



Innovations and investments for transforming India's rice economy: Submergence tolerant rice varieties in rainfed lowlands of North-Eastern Uttar Pradesh

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ABSTRACT

The present study provides a brief overview of India's R&D program and orientation of the public and private research portfolio and investments in reference to the rice research. The farm level and aggregate potential economic benefits from the adoption of improved submergence tolerant rice varieties (Swarna Sub 1, Samba Masuri Sub 1) in the rainfed lowland region of India were estimated based on a field survey conducted in rainfed lowlands of the northeastern region of Uttar Pradesh state. At farm-level, the submergence tolerant varieties had not only 39% higher yield advantage and 63% higher net returns as compared to other popularly grown varieties in the region, but also showed lower yield risk under the prevailing conditions. At the aggregate level, potential benefits from the adoption of these stress-tolerant varieties were also estimated. Farmers' perception showed that Swarna Sub 1 and Samba Masuri Sub 1 rice varieties are preferred mainly because of their better tolerance to the submergence conditions prevailing in the area during the rainy season. Sarjoo-52 is an old variety but still preferred due to its taste, yield and resistance to pests and diseases. The results amply indicate that farmers' perception of crop varietal attributes influences largely their choice of varieties at the farm level.

Key words: Farmers' perception, Rainfed lowland, Rice economy, Submergence tolerant.

Rice is one of the most important food crops for more than half of the world population and influences the livelihoods and economies of several billion people. Globally, the spectacular advances in rice productivity started after the introduction of semi-dwarf, high-yielding varieties during the 1960s, which enabled many rice-growing economies, including India, to attain self-sufficiency in rice production. Subsequently, the thrust of rice breeding programs moved towards improving resilience and self-sufficiency in relatively unfavorable production environments and improving quality traits like grain length and texture, aroma, nutritional content, cooking quality etc. Together, these technological, institutional, and policy initiatives enabled rice production not only geographically dispersed across different ecosystems (Irrigated, Rainfed Upland, Rainfed Lowland, and Flood Prone), but also made the country to attain all-time high rice production of 110.15 million tonnes in 2016–17 (GoI 2017).

In India, rice is being grown in diverse kinds of production environments, i.e. irrigated and rainfed systems.

The irrigated ecosystem contributes the maximum production (63.5%) on account of its highest area and productivity (3 t/ha). The states of Punjab, Haryana, Western Uttar Pradesh, Jammu and Kashmir, Andhra Pradesh, Karnataka, Himachal Pradesh, and Gujarat fall into this region. Likewise, part of Uttar Pradesh and most of the eastern states comprising Bihar, West Bengal, Odisha, Jharkhand, Chhattisgarh, and Assam represent predominantly rainfed lowland systems. The eastern states of India, contribute a substantial share in total rice production in the country and mainly produce non-aromatic varieties. It was estimated that out of 44 million ha of the rice area in the country, rainfed lowlands account for 12–14 million ha (NRRRI 2011). The average rice productivity of submergence-prone areas in eastern India was reported to be as low as 0.5–0.8 t/ha, whereas it is about 2.0 t/ha for favourable rainfed lowlands, being much lower than the input-intensive irrigated system (5.0 t/ha). The reason is that the rainfed ecosystem is more dependent on the monsoon rains, and droughts and floods frequently affect *kharif* season rice production. Despite the region's superior resource endowments and enormous potential for rice production because of the predominance of good soils and freshwater resources (Ismail *et al.* 2013), the region is still food-deficit and poverty-stricken. Improved rice varieties like Swarna Sub-1 and Samba Masuri Sub-1 have been recently introduced as a flood-tolerant version of

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the popular mega-variety Swarna (MTU 7029) and Samba Masuri (BPT-5204) popularly grown in Eastern India. The experimental evidence has shown that under submergence conditions, these stress-tolerant varieties of rice significantly yielded higher than their traditional counterparts. Even in farmers' fields in flood-prone lowlands of Odisha in India, Swarna Sub 1 variety of rice was reported to have yielded up to 45% more than the varieties they had replaced (Dar *et al.* 2013).

