not statistically significant.

Market demand of hybrid rice output and selling price

The minimum support price (MSP), INR 1,250 per quintal for paddy, assures the farmers of a minimum return for their output. Farmers in three states reported that the market paid less than the MSP for hybrid and OPV rice. In 63.3% of the cases, hybrid rice was sold below the MSP, and OPV rice was sold below the MSP in 51.3% of the cases. The farmers reported that hybrid rice often fetched lower prices in the open market than OPV because of poor grain quality. Farmers reported that the government's mechanism of procuring rice functioned better in Chhattisgarh, and 68.0% of hybrid rice and 78.7% of OPV rice fetched a price equal to or greater than the MSP. Overall, the market pays 12.8% less for hybrid rice than for OPV rice (Table 5). Hybrid rice has a price disadvantage of –16.0% in Uttar Pradesh and –16.7% in Chhattisgarh, but a price advantage of 5.1% in Gujarat, where farmers reported that hybrid rice was used for mixing with long-grained basmati rice.

Table 5 Average selling price (INR per kg)

	Hybrid	OPV	Difference
Uttar Pradesh	9.83	11.70	–16.0***
Chhattisgarh	12.28	14.74	–16.7***
Gujarat	11.27	10.72	5.1ns
All three states	11.12	12.75	–12.8***

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%

Table 6 Comparative cost–return profile: all three states

Cost/Returns	Hybrid	OPV	Difference (%)
Grain yield (kg per ha)	5831.8	4579.9	27.3***
Market price (INR per kg)	11.12	12.75	–12.8***
Gross returns (INR per ha)	65,168.4	57,367.0	13.6***
Total cost (INR per ha)	38,013.3	32,749.0	16.1***
Net return (INR per ha)	27,078.7	24,489.9	10.6^{ns}

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%

Note A subset of the data with complete information on cost and yield has been used to compute this table.

Large farmers get the highest price for OPV rice (INR 14.32). Small and marginal farmers earn the least (INR 11.61) because their limited surplus prevents them from bargaining, and they cannot access the market directly or benefit from government schemes. The price disadvantage of hybrid rice is higher for large farmers (–18.9%) and medium farmers (–15.2%), than for small and marginal farmers (–6.8%).

Profitability of hybrid rice cultivation

We compare the two types of rice on yield, market price, and returns (Table 6). On average, hybrid rice yields 27.3% more than OPV rice. Despite the price disadvantage of 12.8%, its gross returns per hectare exceed OPV rice by 13.6%. The total production cost of hybrid rice is 16.1% more than OPV, yielding a higher net profit of 10.6%. While the yield and gross returns for hybrid rice are higher, lower market price and higher cultivation cost lead to insignificant net return.

Table 7 Cost-return profile if hybrid rice has no price disadvantage

Cost/Returns	Hybrid	OPV	% difference
Grain yield (t/ha)	5831.8	4579.9	27.3***
Market price (INR per t)	12.75	12.75	0.0^{ns}
Gross returns	74,355.4	57,367.0	29.6***
Total cost	38,013.3	32,749.0	16.1***
Net return	36,394.2	24,489.9	48.6***

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%

However, if hybrid rice is sold at the same price as OPV, and the yield and the cost of cultivation are the same, the gross returns will increase from 13.6% to 29.6% and the net returns from 10.6% to 48.6% (Table 7).

Table 8 shows the variation in profitability of hybrid rice over OPV across the three states. The advantage in gross returns of hybrid rice over that of OPV is highest in Gujarat (30.2%), followed by Chhattisgarh (17.7%) and Uttar Pradesh (2.5%). The net returns for hybrid rice are highest in Chhattisgarh, followed by Gujarat and Uttar Pradesh. The net return of hybrid rice cultivation is higher than OPV varieties by 58.5% in Gujarat and 28.8% in Chhattisgarh. In UP, farmers got lower returns on hybrid rice cultivation during kharif 2012 than OPV rice.

Table 9 shows the variation in the profitability of hybrid rice by landholding size. The gross returns for hybrid rice increase with landholding; these are highest for large farmers and significantly high only for medium farmers (16.7%) and small farmers (16.3%). Accounting for the cost of cultivation, the advantage of hybrid rice over OPV rice in net returns is highest for medium farmers (20.2%), followed by small and marginal farmers (16.4%), and the least for large farmers (1.6%). But none of these net return advantages are statistically significant. Heterogeneity in returns has also been observed in other agricultural technologies and has been linked to adoption (Suri 2011).

Use of hybrid rice output

The returns from cultivating hybrid rice are higher than OPV rice but not significant enough. Then, why do some farmers continue to cultivate hybrid rice? Table 10 shows the usage of hybrid and OPV rice output.