Further, India has the largest rainfed lowland area in the world, with frequent occurrence of flash floods which is considered as one of the most important abiotic stresses to rice production, after drought and weeds. More so, agriculture in this region is dominated by a large number of marginal farmers and smallholders with varying levels of knowledge, skills, capital and resources. Literature showed that farmers assess an improved variety in terms of not only higher yield but also a range of attributes such as grain quality and taste, straw yield, input requirements (Traxler and Byerlee 1993, Kelley *et al.* 1996), market, and suitability with the existing cropping system. Hence, understanding farmers' preferences for varietal attributes and incentives to grow improved varieties are critical to the success of another green revolution in the region. Furthermore, not much of the empirical evidence was generated on adoption and realized the economic benefits of such technological interventions in the region especially in non-experimental settings. In this context, the present study provides a brief overview of India's R&D program and orientation of the public and private research portfolio and investments in reference to the rice research. The study would help understand the incentives that farmers need in making the choice of technology adoption, as well as the identification of interventions compatible with the resource endowments and farmers' needs in the region.

India's rice breeding program—funding, human capital and innovations: India's R&D spending is historically being undertaken by the government, the Central and State institutions are the main players in agricultural research, education and extension in terms of funding and provision. The Indian Council of Agricultural Research (ICAR) of the Ministry of Agriculture through its network of institutions and the state agricultural universities (SAUs) represents the major public-sector agricultural R&D organization in the country. Besides these institutions, other public organizations such as the Department of Science and Technology (DST), Council of Scientific & Industrial Research (CSIR) organizations, and other general universities also undertake agricultural research activities. Besides this, CGIAR centers have also developed strong linkages with the Indian agricultural research system. Almost all funds from the central government are routed through ICAR. Another major source of funds is the annual block grants from various state governments to their respective SAUs. Taking both the expenditures together, the total real expenditure (2011-12 prices) on agricultural research and education (Ag R&E) was estimated to have risen nearly four-fold in

the last two decades. The all-India real expenditure rose from ₹ 24 billion in TE 1995 to ₹ 89 billion in TE 2014 by witnessing 7.4% annual growth (Singh and Pal 2015).

Within the crops science research, rice R&D has received the utmost attention, both in terms of resources as well as human capital engaged, by various public sector-led institutes. The Indian Institute of Rice Research (IIRR), Hyderabad, and National Rice Research Institute, Cuttack, are two ICAR institutes exclusively engaged in rice research for irrigated and rainfed environments, respectively. IIRR also coordinates rice research across the country under the All India Coordinated Research Improvement Project on Rice (AICRIP). These efforts were further supplemented by the intensive rice improvement programs of SAUs aiming to enhance the yield frontier, improve tolerance of abiotic and biotic stresses, and improve grain and nutritional quality to meet the future demand for rice in domestic and international markets. Though, the multidisciplinary nature of the agri-research portfolio makes it difficult to estimate the magnitude of funds spent exclusively on rice research; however, annual rice research expenditure was estimated as ₹ 4.879 billion in 2012-13. This expenditure constituted 22% of the crop science research expenditure of ICAR and 10% of the all-India agricultural research and education expenditure in 2012–13 (Singh *et al.* 2017). In addition to the monetary sources, approximately 780 scientists are working directly or indirectly (Janaiah and Hossain 2004) on different aspects of rice research, constituting 17 scientists per million ha of rice area in the country. A majority of the scientific efforts are devoted to varietal development apart from other areas such as plant protection, natural resource management, mechanization, and transfer of technology. In all, 620 varieties and hybrids of rice over the past 35 years were developed for cultivation in different agro-ecological regions of India (Janaiah *et al.* 2006) from 1965–2000. During 2000 decade 481 rice varieties have been released and the trend showed that the number of rice varieties released was significantly higher in the 2000 s decade than in the previous decades. Of these, the majority of the varieties were evolved for the irrigated ecosystem, followed by rainfed uplands. In contrast to this, the rainfed lowlands and waterlogged rice ecosystem received much lower attention (Table 1). Having realized the scope and potential of quality rice for niche markets, the rice research orientation during recent years has aggressively focused on the genetic enhancement of super fine-quality aromatic and non-aromatic rice in the country. In this arena, public-sector organizations played a leadership role, which led to the development and commercialization of several export-quality basmati and aromatic rice varieties.

Of late, the private sector has also made their entry into crop research and seed markets, but their presence was especially seen in the case of hybrids of cotton, vegetables, and cereals, especially hybrid maize and rice, and basmati rice. The share of proprietary hybrids developed by private firms in total hybrids has also increased significantly in these crops. However, there is only limited information

Table 1 Trends in rice varieties developed in India by different rice ecosystems (2000–17)

Period	Total notified rice varieties	Per cent share of rice varieties developed by major rice ecosystems				
		Irrigated	Rainfed upland	Rainfed lowland	Hills	Coastal/water-logged
2000-05	135	65	14	10	3	8
2006-12	225	78	8	5	3	6
2013-17	121	60	17	8	2	10

Source: Calculation based on Directorate of Rice Development report (2017)

on the level of private sector and type of private research as many private firms do not reveal their research agenda and share expenditure data in detail. Further, as research activities are closely tied with market development and promotional efforts, it is all the more difficult to ascertain their research expenditure. The area under proprietary rice hybrids, especially in eastern India (eastern UP, Bihar, Odisha), has seen an expansion (covering 6% of the total rice area). Industry data show that almost 95% of the hybrid rice market was controlled by the private sector. The estimated annual R&D investments by private firms were valued at USD 9 million in 2009 in hybrid rice (Spielman 2013).