Overall, only 17.1% of the farmers grew hybrid rice solely for consumption—17.9% in Uttar Pradesh, 14.8% in Chhattisgarh, and 18.6% in Gujarat. At the same time, 60.6% of the farmers grew it solely for selling in the market—47.6% in Uttar Pradesh, 68.2% in Chhattisgarh, and 67.7% in Gujarat. 22.3% of farmers grow hybrid rice for selling as well as consumption. More farmers prefer to eat OPV rice than hybrid rice. We also captured the percentage of hybrid and OPV rice output sold or kept at home. Overall, 76% of the hybrid rice output is sold in the market,

Table 8 Variation in profitability with location

Cost/Returns	Uttar Pradesh Hybrid	Uttar Pradesh OPV	Uttar Pradesh %difference	Chhattisgarh Hybrid	Chhattisgarh OPV	Chhattisgarh %difference	Gujarat Hybrid	Gujarat OPV	Gujarat %difference
Yield (kg/ha)	5930.4	4864.2	21.9***	5978.7	4438.9	34.7***	5555.5	4452.6	24.8***
Price (INR per kg)	9.83	11.70	–16.0***	12.28	14.74	–16.7***	11.27	10.72	5.1ns
Gross returns	59,052.0	57,593.3	2.5ns	73,720.9	62,609.4	17.7***	62,632.8	48,096.2	30.2***
Total cost	39,759.4	33,967.4	17.1***	32,097.1	30,263.5	6.1ns	42,412.7	35,520.0	19.4***
Net returns	18,536.5	23,197.6	–20.1ns	41,443.0	32,185.0	28.8***	20,480.2	12,919.1	58.5*

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%

Table 9 Variation in profitability with landholding

Returns	Large Hybrid	Large OPV	Large % Difference	Medium Hybrid	Medium OPV	Medium % Difference	Small and Marginal Hybrid	Small and Marginal OPV	Small and Marginal % Difference
Yield(kg/ha)	6139.9	4806.9	27.7***	6040.6	4558.5	32.5***	5651.5	4523.2	24.9***
Price (INR per kg)	11.60	14.31	–18.9***	11.43	13.48	–15.2***	10.83	11.61	–6.7*
Gross returns	71,541.3	65,313.8	9.5ns	69,649.3	59,679.8	16.7**	61,206.7	52,631.0	16.3**
Total cost	37,115.6	31,415.9	18.1*	37,149.3	32,900.6	12.9*	38,686.8	33,053.1	17.0***
Net return	34,425.7	33,897.9	1.6ns	32,229.8	26,806.0	20.2ns	22,393.0	19,238.5	16.4ns

ns= Not significant,*= significant at <5%, **= significant at <1%, ***=significant at 0%

and farmers consume only 24%. On the other hand, 63.3% of the OPV rice is used at home, and only 37.7% is sold in the market.

Who eats hybrid rice?

If farmers sell 76% of their hybrid rice output in the market and about 60% of them do not consume it at home, it is essential to identify the farmers who eat hybrid rice at home. Interestingly, no large farmer reported growing hybrid rice solely for consumption at home, but 9.8% of medium farmers and 25.0% of small and marginal farmers grew hybrid rice only for consumption (Figure 1). Simultaneously, 86.4% of large farmers, 80.4% of medium farmers, and 47.4% of small and marginal farmers grew hybrid rice only to sell. About 27.6% of small and marginal farmers grew hybrid rice to eat and sell. Overall, 52.6% of small and marginal farmers, 19.6% of medium farmers, and 13.6% of large farmers eat hybrid rice.

Table 10 Use of rice by state

		Farmers (%)			Total rice output (%)	
		Consumption at home	Selling in market	Consuming as well as selling	Used at home	Sold in market
Uttar Pradesh	Hybrid	17.9	47.6	34.5	31.2	69.8
	OPV	55.3	20.0	24.7	69.9	33.1
Chhattisgarh	Hybrid	14.8	68.2	17.0	22.1	77.9
	OPV	57.9	23.7	18.4	63.3	36.7
Gujarat	Hybrid	18.6	67.7	13.7	18.8	81.2
	OPV	37.5	25.0	37.5	54.4	45.6
All three states	Hybrid	17.1	60.6	22.3	24.0	76.0
	OPV	52.1	22.8	25.1	63.3	37.7

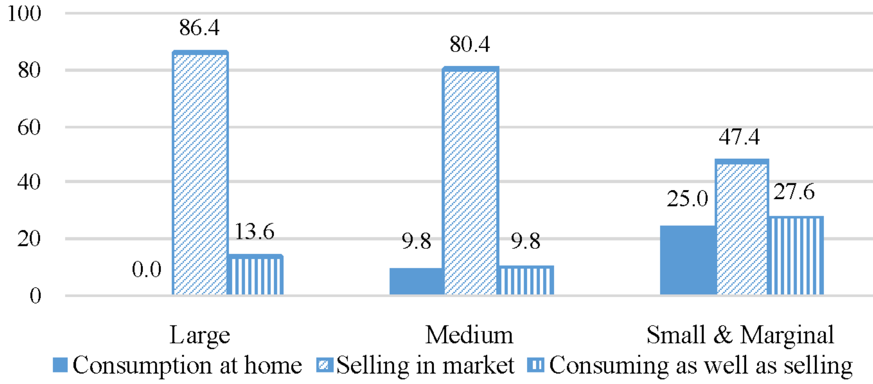

Figure 1 Use of hybrid rice by farmers (%)

Interestingly, no large farmer reported growing hybrid rice solely for consumption at home, but 9.8% of medium farmers and 25.0% of small and marginal farmers grew hybrid rice only for consumption. Simultaneously, 86.4% of large farmers, 80.4% of medium farmers, and 47.4% of small and marginal farmers grew hybrid rice only to sell. About 27.6% of small and marginal farmers grew hybrid rice to eat and sell. Overall, 52.6% of small and marginal farmers, 19.6% of medium farmers, and 13.6% of large farmers eat hybrid rice.

Large farmers sell 94.1% of their hybrid rice output, medium farmers 86.4%, and small and marginal farmers 66.%. Small and marginal farmers consume 33.5% of their total hybrid rice output. The data shows that most small and marginal farmers consume hybrid rice; over 50.0% eat what they grow. Large and medium farmers, on the other hand, have more land. They grow OPV varieties for eating at home and hybrid rice varieties for selling in the market.

Accordingly, we find that the adoption of hybrid rice is highest among small and marginal farmers (80.5%) and lowest among large farmers (57.6%). Medium farmers allocate 70.8% of their rice area to hybrid rice cultivation. Large farmers allocate a large part of their rice area to OPV rice used at home. Small and marginal farmers allocate most of their rice to hybrid rice because its output is higher than that of OPV rice, and hence it can be used for consuming and selling.

Regression model

To arrive at the determinants of the extent of adoption, we run an OLS regression model; Table 11 lists the dependent and explanatory variables used.

The percentage of rice area under hybrid rice cultivation, i.e., *extent of adoption*, has been taken as the dependent variable. The *extent of adoption* varies between 0% and 100%. The explanatory variables are farm- and farmer-specific variables, farmers' perception of hybrid rice cultivation, and dummy variables.

The farm- and farmer-specific variables are experience, education, landholding, and area under rice. The variables that capture perceptions of hybrid rice

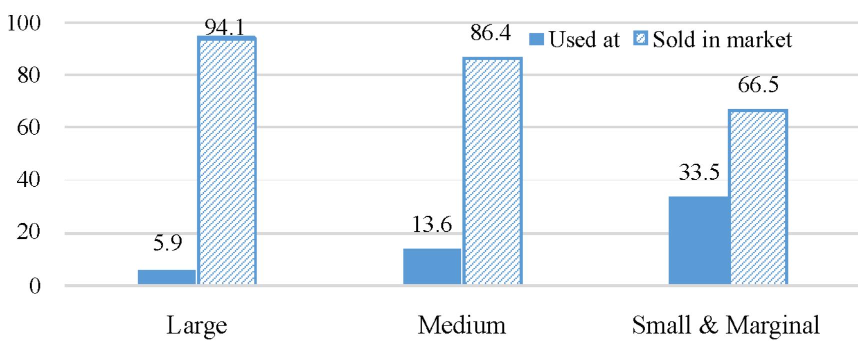

Figure 2 Use of hybrid rice by quantity (%)

cultivation are *availability of adequate water*, *good market demand*, *good market price*, *lower cost of cultivation*, *awareness about hybrid rice*, *easy availability of seeds*, *reasonable price of seeds*, and *credit* seeds.

The response to these variables was captured on a scale of 1–5, where 1 meant strongly disagree and 5 strongly agree. The dummy variables included subsistence farmer dummy (if the output was predominantly consumed at home, cattle ownership dummy, CG dummy, and GJ dummy (Table 11). Table 12 lists the coefficients of the regression model using these variables.