Farmers' perception and economic benefits of submergence tolerant rice varieties in northeastern Uttar Pradesh: This region is characterized by the predominance of small and marginal farmers and the majority of the rural families are directly or indirectly engaged in agricultural activities. The annual rainfall ranges between 1000–1250 mm, but is quite erratic and confined to mainly July–September months. The majority of the farm families are illiterate and nearly 82% of the farmers possess holding size less than 1 ha (0.52 ha), and only 12% of farmers have 1–2 ha (1.39 ha) land. Irrigation status of agricultural land indicates that about 40% of the net sown area is wholly dependent on rainfall and remaining (60%) is irrigated; out of which only 18% of the area is fully irrigated. The majority of the cropped area of the region is occupied by a rice-wheat cropping system having the cropping intensity of 150%. Sharecropping is the most popular form of land tenure. A field survey of submergence-prone rice-growing districts namely Gorakhpur and Siddharthnagar in rainfed lowlands of northeastern Uttar Pradesh was done by the authors. Two blocks namely Sardarnagar and Uruwa from Gorakhpur district and Birdpur and Naugarh blocks from Siddharthnagar district were selected purposively for the study which accounts for higher intensity of rice cultivation. In all, 120 farmer households were selected randomly from these blocks and qualitative and quantitative information on rice varietal diversity, farmers' perception and production practices for the *kharif* season of 2015–16 was collected using structured questionnaires. The survey results revealed that altogether 11 improved as well as traditional rice varieties were reported in the study area, and four of these varieties were of local landraces. The majority of sample farmers in Gorakhpur district (45% of sample farmers) have grown Sarjoo-52 followed by Samba Masuri and Swarna varieties, while in Siddharthnagar district, 31 percent sample farmers

were found cultivating Samba Masuri during the study period. An improved version of Swarna and Samba Masuri was released recently with submergence tolerance trait which is most suited in conditions when fields are submerged for 7 to 14 days with no yield penalty under without flooding conditions. Kalanamak, a super fine variety of rice that is indigenous to the region and rated as very good in taste was grown by 73% of sample farmers in Siddharthnagar. This variety is also rated as premium rice and commands a higher market price (Table 2).

Table 2 Distribution of rice varieties grown on sample farms, 2015–16

Variety	Gorakhpur		Siddharthnagar	
	Per cent share to farmers growing the rice variety	Average area under variety (ha)	Per cent share to farmers growing rice variety	Average area under variety (ha)
Samba Masuri sub1	11.67	7.09	6.67	1.62
Swarna Sub1	3.33	2.02	27.00	8.02
Kalanamak	3.33	1.21	73.33	18.32
Sarjoo-52	45.00	21.26	--	--
Swarna	16.67	9.05	3.56	1.39
Samba Masuri (BPT-5204)	28.33	13.77	31.23	8.62
Local varieties	20	11.34	6.67	1.62

Source: Field survey

Table 3 Distribution of farmers according to rice varietal diversity index

Rice varietal diversity categories	Number of farmers (%)		
	Gorakhpur	Siddharthnagar	Total
No rice varietal diversity (0)	40.33	45.33	45.83
Low rice varietal diversity (0.01–0.25)	0	0	0
Medium rice varietal diversity (0.26–0.50)	43.00	48.66	43.33
High rice varietal diversity (>0.5)	16.67	5.00	10.83
Total	100	100	100