The variables found positively significant in the model are *experience, education, easy availability of seeds, reasonable price of seeds, subsistence farmer dummy, and GJ dummy*. The coefficients and their signs indicate that the extent of hybrid rice adoption is greater among experienced and educated farmers. Also, farmers tend to have more rice area under hybrid rice cultivation as the seeds are easily available and sold at a reasonable price. These two are critical factors related to the supply and availability of seeds, given that they are far more expensive than OPV seeds.

We also find the dummy variables of subsistence farmer and Gujarat state as positive and significant. This indicates that compared to commercial farmers, farmers who grow hybrid rice only for consumption at home and do not sell any part of their produce in the market have a greater extent of adoption. These farmers are likely to be marginal or landless farmers. This finding also supports our initial observation regarding the usage of hybrid rice.

The following variables were significant and had negative coefficients: landholding, area under rice, and adequate water. This indicates that the adoption is greater among farmers with smaller landholdings and those having a limited area under rice. These farmers are probably small and subsistence and tend to grow multiple crops on the limited piece of land they have. Also, water's perceived adequacy is negatively related, indicating that farmers who do not have enough irrigation resources exhibit a greater extent of adoption than wealthy farmers who have irrigated lands.

Table 11 Explanatory variables

	Description
Dependent variable	
Extent of adoption	Percentage of rice area under hybrid rice cultivation (0–100)
Independent variables	
Experience	Experience of hybrid rice cultivation (in years)
Education	Education of the farmer (in years)
Landholding	Land owned by the farmer (in hectare)
Area under rice	Percentage of the operated area under rice cultivation (%)
Adequate water	Adequate water available for hybrid rice irrigation (1–5)
Good market demand	The market demand for hybrid rice is high (1–5)
Good market price	Hybrid rice fetches a good market price (1–5)
Less cost of cultivation	Hybrid rice costs less to produce (1–5)
Awareness about hybrid rice	You are completely aware of hybrid rice benefits (1–5)
Easy availability of seeds	Hybrid rice seeds are easily available (1–5)
Reasonable price of seeds	Hybrid rice seeds are sold at a reasonable price (1–5)
Credit for seeds	Credit is made available by the seed dealers (1–5)
Subsistence farmer dummy	1- for consumption only 2 - for selling/selling + consumption
Cattle ownership dummy	No cattle =0, Cattle owned = 1
CG dummy	Chhattisgarh =1, all others = 0
GJ dummy	Gujarat =1, all others = 0

Scale: 1 – Strongly disagree 2 – Disagree, 3 –Neither disagree nor agree, 4 – Agree, and 5 – Strongly agree

Table 12 OLS Regression Results

Coefficients Model	Unstandardized coefficients B	Unstandardized coefficients Std. Error	Standardized coefficients Beta	t	Sig.
1 (Constant)	68,414	11,135		6.144	.000
Experience	**1.958**	**.439**	**.201**	**4.462**	**.000**
Education	.782	.289	.129	2.709	.007
Landholding	–2.145	.505	–.202	–4.249	.000
Area under rice	–.190	.055	–.168	–3.430	.001
Adequate water	–4.440	1.775	–.123	–2.501	.013
Good market demand	4.395	2.565	.087	1.714	.087
Good market price	–6.093	4.654	–.062	–1.309	.191
Less cost of cultivation	–9.098	4.646	–.086	–1.958	.051
Awareness about hybrid rice	2.720	2.019	.065	1.347	.179
Easy availability of seeds	**3.315**	**1.355**	**.116**	**2.446**	**.015**
Reasonable price of seeds	4.376	2.155	.093	2.030	.043
Credits for seeds	7.329	6.025	.053	1.216	.225
Subsistence farmer dummy	**9.055**	**2.894**	**.156**	**3.129**	**.002**
Cattle ownership dummy	–8.590	4.390	–.087	–1.957	.051
CG dummy	2.440	3.874	.040	.630	.529
GJ dummy	**8.000**	**4.053**	**.129**	**1.974**	**.049**

a. Dependent Variable: Extent_of_adoption

Conclusion

This study uses data collected from 441 hybrid rice-growing farmers, over half of them growing inbred rice in parallel, to analyse the agronomic and agroeconomic potential of hybrid rice. Hybrid rice varieties yield more than OPV rice, and this yield gap advantage is higher in unsuitable/less productive, rain-fed, and low-input conditions. These findings align with our regression model and the adoption pattern of states. We observe that the relative advantage is higher for marginal and landless or resource-poor farmers and, therefore, they adopt hybrid rice to a greater extent.