Source: Field survey

On average, the majority of farmers have cultivated more than one rice variety followed by two to three varieties. Farmers were cultivating more than one variety as part of risk minimization and income diversification strategy owing to the frequent onset of droughts and flash floods, diverse household needs and market demand. The estimated rice varietal diversity index in the region ranged from 0 to 0.70, and results indicate that 46% of the farmers had no rice varietal diversity (grew only one variety) followed by medium rice varietal diversity (43%). Only 11% of sample farmers have reported high rice varietal diversity. A comparison of two selected districts showed that in Gorakhpur district, 17% of farmers had high rice varietal diversity index as against only 5% in Siddharthnagar district. Hence results do not support the hypothesis that varietal diversity increases with an increase in environmental heterogeneity as the average number of varieties grown by farmers are less, reflecting socio-economic constraints in technology adoption. This was made explicitly clear when sample farmers were further examined regarding their seed purchasing behavior. The frequency of paddy seed purchased as well as sources of seed purchase by the sample farmers during 2015–16 revealed that only one-third of farmers were purchasing paddy seed every year. The maximum number of sample farmers (40%) reported having purchased seed every alternate year, while another one-fifth of farmers purchased rice seed every two years. It was also reported that the majority of the sample farmers (39%) used seed from own saved sources followed by seed from the local market (32%), fellow farmers (18%) and seeds provided by the govt. scheme (11%). Hence, results amply made clear that there still exist informal seed systems in the study area as most of the selected farmers preferred to use self-retained seeds for low-cost reasons.

Farmers' preference and perception of rice varietal traits: An analysis of farmers' preferences and perceptions showed that the majority of sample farmers cultivating Sarjoo-52 (89%) and Kalanamak (100%) preferred these varieties for their good eating quality. However, Swarna Sub 1 and Samba Masuri Sub 1 were preferred by the majority of farmers (84%) for higher yield performance during field submergence conditions. Out of all the major rice varieties grown, farmers opined that no variety is resistant to the drought conditions. Kalanamak, a traditional variety of the area was perceived by the respondents as somewhat resistant to the drought. It is important to note that all the farmers were fully aware of the fact that Swarna Sub 1 and Samba Masuri Sub 1 performs better in submergence conditions as compared to other existing rice varieties. Similarly, 81% sample farmers preferred these two varieties because of resistance to major diseases and pests. More than 90% farmers also opined that both the Sub 1 varieties and traditional variety like Kalanamak are also having resistance to lodging. Further probing of respondents also revealed that the varietal attributes which farmers from the region demand in the new rice variety are the higher yield, tolerance to drought and submergence together due

to frequent occurrences of drought and flash floods in the region. Next to this, better taste and cooking quality received a high on preference scale.

Farm-level effects of improved submergence tolerant rice varieties: A farm-level comparison of costs and benefits of improved rice varieties, i.e. submergence tolerant rice varieties like Swarna Sub 1 and Samba Masuri Sub 1 over the other commonly grown varieties on adopters and non-adopter farms was done in partial budgeting framework and results are presented in Table 4 and 5.

The operational cost of paddy cultivation on adopter farms of improved variety was estimated ₹ 20368 per ha, which is slightly higher than that of non-adopters ₹ 19687 per ha. The share of different inputs in paid out costs shows that expenditure on human labor alone accounted for 52% and 47% of total cost respectively on adopter and non-adopter farms. The expenditure on machine labour constitutes 13% and 10% of the total operational expenditure respectively by adopters and non-adopters. The expenditure of chemical fertilizers constitutes about 12% of the total cost each on both kinds of farmers in the study area. The average yield of improved varieties on adopter farms were estimated higher (38.05 q/ha) than that of non-adopter farms (23.09 q/ha) during the study period. By comparing the mean yield and coefficient of variation in yield of both the groups of varieties, the study clearly showed a significantly higher yield (39%) on adopter farms of improved varieties than that of non-adopter farms. The yield variability was also observed lower on adopter farms (12 %) than that of non-adopter farms (14%). The per quintal cost of production of improved variety for rice (₹ 535 per q) was found significantly lower than that of

Table 4 Economics of paddy cultivation on sample farms

Expenditure items (₹/ha)	Adopters of improved variety	Non-adopters of improved variety
Seed (both farms produced and purchased)	1065.59 (5.23)	1826.58 (9.28)
Fertilizers	3349.16 (16.45)	3370.41 (17.12)
Insecticide and pesticides	495.30 (2.43)	584.61 (2.97)
Irrigation	2208.70 (10.84)	2766.76 (14.05)
Machinery	2638.38 (12.95)	1983.34 (10.07)
Human labour	10611.74 (52.10)	9155.10 (46.50)
Total operational expenditure	20367.88	19686.80
Yield (q/ha)	38.05	23.09
Coefficient of variation of yield (%)	11.97	13.69

Figures in parentheses denote percent share to total operational expenditure. Source: Field survey

Table 5 Unit cost of production and yield of improved variety and non-adopter of improved variety of rice farms

Particulars	Adopters of improved variety	Non-adopter of improved variety	Mean difference
Cost of production (₹/q)	535	853	-318* (59.44)
Cost of cultivation (₹/ha)	20368	19687	681* (3.34)
Net return (₹/ha)	24721	9130	15591* (63.07)
Yield (q/ha)	38.05	23.09	14.96* (39.32)

*indicates significant at 1% level; Figures in parentheses denote percent change over adopters of improved variety. Source: Field survey

non-adopters (₹ 853 per q). The estimated net returns over paid out cost was also found higher for improved varieties over other rice varieties on sample farms. These findings clearly establish the comparative advantage of submergence tolerant rice varieties over other varieties in terms of both yield improvement and risk reduction on sample farms.

Aggregate economic benefits from the adoption of improved submergence tolerant rice varieties: The economic surplus of the farm-level benefits of these varieties was further scaled up to the entire rainfed lowlands of the country suitable for large scale adoption of these varieties under certain assumptions. The changes in economic surplus due to yield improvement in submergence conditions shift the rice supply curve downwards, whereas the demand curve is assumed to remain unchanged. With no change in prices due to an increase in domestic production, consumer surplus remains constant, and the entire benefits from the adoption of the improved variety are assumed to accrue to the producers only. The change in producer surplus in a small open economy can be represented with the following expression:

$$\Delta PS_t = \Delta TS_t = P_0 Q_0 (K_t - Z_t) (1 + 0.5 Z_t \eta)$$

where ΔPS_t is the change in producer surplus in the year t , ΔTS_t is the change in total surplus in the year t , P_0 is the initial price, Q_0 is the initial level of production, Z_t is the reduction in price in the year t as a result of an increase in supply due to adoption of improved variety, η is the absolute value of demand elasticity and K_t is the proportionate supply shift in the year t due to adoption of improved variety.

The required parameters for estimation of economic surplus are the elasticities of demand and supply, discount rates, estimated farm-level yield increase, prices etc. The price of rice was taken as the Minimum Support Price (MSP) of paddy for the year 2015–16 (GoI 2017). Further, we have assumed that their adoption rate will follow a sigmoid curve to reach the ceiling. No depreciation on the yield of improved varieties is anticipated. Assuming the estimated yield advantage of about 39% and 40% coverage of total rice area under rainfed lowlands, these submergence tolerant

rice varieties could provide producer surplus ranging from ₹ 195 million to ₹ 263 million at 5% and 8% discount rates respectively. An alternative scenario of adoption of these varieties on 60% of rainfed lowland areas would be able to generate up to ₹ 296 million to ₹ 398 million respectively at 8% and 5% discount rates. These results are further substantiating the need for focusing rice research agenda towards consideration of the existing and emerging abiotic stresses and development and dissemination of improved varieties along with crop management practices in the region.

There has been a growing recognition in the national agricultural research systems of the potential adverse effects of natural disasters and extreme climatic events on agricultural production and livelihood of the farmers; hence the need to enhance the resilience of agriculture through technological and other interventions. This realization transformed the focus of rice breeding program towards the priorities of vulnerable production environments unlike yield improvement as the only focus in the past. This study revealed that still, the farmers have the practice of growing old but long-tested improved and traditional rice varieties in the region. This is due to their experience and perception about varietal traits suitability to the local environment, which seem to be major determinants of technology choices in the region. The study clearly demonstrated significant yield advantage of Swarna Sub 1 and Samba Masuri Sub 1 under submergence conditions of varying days in the study area. The estimated likely economic benefits from its adoption in the rainfed lowland are huge; ranging from ₹ 195 to 398 million, under various assumptions. The analysis provided policy input to the existing government schemes in the region and can be used as a guide to rice seed distribution programs in the region. The adoption rate of Swarna Sub 1 and Samba Masuri Sub 1 was found among less than 25% of the sample households in the region, although all sample households in the region suffered from flash floods almost on a recurrent basis. The analysis clearly showed that significant amounts of rice could have been saved among the non-adopters if they had adopted the improved varieties. The low level of adoption of improved varieties in the study area, despite significant yield advantage clearly indicates a range of socio-economic and institutional constraints limiting technology adoption. Thus, the scope does exist for encouraging the adoption of improved varieties through appropriate policy and institutional interventions. The findings also suggest that there is a great scope for improving and stabilizing the production and productivity of rainfed lowland rice once key constraints such as drought as well as submergence tolerance together may be addressed aggressively by rice breeding programs. Besides this, the timely availability of quality seeds, improved crop management, and remunerative prices with effective procurement also need to be addressed adequately.

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