Hybrid rice costs more to produce than inbred rice. The difference in cost of cultivation is highest for farmers in Gujarat and large farmers across the three states. A detailed look at the costs suggests that seeds, manure, and fertilizers for hybrid rice cost more than for inbred rice. The cost of cultivation of hybrid rice, and the difference in cost of cultivation of the two types of rice, varies by state and farmer type: both are highest for farmers in Gujarat. On the other hand, small and marginal farmers spend the most per hectare on cultivating hybrid rice. Our findings on the yield differential are similar to that of Azad and Rahman (2017), which indicates differences in productivity of hybrid rice across farm sizes and regions in Bangladesh.

From the demand perspective, MSP availability is an issue for all rice varieties across states and farmer types. Hybrid rice fetches a lower price than inbred rice; farmers cite as reasons poor grain quality and the lack of demand from the millers. Hybrid rice fetches the lowest market price for farmers in Uttar Pradesh and small and marginal farmers in general. Overall, the higher yield and cost of cultivation of hybrid rice, but lower market price, leads to lower net returns for the technology. Hybrid rice is 10.6% more profitable than inbred rice on average, but it would have been 48.6% more profitable if its market price were the same. Thus, even though hybrid rice yields more, its economic potential is negatively impacted by its price disadvantage in the market, mainly because of poor grain quality.

The profitability of hybrid rice varies by state and farmer type. Farmers in Uttar Pradesh reported lower net returns on hybrid rice than on inbred rice for the kharif 2012 crop, but the net returns were higher in the other two states. At the same time, the net returns were higher for medium farmers and for small and marginal farmers. Thus, the technology is profitable for certain farmers and specific regions. The reason cannot be ascertained with the data for the current study.

The data on the usage of hybrid rice output suggests that hybrid rice provides food security to small and marginal farmers with limited land and other resources. We also find that the adoption rate is higher for small and marginal farmers than the large and medium farmers. The large and medium farmers grow hybrid rice mainly for selling in the market.

Overall, the study concludes that the relative advantage and profitability of hybrid rice cultivation are not the same everywhere and for all farmer types. This might be the probable reason for the difference in the adoption pattern across states. Lower market price and higher cost of cultivation often make the advantage in net returns insignificant. Farmers continue to grow hybrid rice, and adoption is higher among small and marginal farmers whose resource endowments are limited, probably because the output of hybrid rice is higher than that of inbred varieties, and hybrid rice provides food security.

The survey data helps us conclude that the hybrid rice varieties yield more than OPV rice. The yield gap advantage is higher in unsuitable/less productive land, rain-fed areas (or areas with inadequate irrigation), and low-input conditions. As a result, hybrid rice is more likely to be adopted in regions that are conventionally not for rice cultivation or are not fertilized, irrigated, or transplanted. Our regression model supports these findings, and are in line with the states' adoption pattern of hybrid rice.

The study and its findings have implications for policy as well as practice. It indicates that the prospective regions for introduction and, hence, adoption of hybrid rice should be the non-conventional rain-fed and hilly regions with lower productivity. Since the adoption is better among small, marginal, and landless farmers, policies to encourage hybrid rice adoption could target farmers based on their landholdings. Small and marginal farmers (farmers whose landholdings are less than 2 hectares) account for 85.01% of the country's total operational landholdings (Agriculture Census Division 2015). The programmes should attempt to persuade them to adopt hybrid rice because it helps them ensure household food security, and they can sell the surplus if any. The results indicate that policymaking and implementation should apply the MSP and equally price hybrid and inbred rice. The study observes a need for concentrated research efforts to improve the yield potential and grain quality. This should result in better profitability and, hence, acceptance of the technology.

The findings have implications for the practice/ companies. It shows a need for research and development in enhancing the yield potential of hybrid rice for irrigated conditions and high-potential regions. Improving the grain quality would raise acceptance and price. Input marketing companies can focus on low-potential regions and provide technical know-how and guidance for resource-poor farmers. The study finds that the retailer's easy supply of seeds at a reasonable price and credit availability are important determinants of the extent of adoption. A better supply and distribution can further enhance hybrid rice's adoption levels.

This study adds to the limited literature on hybrid rice in India. Its results and conclusions are based on the data collected from three Indian states. Although these states cover different agroclimatic conditions, the results cannot be generalized to other rice-growing regions. Also, the farmers' information is entirely based on their memory of cultivating hybrid rice a few months before the survey.

In the future, the impact of hybrid rice technology adoption on food security can be assessed using a statistical model. Additionally, this work can be extended by using efficiency analysis to determine if the efficiency of the cost of cultivating hybrid rice differs across the states and landholding. This will help identify the target regions and farmers for promoting similar agricultural technologies.

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